Development and Assessment of Scientific Literacy for Secondary Level Science Education

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Declaration

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Table of Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

AAAS – American Association for the Advancement of Science

CfE – Curriculum for Excellence

DCU – Dublin City University

NCCA – National Council for Curriculum and Assessment

NOS – Nature of Science

NRC – National Research Council

NSES – National Science Education Standards

OECD - Organisation for Economic Co-operation and Development

PISA – Programme for International Student Assessment

PST – Pre-service Teacher

SSI – Socioscientific issues

SQA – Scottish Qualifications Authority

TIMSS - Trends in International Mathematics and Science Study

UNESCO - The United Nations Educational, Scientific and Cultural Organization

Development and Assessment of Scientific Literacy for Secondary Level Science Education

Ruth Chadwick

Scientific literacy is widely regarded as an important goal of science education. Scientific literacy is a range of scientific skills and knowledge that an individual has developed, which allow them to contribute to, and receive enrichment from society (OECD, 2013). However, the best way to achieve this goal remains contentious.

This thesis explores the development and assessment of scientific literacy in summative, written exams and through approaches using inquiry in the context of socioscientific issues (SSI), in secondary school contexts. Case studies explored the teacher and student experience of inquiry in the context of SSI and findings indicated that a range of skills were developed and assessed, and scientific knowledge was demonstrated which considered implications for society. The teachers' pedagogical approach related to the level of inquiry and authenticity of the SSI contexts used, and these pedagogical approaches had a large influence on the skills and knowledge developed and assessed.

Findings relating to the teacher and student experience in secondary school contexts informed the design of a module for pre-service science teachers. This module aimed to develop and assess the skills and knowledge of scientific literacy in PSTs as *learners* and develop the PSTs' pedagogical approach to inquiry in the context of SSI as *teachers*. Findings indicated that the PSTs successfully combined experimental inquiry with authentic SSI contexts and in doing so developed a range of skills and knowledge as *learners*. The PSTs also developed as *teachers*, and there was evidence of changes in the pedagogical approaches, from structured inquiry approaches to guided approaches.

This research culminates in the presentation of a Framework for Scientific Literacy, informed by literature research and the studies described in the thesis. This framework describes scientific literacy on an individual and societal level, and discusses the pedagogical approaches that best develop scientific literacy in both secondary school and tertiary level learners.

Introduction to research

This thesis explores the overarching question: *How can the teacher and student experience of the development and assessment of scientific literacy in secondary schools inform initial science teacher education?*

Recent changes to the secondary school science curriculum of Scotland and Ireland have been driven by a desire to increase scientific literacy in students (Scottish Government, 2010a; NCCA, 2015). However, the best way to achieve this goal remains contentious. Firstly, the term scientific literacy while widely used in curricular policy, has not been universally defined and so the goal itself remains unclear. Secondly, how policy makers expect secondary school teachers to approach this, in terms of day-to-day learning and assessment, is not clearly described or universally agreed. This lack of clarity at secondary level poses further questions in relation to the most effective ways to prepare pre-service teachers (PSTs) to develop and assess the scientific literacy of their students, as required by the curriculum.

The research presented in this thesis was designed with these policy and curricular considerations in mind. The researcher's own experience as a teacher in Scotland, having begun her teaching career during a time of curricular change in Scotland, allowed her to experience, first-hand, the impact of large scale curriculum policy changes on teachers' practice. During the research, researcher was based within an Irish university and involved in PST education in this setting. This led to an interest in initial teacher education and opportunities to carry out research with PSTs. As the literature research progressed, gaps were identified between literature and policy, further widening the gap between the literature and the practice of teachers. This research was undertaken with the aim of narrowing the gaps observed between literature, policy and practice.

Taking account of the varied descriptions in published research, scientific literacy can be considered to be a set of skills and knowledge possessed by the individual that influence the their interactions with society, and this influences society as a whole (Miller, 1983; DeBoer, 2000; Laugskch, 2000; OECD, 2013).

High-profile, global and national assessments of the skills and knowledge of scientific literacy include the Programme for International Student Assessment (PISA) (OECD, 2013) and Trends in International Mathematics and Science Study (TIMSS) (Mullis & Martin, 2013). These assessments have a large influence on the secondary school curricula of countries around the globe. However, they tend to be based on written, summative formats which are taken under timed, closed-book conditions and there are those who question the validity of these written, summative assessments, compared to other approaches such as tasks carried out within the classroom (Ratcliffe & Grace, 2003).

Contrary to these summative, written assessments, scientific literacy can be developed and assessed through inquiry approaches, carried out with the teacher in a classroom setting (Colburn, 2000; Olson & Loucks-Horsley, 2000; Wenning, 2005). Broadly speaking, inquiry-based instruction is where students engage in 'hands-on activities' in a student-centred way, with students involved in active-construction of learning (Colburn, 2000 p42). SSI can be used to provide a context for inquiry, and provide opportunities for dialogue, discussion and debate (Sadler, 2009; Zeidler & Nichols, 2009). SSI are social issues with conceptual and procedural connections to science (Sadler, 2009). They are contemporary and controversial issues that can be used to encourage student activism (Oulton, Dillon & Grace, 2004; Hodson, 2010).

Inquiry in the context of SSI is increasingly being embedded into science curricula (NCCA, 2015; SQA, 2016). The Scottish Curriculum for Excellence (CfE) and the Irish science secondary school science curriculum both aim to assess inquiry in the context of SSI. These novel assessments, the Scottish National 5 Assignment and the Irish Junior Cycle Science in Society Investigation, aim to assess a range of skills and knowledge of scientific literacy. These assessments are of interest as they are likely to assess different skills and knowledge than summative, written exams (Ratcliffe & Grace, 2003).

At tertiary level education, use of inquiry, particularly using SSI contexts, is relatively understudied. In initial teacher education, PSTs need to develop their own scientific literacy but also be prepared to develop scientific literacy in their own students. Research suggests that the ideal way to do this is to cater for their dual role as *learners* and as *teachers* (Topcu, Sadler & Yilmaz-Tuzun, 2010).

This thesis presents studies exploring the development and assessment of scientific literacy in secondary schools and initial teacher education. Chapters 3 and 4 are set within secondary school contexts and explore the development and assessment of scientific literacy using both summative, written assessments and through approaches using inquiry in the context of SSI. Chapter 5 builds on the findings and conclusions from these studies to design, implement and present a case study of an initial teacher education module for pre-service science teachers. This module aims to develop the PSTs' skills and knowledge of scientific literacy as *learners* and prepare them as *teachers* to use inquiry in the context of SSI with the aim of developing scientific literacy in their students.

Chapter 1 provides an overview of the theory informing the studies. It explores the various descriptions of scientific literacy in literature and devises a Framework of Scientific Literacy that ties together the central ideas from the published research. This chapter then discusses the development and assessment of scientific literacy in secondary school contexts before shifting the focus to the preparation of PSTs for the development and assessment of scientific literacy in their own students.

Chapter 2 discusses the methodological approaches used in the studies. A variety of approaches were used throughout the studies described in this thesis. This chapter first discusses the theory and rationale for the chosen approaches and then describes the methodology of each study.

Chapter 3 focusses on the assessment of scientific literacy in summative, written assessments and uses the PISA description of scientific literacy. PISA describes scientific literacy in terms of competencies and knowledge types and the first study presented in this chapter explores the competencies and knowledge types assessed in a PISA assessment item. The second study of Chapter 3 focusses on the assessment of PISA's competencies and knowledge types in the curricular exams of Scotland and Ireland.

Chapter 4 focusses on the development and assessment of scientific literacy using inquiry in the context of SSI. The first study presented is set within the Scottish curriculum and this large case study (Thistle Wood School case study) explores the skills and knowledge developed and assessed as students carry out the National 5 Assignment. Following this study, two smaller case studies (Clover Field School and Daisy Park School case studies) are presented which are set within the Irish curriculum. Each of these case studies follows an individual teacher and their class as they prepare to carry out the Junior Cycle Science in Society Investigation. This chapter also discusses the shifting curricular and policy landscape within which the case studies are set.

Chapter 5 presents the design of an initial teacher education module that aims to prepare pre-service science teachers to use inquiry in the context of SSI with the aim of developing the skills and knowledge of scientific literacy in their students. This module was informed by the studies carried out in Chapter 3 and 4. A case study is presented which explores the experiences of the pre-service teachers (PSTs), as both *learners* and (trainee) *teachers*.

Chapter 6 presents the overall conclusions and implications from the studies carried out in secondary school contexts and with PSTs. This chapter presents a Framework for Scientific Literacy, informed by literature research and the studies described in the thesis. This framework describes scientific literacy on an individual and societal level and discusses the pedagogical approaches that best develop scientific literacy in both secondary school and tertiary level learners. Chapter 6 then goes on to describe, in detail, the conclusions and implications for the development and assessment of scientific literacy in secondary schools. Finally, this chapter discusses how these conclusions can inform initial teacher education for the development of PSTs as both *learners* and *teachers*.

1 Theoretical background

Chapter 1 discusses the theoretical background to the overarching question: *How can the teacher and student experience of the development and assessment of scientific literacy in secondary schools inform initial science teacher education?*

Section 1.1 explores the varied descriptions of scientific literacy in published research and literature. Section 1.2 then presents a Framework of Scientific Literacy for use in this thesis. This framework goes beyond the summary of the literature that was presented in Section 1.1. It provides a synthesis of the literature, connecting the many descriptions into a single framework that aims to represent scientific literature as observed in the literature.

Sections 1.3 and 1.4 explore the development and assessment of scientific literacy in secondary schools. Section 1.3 discusses the assessment of scientific literacy as reported in the literature, through high-profile, global and national assessments (PISA & TIMSS) and the impact of these assessments on science curricular policy around the world. Section 1.4 the explores the development and assessment of scientific using inquiry in the context of socioscientific issues (SSI) in secondary schools.

Section 1.5 focusses on the development and assessment of scientific literacy in initial teacher education, using inquiry in the context of SSI. This section explores the dual role of PSTs as both *learners* and *teachers,* and the implications this has for the development of initial teacher education programmes.

1.1 Scientific literacy

This section presents an overview of research is presented chronologically from oldest to most recent. Then one of the most recent descriptions of scientific literacy, that of PISA 2015, is presented (OECD, 2013). In Section 1.2, a detailed framework for scientific literacy is developed that aims to take account of the literature outlined in Section 1.1.

It is important to note early on in this thesis the differences in interpretation of the term “literacy”. Scientific literacy differs from traditional literacy which focusses on the ability to read and write (Norris & Phillips, 2003, Laugksch, 2000). Scientific literacy is more than simply the ability to read and write in scientific contexts, it is the accumulation and mastery of knowledge and more broadly knowledgeability, learning and education (Laugskch, 2000; Norris & Phillips, 2003; Roberts, 2007). It can be compared to the use of the term literacy as used in terms such as digital literacy or political literacy (Laugksch, 2000). In fact, in French the term literacy is inappropriate for what is being described and the translated term “culture” is more appropriate (UNESCO, 1993).

1.1.1 Scientific literacy: A brief historical overview

The term scientific literacy was first described in the 1950s and the majority of literature about scientific literacy has been written in the last three decades (DeBoer, 2000; Laugksch, 2000). There is still, however, no universally accepted definition.

One early attempt to define scientific literacy came from Showalter in 1974 (cited in Laugksch, 2000, pp. 76-77). He attempted to clarify the term by breaking it into specific characteristics of the scientifically literate individual, who “understands the nature of scientific knowledge” and “*applies* appropriate science *concepts, principles, laws, and theories* in interacting with his universe”. They also have “numerous manipulative *skills* associated with science and technology.” They use “*processes of science* in solving problems, making decisions, and furthering their own understanding of the universe” and “interact with the various aspects of their universe in a way that is consistent with the *values that underlie science”.* They also “understand and appreciate the joint enterprises of *science and technology* and the interrelationship of these with each and with other *aspects of society*”. Through their knowledge, understanding and skills of science (i.e. scientific literacy) they have *a “richer, more satisfying, more exciting* view of the universe (Laugksch, 2000, pp. 76-77). According to Showalter (cited in Laugksch, 2000), the scientifically literate individual possesses knowledge of science, of the concepts, principles, laws and theories, and of the processes of science, and the nature and values of science. They apply this knowledge in their daily lives. The scientifically literate individual also possesses skills relating to science. These knowledge and skills enhance the individual's ability to interact with the world around them and to participate in society.

Miller (1983) described scientific literacy as the "ability of an individual to read about, comprehend and express an opinion on scientific matters" (p. 30) which is related to traditional literacy. He described three components to scientific literacy: understanding the scientific approach; understanding basic scientific constructs, terms and concepts; and understanding of science policy issues including potential benefits and harms. Miller (1983) clearly linked the scientific literacy of the individual to the implications for a democratic society. He asserted that the majority of the population (of the USA) is *not* scientifically literate and this results in the inability of many individuals to make informed judgements relating science and technology policy formulation (Miller, 1983). This has a negative impact on society. Miller (1983) argued that the most effective place to begin efforts to increase scientific literacy in the general population is through science education in schools.

In 1993, UNESCO attempted to provide a succinct yet full definition of scientific literacy, giving an operational meaning to the term and defining it as:

> The capability to function with understanding and confidence, and at appropriate levels, in ways that bring about empowerment in the made world and in the world of scientific and technological ideas (UNESCO, 1993, p. 15)

This definition required the scientifically literate individual to have acquired: a core of knowledge; experience of and understanding of the ways in which scientists work; and an understanding of the cultures, values, attitudes and assumptions, organisational structures, and limitations of scientific enterprises (UNESCO, 1993).

The American Association for the Advancement of Science (AAAS) (1994) produced a comprehensive description of scientific literacy in their book outlining secondary school science curriculum standards for the USA. The book, Science for all Americans: Project 2061 (AAAS, 1994), described scientific literacy in terms of skills and knowledge and how this leads to individual personal fulfilment, and the national and global consequences of increasing scientific literacy. The chapters of the book gave an insight into what the AAAS considered to be the essential components of scientific literacy. Three chapters focussed on the human enterprise of science, mathematics and technology: The Nature of Science (NOS), Nature of Mathematics and Nature of Technology. Six chapters focussed on the basic scientific content knowledge required to be scientifically literate. Two chapters described the history of science and the final chapter described the scientific Habits of Mind, outlining essential knowledge of the values of science and skills or competencies required to be scientifically literate (AAAS, 1994).

Two years later, the National Science Education Standards (NSES) (NRC, 1996) also described scientific literacy as an outcome of science education and outlined a curriculum. NRC (1996) described what students should know, understand, and be able to do to be scientifically literate at different grade levels. It stated that to create a scientifically literate society, individuals should: know and understand the natural world; use scientific processes in making personal decisions; engage in public discourse about matters of scientific concern; and increase their individual economic productivity through use of knowledge, understanding, and skills of the scientifically literate person in their careers (NRC, 1996). However, it also reiterated the link between individual scientific literacy, developed at school, and societal implications of individual scientific literacy (NRC, 1996).

DeBoer (2000) provided a comprehensive overview of the historical and contemporary aspects of scientific literacy in relation to science curricular policy. In culmination he developed his own theoretical framework drawing together available research. DeBoer focussed on how to teach to increase scientific literacy. They described teaching and learning about science as a cultural force in the modern world with a focus on science that has direct application to everyday living. In DeBoer's description of scientific literacy, the aim of science education is to prepare individuals for the world of work and to be informed citizens who are sympathetic to science and benefit from its aesthetic appeal. Skills of scientific literacy described by DeBoer (2000) relate to understanding reports and discussions of science that appear in the popular media (DeBoer, 2000 pp. 591-592). DeBoer's (2000) description of scientific literacy was heavily focussed on the impact of increasing individuals' scientific literacy on society. There was little discussion of the skills and knowledge that the individual should possess to be "informed citizens" or understand the reports in the media. DeBoer (2000) stated that scientific literacy leads to a "sympathetic" view of science and promotes a positive view of science.

Around the same time, Laugksch (2000) also provided a review of the literature regarding scientific literacy. This attempted to clearly delineate the individual characteristics of scientific literacy ("micro-view") from the societal implications ("macro-view") (p. 84). The macro-view was concerned with the connection between scientific literacy and the economic well-being of a nation. High levels of scientific literacy of the populace positively affect a nation's wealth, increase public support for science and give the public more realistic expectations of science, and allow the public to be involved in the science policy-making process (Laugksch, 2000). The micro-view was concerned with the impact of scientific literacy on the individual. High levels of scientific literacy increase citizens' confidence when faced with everyday science situations requiring informed decision making. Individuals' employment prospects are greater, and they benefit from aesthetic, intellectual and moral benefits (Laugksch, 2000).

Holbrook and Rannikmae (2007) described three aspects of scientific literacy: what people know; what people do; and what people value. They described scientific literacy in terms of personal skills such as interaction, communication, exhibiting sound and persuasive reasoning and making socio-scientific arguments. Scientific literacy was described as developing knowledge and skills relevant to everyday life and a future career, problem solving and socio-scientific decision making. They also recognised that through responsible citizenship, made possible by scientific literacy, society will be positively influenced (Holbrook & Rannikmae, 2007). Holbrook and Rannikmae (2007) discussed the importance of an understanding of the "nature of science" (NOS) and described the difficulty with this because of the varied and constantly evolving interpretations of NOS. To reconcile these varying definitions, NOS was defined by Holbrook and Rannikmae (2007) as: a human endeavour, including limited but present human fallibility and inferences; tentative, meaning it is subject to change; being based on human inference; including, not excluding, imagination and creativity; and influenced by culture and society (Holbrook & Rannikmae, 2007).

More recently, the OECD's Programme for International Student Assessment (PISA) 2015 Science Framework described scientific literacy as "the ability to engage with science related issues and ideas of science as a reflective citizen" (OECD, 2013, p. 7). This framework will be discussed in detail in section 1.1.2.

1.1.2 Scientific literacy: PISA

The Organisation for Economic Co-operation and Development (OECD) is an organisation consisting of 34 countries, which aims to improve the economic and social wellbeing of people around the world (OECD, 2018a). The OECD's PISA aims to assess scientific literacy of students and as part of this assessment the OECD devised a detailed description of scientific literacy (OECD, 2013). The PISA assessment of scientific literacy that took place in 2015 included 72 countries (or economies) and over half a million students took part (OECD, 2018a). PISA aims to provide a consensus definition of the concept of scientific literacy for science educators, based on research (OECD, 2013). As such it contains many features in common with the definitions described earlier in this chapter. PISA's description of scientific literacy is based on the skills (competencies) and knowledge of the individual (see Table 1-1 and Table 1-2). These skills and knowledge have implications both for the individual in their interaction with society and, in turn, for society as a whole. The OECD strived, since PISA first began in 2000, to provide a full and comprehensive description of scientific literacy and this description has become more detailed over subsequent assessments (OECD, 2003; OECD, 2006; OECD, 2013).

In 2003, PISA's short definition focussed on the skills and knowledge possessed by the scientifically literate individual. Only two skills were stated: the ability to identify questions and draw conclusions. Different knowledge types were not distinguished.

In 2006, knowledge was placed centre stage and three skills were stated: identify questions, explain scientific phenomena and draw evidence-based conclusions. The 2006 definition included elements that relate to knowledge of NOS: "Understanding of the characteristic features of science as a form of human knowledge and enquiry" and "awareness of how science and technology shape our material, intellectual, and cultural environments".

The 2015 PISA definition has a clear focus on competencies and knowledge. PISA 2015 defines scientific literacy as consisting of three competencies and three knowledge types. Table 1-1 and Table 1-2 provide a summary of the competencies and knowledge types.

PISA 2003 Definition

Scientific literacy is the capacity to *use scientific knowledge*, to *identify questions* and to d*raw evidence-based conclusions* in order to understand and help make decisions about the natural world and the changes made to it through *human activity* (OECD 2003 p133) .

PISA 2006 Definition

Scientific literacy refers to an individual's:

• *Scientific knowledge* and use of that knowledge to *identify questions*, acquire new knowledge, *explain scientific phenomena* and *draw evidence-based conclusions* about science-related issues

• Understanding of the characteristic features of science as a form of *human knowledge and enquiry*

• Awareness of how *science and technology* shape our material, intellectual, and cultural environments

• Willingness to engage in science-related issues and with the ideas of science, as a *reflective citizen* (OECD 2006 p23)

PISA 2015 Definition

Scientific Literacy is the ability to engage with science-related issues, and with the ideas of science, as a *reflective citizen*. A scientifically literate person, therefore, is willing to engage in reasoned discourse about science and technology which requires the competencies to:

1. *Explain phenomena* scientifically: Recognise, offer and evaluate explanations for a range of natural and technological phenomena.

2. *Evaluate and design scientific enquiry*: Describe and appraise scientific investigations and propose ways of addressing questions scientifically.

3. *Interpret data and evidence scientifically*: Analyse and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions. (OECD, 2013 p7)

The three competencies required for scientific literacy require three forms of knowledge: Content knowledge, procedural Knowledge and epistemic knowledge (OECD, 2013 p17)

Figure 1-1 Evolution of the PISA definition of scientific literacy

PISA 2015 outlines three overall competencies of scientific literacy: *explain phenomena scientifically*, *evaluate and design scientific inquiry*, and *interpret data and evidence scientifically*. Each competency consists of five sub-competencies (Table 1-1) that contribute to performance of the overall competency (OECD, 2013).

Competency 1 focusses on giving scientific explanations, including making predictions and forming explanatory hypotheses. Individuals can give scientific explanations of the implications of scientific knowledge for society. This competency mainly requires content knowledge of science (Table 1-2) (OECD, 2013).

Competency 2 focusses on scientific investigations, including stating and recognising questions, planning and evaluating investigations. This competency mainly requires the use of procedural and epistemic knowledge (Table 1-2) (OECD, 2013)

Competency 3 focusses on presentation and interpretation of data and evidence, including critical evaluation of information from different sources. This competency requires the use of all three knowledge types (Table 1-2) (OECD, 2013).

Table 1-1 PISA's competencies and sub-competencies for scientific literacy (OECD, 2013, pp. 15-16)

Competency 1: Explain phenomena scientifically
Recognise, offer and evaluate explanations for a range of natural and technological phenomena demonstrating the ability to:
A Recall and apply appropriate scientific knowledge;
B Identify, use and generate explanatory models and representations;
C Make and justify appropriate predictions;
D Offer explanatory hypotheses;
E Explain the potential implications of scientific knowledge for society

Competency 2: Evaluate and design scientific inquiry
Describe and appraise scientific investigations and propose ways of addressing questions scientifically demonstrating the ability to:
A Identify the question explored in a given scientific study;
B Distinguish questions that are possible to investigate scientifically;
C Propose a way of exploring a given question scientifically;
D Evaluate ways of exploring a given question scientifically;
E Describe and evaluate a range of ways that scientists use to ensure the reliability of data and the objectivity and generalisability of explanations.

Competency 3: Interpret data and evidence scientifically
Analyse and evaluate scientific data, claims and arguments in a variety of representations and draw appropriate conclusions demonstrating the ability to:
A Transform data from one representation to another;
B Analyse and interpret data and draw appropriate conclusions;
C Identify the assumptions, evidence and reasoning in science-related texts;
D Distinguish between arguments which are based on scientific evidence and theory and those based on other considerations;
E Evaluate scientific arguments and evidence from different sources (e.g. newspaper, internet, journals).

Table 1-2 PISA's knowledge types for scientific literacy (OECD, 2013, pp. 18-21)

Content knowledge		
Physical systems	Living systems	Earth and space
Structure of matter (*e.g.*, particle model, bonds) Properties of matter (*e.g.*, changes of state, thermal and electrical conductivity) Chemical changes of matter (*e.g.*, chemical reactions, energy transfer, acids/bases) Motion and forces (*e.g.*, velocity, friction) and action at a distance (*e.g.*, magnetic, gravitational and electrostatic forces) Energy and its transformation (*e.g.*, conservation, dissipation, chemical reactions) Interactions between energy and matter (*e.g.*, light and radio waves, sound and seismic waves)	Cells (*e.g.*, structures and function, DNA, plant and animal) The concept of an organism (*e.g.*, unicellular and multicellular) Humans (*e.g.*, health, nutrition, subsystems such as digestion, respiration, circulation, excretion, reproduction and their relationship) Populations (*e.g.*, species, evolution, biodiversity, genetic variation) Ecosystems (*e.g.*, food chains, matter and energy flow) Biosphere (*e.g.*, ecosystem services, sustainability)	Structures of the Earth systems (*e.g.*, lithosphere, atmosphere, hydrosphere) Energy in the Earth systems (*e.g.*, sources, global climate) Change in Earth systems (*e.g.*, plate tectonics, geochemical cycles, constructive and destructive forces) Earth's history (*e.g.*, fossils, origin and evolution) Earth in space (*e.g.*, gravity, solar systems, galaxies) The history and scale of the Universe and its history (*e.g.*, light year, Big Bang theory)

Procedural knowledge
The concept of variables including dependent, independent and control variables;
Concepts of measurement *e.g.*, quantitative [measurements], qualitative [observations], the use of a scale, categorical and continuous variables;
Ways of assessing and minimising uncertainty such as repeating and averaging measurements;
Mechanisms to ensure the replicability (closeness of agreement between repeated measures of the same quantity) and accuracy of data (the closeness of agreement between a measured quantity and a true value of the measure);
Common ways of abstracting and representing data using tables, graphs and charts and their appropriate use;
The control of variables strategy and its role in experimental design or the use of randomised controlled trials to avoid confounded findings and identify possible causal mechanisms;
The nature of an appropriate design for a given scientific question *e.g.*, experimental, field based or pattern seeking.

Epistemic knowledge
The constructs and defining features of science: The nature of scientific observations, facts, hypotheses, models and theories; The purpose and goals of science (to produce explanations of the natural world) as distinguished from technology (to produce an optimal solution to human need), what constitutes a scientific or technological question and appropriate data; The values of science e.g., a commitment to publication, objectivity and the elimination of bias; The nature of reasoning used in science e.g., deductive, inductive, inference to the best explanation (abductive), analogical, and model-based;
The role of these constructs and features in justifying the knowledge produced by science: How scientific claims are supported by data and reasoning in science; The function of different forms of empirical enquiry in establishing knowledge, their goal (to test explanatory hypotheses or identify patterns) and their design (observation, controlled experiments, correlational studies); How measurement error affects the degree of confidence in scientific knowledge; The use and role of physical, system and abstract models and their limits; The role of collaboration and critique and how peer review helps to establish confidence in scientific claims; The role of scientific knowledge, along with other forms of knowledge, in identifying and addressing societal and technological issues.

1.2 Development of a framework of scientific literacy

In Section 1.1, various descriptions of scientific literacy were discussed. Although there were differences between these descriptions, there were aspects that were common to most, if not all, definitions. Taking account of these varied descriptions of scientific literacy, it can be considered to be a set of skills and knowledge possessed by the individual that influence the individual’s interactions with society, and this influences society as a whole. Figure 1-2 shows a Framework of Scientific Literacy which has been developed by the author for use in this thesis. It aims to go beyond a summary of the literature (presented in Section 1.1) and provide a synthesis that draws together the central ideas from the literature. This framework shows how the skills and knowledge of scientific literacy acquired by the individual impact on their interactions with society. This framework will be revisited in Chapter 6 where findings from the studies carried out as part of this thesis will be added . The framework for scientific literacy, described later in Chapter 6, will enhance the framework described here in Chapter 1 by detailing how scientific literacy may be developed and assessed in practice.

Figure 1-2 shows two circles that represent different aspects of scientific literacy. The inner circle shows the individual aspects of scientific literacy, which consist of the skills and knowledge that the scientifically literate individual should possess. The outer circle shows the societal aspects of scientific literacy which relate to how the individual interacts with society. It is important to note that the outer and inner circle are connected. The skills and knowledge depicted in the inner circle of Figure 1-2 influence the individual’s interactions with society and society as a whole and all four individual aspects (inner circle) influence all three societal aspects (outer aspects).

The separation of individual and societal aspects of scientific literacy is described by Laugksch (2000), who describes the micro and macro view of scientific literacy. The micro-view is depicted in the inner circle of Figure 1-2 and relates to the enhancement to the lives of the individual, while the macro-view is depicted in the outer circle of Figure 1-2 and relate to the benefits to the nation or society.

While depicted separately, the inner and outer circle are connected and this connection between the skills and knowledge of the individual and the implications for society is described by Showalter (cited in Laugksch, 2000). The scientifically literate individual possesses a range of skills and knowledge of science, which when applied in their daily lives enhance their ability to interact with the world around them and to participate in society (Showalter, 1974, cited in Laugksch, 2000). This idea that the skills and knowledge of scientific literacy have societal implications was described by Miller (1983). They asserted that knowledge and understanding of science (contributing to scientific literacy) allows individuals to participate in society by making informed judgements relating to science and technology policy formulation.

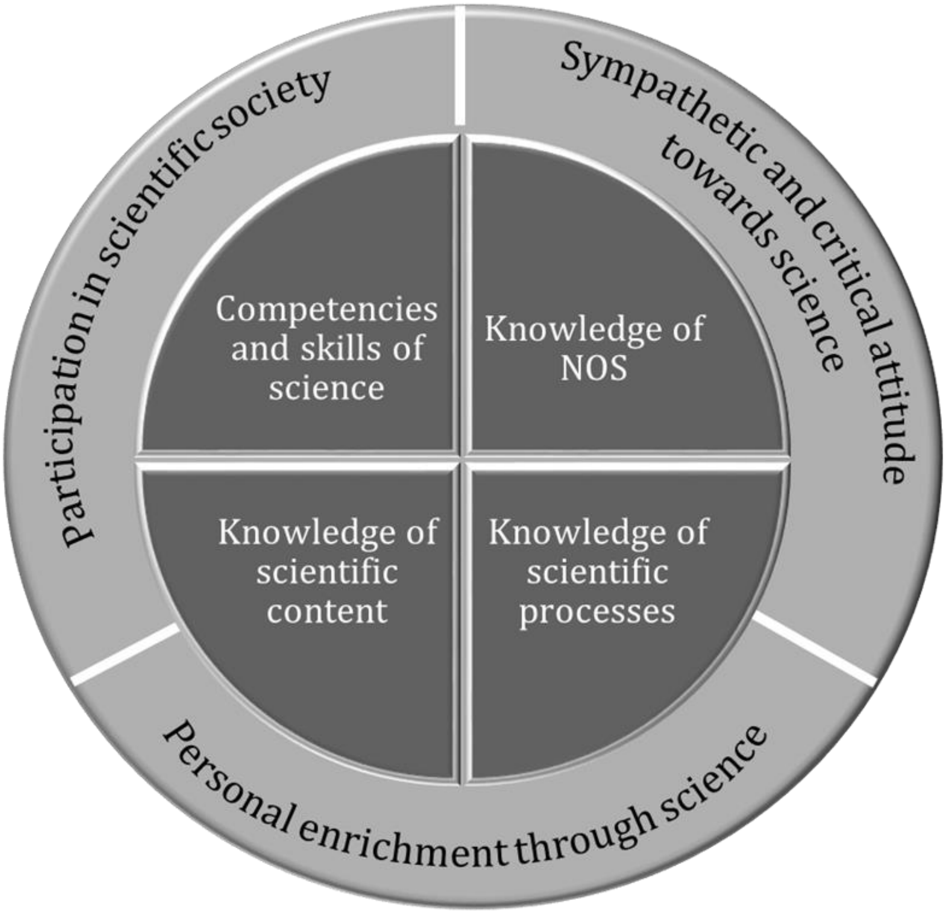


Figure 1-2 A Framework of Scientific Literacy including individual and societal aspects

1.2.1 Individual aspects of scientific literacy

The inner circle of Figure 1-2 shows the individual aspects of scientific literacy. It is these four aspects that are covered in the learning outcomes of curriculum documents that form the basis of everyday classroom practice. Three knowledge types are described in Figure 1-2. Content knowledge of science relates to the main concepts and theories of science. Knowledge of scientific processes and knowledge of NOS relate to knowledge of common practices in scientific inquiry and the rationale behind these (OECD, 2013). Use of the different types of knowledge underpins performance of the skills (OECD, 2013). The competencies and skills of science that an individual should possess are wide-ranging and discussed throughout this thesis.

There was evidence from the literature that the skills and knowledge of scientific literacy consisted of four aspects: Knowledge of NOS, knowledge of scientific processes, knowledge of scientific content and competencies and skills of science. While authors may describe these aspects differently and not all authors described all four aspects, there was strong evidence from the literature to support the four individual aspects of scientific literacy described in the inner circle of Figure 1-2. For example, Showalter (cited in Laugksch, 2000) described: knowledge of science concepts, principles, laws and theories (knowledge of the content of science); processes of science (knowledge of scientific processes); understanding of the values that underlie science (knowledge of NOS); and manipulative skills associated with science (competencies and skills of science). The AAAS (1994) also described three of these four individual aspects of scientific literacy. They mainly focussed on knowledge of the content of science but also described competencies and skills of science, the human enterprise of science (knowledge of NOS). They did not explicitly discuss knowledge of scientific processes. Miller (1983) focussed less so on the individual aspects compared to societal implications but described how individuals should understand basic scientific constructs, terms and concepts (knowledge of the content of science), and the scientific approach (knowledge of scientific processes). UNESCO's (1993) definition described individual aspects as a core of scientific knowledge (knowledge of the content of science) and knowledge of the cultures, values, attitudes and limitations of science (knowledge of NOS). The following paragraphs discuss the four individual aspects of scientific literacy: Knowledge of scientific content (i), knowledge of scientific processes (ii), knowledge of the Nature of Science (NOS) (iii) and competencies and skills of science (iv).

(i) Knowledge of scientific content

Knowledge of scientific content is widely agreed to be essential for scientific literacy and has been, and continues to be, the focus of secondary school science curricula globally (NGSS Lead States, 2013; SQA 2013a, b; NCCA, 2015; SQA 2017a). However, what constitutes essential science knowledge is not widely agreed. PISA 2015 describes the content knowledge it expects students to have learnt by the end of compulsory science education (Table 1-2) (OECD, 2013). The AAAS (1994), in their curriculum (Science for all Americans: Project 2061), dedicated six chapters to describing the content knowledge required for scientific literacy. For the development of scientific literacy, the core content knowledge should be key scientific concepts, principles, laws and explanatory theories, selected for their relevance and usefulness to students' lives (Miller, 1989; DeBoer, 2000).

(ii) Knowledge of scientific processes

This outcome of scientific literacy focuses on the students' knowledge of scientific processes but should not be limited to knowledge of "the scientific method". Scientific processes cannot be defined as rigorously and unambiguously as "the scientific method" (Bauer, 1994). On the other hand, the term "scientific processes" rather than "scientific inquiry" was chosen because it is a narrower term and only includes the procedural aspects of scientific inquiry without the epistemic aspects which would be more comfortably housed under the heading knowledge of NOS (OECD, 2013). Scientific processes as described here more closely align with PISA's 2015 description of the procedural knowledge required for scientific literacy (OECD, 2013).

(iii) Knowledge of the Nature of Science (NOS)

Knowledge of NOS is essential for scientific literacy (McComas & Olson, 1998; Schwartz, Lederman & Crawford, 2004; Holbrook & Rannikmae, 2007). As with the term scientific literacy itself, there are varying interpretations of NOS. It has been described by Lederman (2007) as referring to the epistemology of science, science as a way of knowing, and the values and beliefs of scientific knowledge generation. The scientifically literate individual understands that science is empirical and evidence based and hence aims to explain and predict. They also know that science cannot provide answers to all questions, it is tentative and subjective. They understand that science is undertaken as a social, human endeavour and so is influenced by society and culture but is upheld by ethical principles and practices and aims to avoid bias (AAAS, 1994; Lederman, 2007). Epistemic knowledge, which relates to the procedures of knowledge building in science, can be subsumed under the heading of NOS (OECD, 2013).

(iv) Competencies and skills of science

It is widely agreed that there are a wide range of competencies and skills required to be scientifically literate. The PISA 2015 Science Framework (OECD, 2013) provides a comprehensive list of what are considered to be the competencies of scientific literacy (see Table 1-1). NSES describes the fundamental abilities necessary to do scientific inquiry (Olson & Loucks-Horsley, 2000 p. 19). DeBoer (2000) refers to citizens needing skills to independently investigate issues affecting society in order to make informed decisions, read and understand accounts of scientific discoveries, and follow and engage in discussions about science. The skills of scientific literacy according to AAAS (1994) include: computational skills such as basic number and calculator skills, and estimation; skills associated with manipulation and observation; communication skills; and critical response skills. Although this paragraph lists some of the skills required for scientific literacy, the range of skills is so broad it cannot be summarised in a single paragraph. In fact, much of this thesis is dedicated to exploring the skills associated with scientific literacy.

1.2.2 Societal aspects of scientific literacy

The aspects of scientific literacy in the outer ring of Figure 1-2 all relate to how an individual interacts with a scientific society. Although not all authors discussed in Section 1.1 described all three societal aspects, overall the literature supported the separation of these societal elements of scientific literacy into three distinct but related aspects: participation in scientific society, personal enrichment through science and sympathetic and critical attitude towards science. The aspect, participation in society, focusses on the individual’s interaction with science in society and how this impacts society. This contrasts with the other two aspects of scientific literacy, personal enrichment through science and sympathetic and critical attitude towards science, which relate more to personal, individual enrichment but also have implications for society more widely. DeBoer (2000) focussed more on the societal aspects of scientific literacy (outer circle of Figure 1-2) than the individual aspects (inner circle of Figure 1-2). They described how high levels of scientific literacy of the individual impacts the nation's economic wellbeing through participation in science as an informed citizen (participation in scientific society) and increased employment prospects (personal enrichment through science). DeBoer (2000) also discussed individual benefits relating to a person's interactions with society such as enjoyment of aesthetic appeal of science (personal enrichment through science) and the sympathetic views of the individual in their dealings with science in society (sympathetic and critical attitude towards science). Laugksch (2000) also described the three societal aspects of scientific literacy as they described how individual scientific literacy allows citizens to be involved with science policy-making (participation in scientific society), greater employment prospects (participation in a scientific society / personal enrichment through science), aesthetic, intellectual and moral benefits (personal enrichment through science) and increased public support for science (sympathetic and critical attitude towards science). Miller (1983) also focussed mainly on the impact of individual scientific literacy on society in general and the individual's interactions with society. They discussed how higher levels of individual scientific literacy led to increased participation in society through democratic involvement in decision making relating to science policy issues. The following paragraphs discuss the three societal aspects of scientific literacy: (i) participation in scientific society, (ii) personal enrichment through science and (iii) sympathetic and critical attitude towards science.

(i) Participation in scientific society

This outcome relates to individual understanding and participation in the scientific aspects of societal and national concerns such as social-justice, economic benefits and national security, and global concerns such as population growth, biodiversity and distribution of wealth (AAAS, 1994). Miller (1989) argues that there is a threshold or minimum level of scientific literacy (skills and knowledge) that allows citizens to function minimally in society as consumers of science. This aspect of scientific literacy is demonstrated by informed and attentive citizens who participate in society, for example by voting responsibly and influencing public policy about science (Miller, 1983; DeBoer, 2000).

(ii) Personal enrichment through science

This outcome of scientific literacy is concerned with increasing individual well-being, physically, socially and emotionally through their interactions with science in society. It relates to benefits to the individual through increased employment prospects, lifelong learning and personal enjoyment of science. Scientifically literate individuals are prepared to engage with science in the world of work, which may result in increased employment prospects, whether that employment will be in science or in other areas. They continue to learn about science into their adult lives (DeBoer, 2000). Scientifically literate individuals learn about science for its "aesthetic appeal" and appreciate the "truth and beauty in nature" (DeBoer, 2000, p. 593). Scientifically literate individuals have "a richer, more satisfying, more exciting view of the universe" (Laugksch, 2000, p. 77).

(iii) Sympathetic and critical attitude towards science

Scientifically literate individuals are "thoughtful supporters of science" (AAAS, 1994) and "sympathetic to science" (DeBoer, 2000, p. 593). They see science as an overall force for good and adopt a realistic and positive view of the potential of science (DeBoer, 2000). Scientifically literate individuals are not antagonistic towards science but neither are they uncritically positive (AAAS, 1994). Scientifically literate individuals think critically and independently when faced with arguments that may conflict with their own views (AAAS, 1994; Oulton, Dillon & Grace, 2004). This can include learning to carry out basic critical evaluation of reports in the media and being able to participate in discussion about aspects of science they come across in their daily lives through a critical lens (OECD, 2013). Individual's use their sympathetic and critical attitude towards science in their interactions with science in society.

The remainder of this chapter focusses on how scientific literacy is currently, and has been, developed and assessed in practice in secondary schools and how this has been translated into initial teacher education. The focus is on development and assessment of the knowledge and skills of scientific literacy, to prepare individuals for participation in society and personal enrichment through science now and in later lie.

1.3 Assessment of scientific literacy in secondary schools

Section 1.3 will explore the assessment of scientific literacy in practice. It will discuss the assessment of scientific literacy through high-profile, global and national assessments, with a focus on PISA. It will then discuss the impact of these assessments on national, science curricular policy, and the limitations for this purpose.

There are a variety of high profile national and global assessments that aim to (and claim to) assess scientific literacy in secondary school students. One of the biggest and most widely recognised assessments is the Programme for International Student Assessment (PISA) from the OECD (OECD, 2013). TIMSS is also discussed here as an influential assessment of the skills and knowledge of science (Mullis & Martin, 2013).

1.3.1 Assessment of scientific literacy: PISA 2015

PISA 2015 was the fifth PISA assessment to be undertaken by the OECD since it began in 2000, but only the second to have the main focus on science (2006 was the last science focus) (OECD, 2018a). PISA 2015, aimed to assess the competencies of scientific literacy, at the appropriate level of scientific knowledge, in contexts that are appropriate to the age of the students (15 years old). The purpose of the assessment was to gain a measure of individual students' scientific literacy, in order to compare science performance of participating countries and report trends in science performance for the purpose of policy decision making (OECD, 2016).

PISA 2015 based its assessment on performance of competencies and demonstration of knowledge (Table 1-1 and 1-2). PISA 2015 was a two-hour long assessment and items included simple multiple choice, complex multiple choice and constructed response questions (OECD, 2013). PISA 2015 was the first year to use computer-based assessment, rather than a pencil and paper test. This allowed the assessment to include some simulation assessment items (Figure 1-3). However, many of the items remained in the same format as previous cycles of PISA, albeit reading from a screen and typing rather than reading and writing on paper (OECD, 2013). PISA uses contexts as the settings to frame questions, which allows students to apply their knowledge to a relevant situation (OECD, 2013). Contexts aim to be appropriate to the life experiences and knowledge that students are likely to have acquired by the age of fifteen. The contexts chosen are not limited to school science curricula of participating countries but relate to the self, family and peer groups (personal), to the community (local and national), and to life across the world (global). To ensure assessment validity, linguistic and cultural differences between the participating countries are considered when choosing contexts (OECD, 2013).

An example of a PISA 2015 assessment item is shown in Figure 1-3:

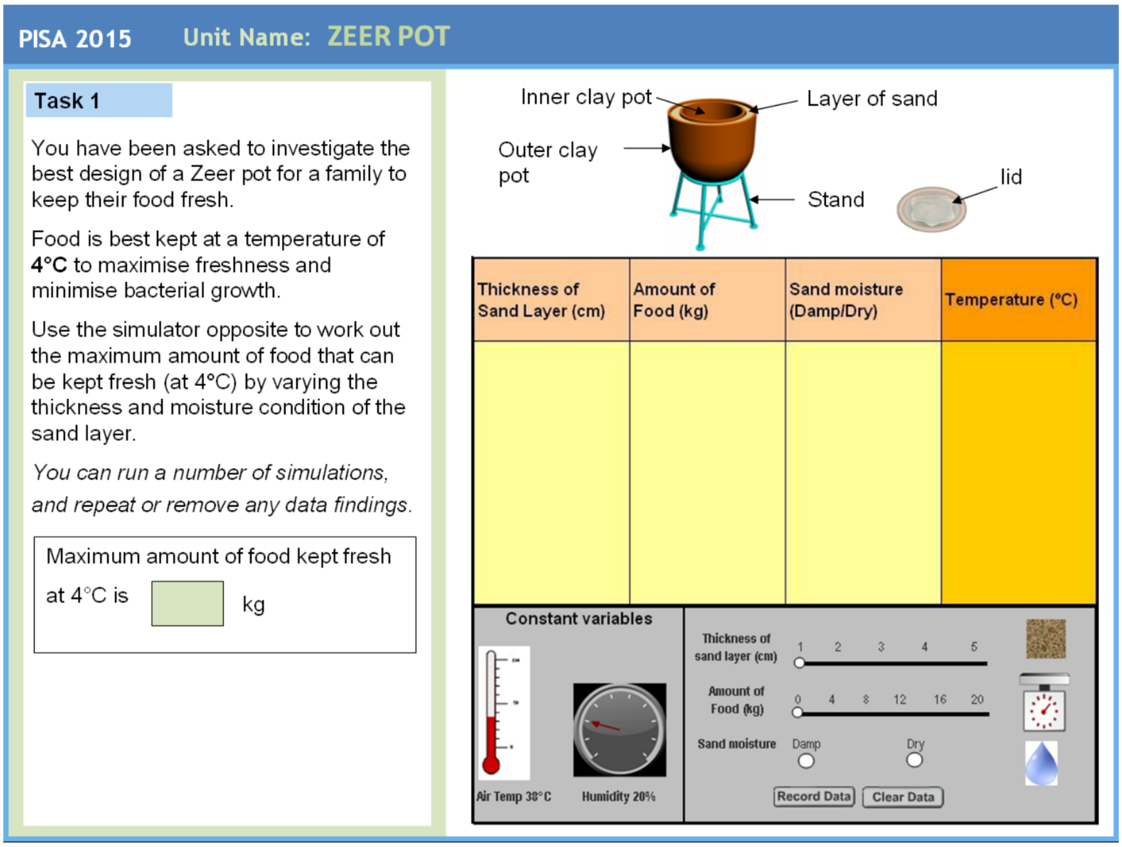


Figure 1-3 PISA 2015 assessment item (OECD, 2013, p. 35)

Figure 1-3 shows a new style of assessment question based on a computer-generated simulation of an investigation. Sliders can be used to vary conditions before running a simulation to gather data. Students are then tested on their ability to interpret their data. The PISA assessment item shown aims to assess PISA Competency 2 *evaluate and design scientific inquiry* (Table 1-1). The knowledge type assessed is procedural knowledge and the context is natural resources (Table 1-2) (OECD, 2013, p. 35).

PISA Scientific Literacy Assessments record information about the student's background using student, parent and school questionnaires. The student questionnaire collects data about a student's gender, economic social and cultural status (ESCS), socioeconomic status (SES), immigration status, language spoken at home, age of arrival in the country and country of origin. The school questionnaire collects data about the school location; type and size of school; amount and source of resources; social, ethnic, academic composition of the school as a whole; class size and teacher qualifications. The parent questionnaire collects data about the level of parental support received by the student. This information is used to compare performance to demographic, social, economic and education variables.

1.3.2 Assessment of Scientific Literacy: TIMSS

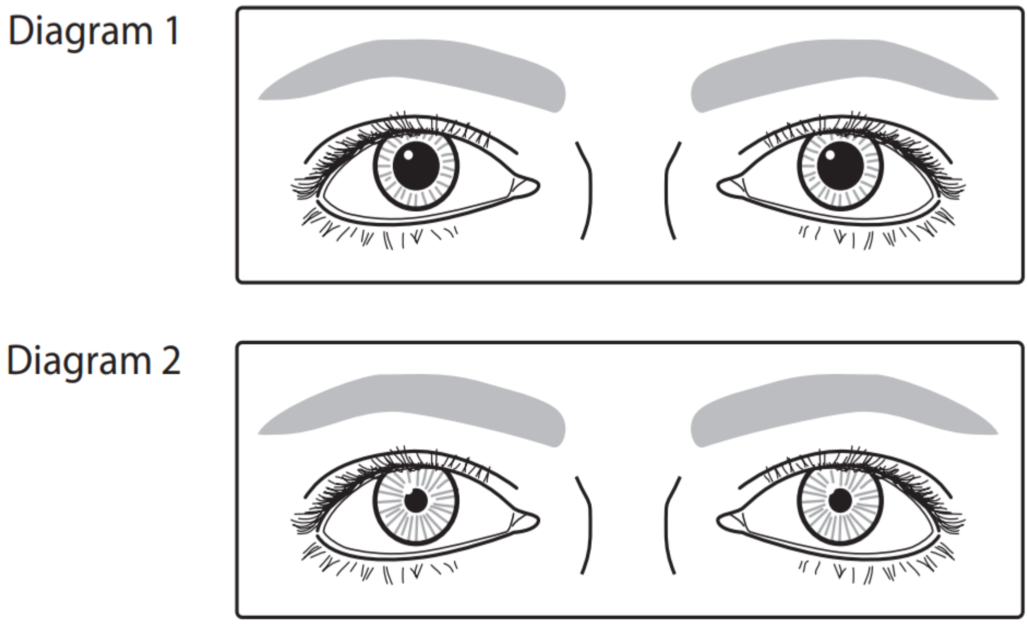
There are alternative assessments of science that can be used instead of or alongside PISA. TIMSS is an established assessment of school level science, carried out by the International Association for the Evaluation of Educational Achievement (IEA). Although TIMSS does not refer to scientific literacy explicitly, their aims align with many of the key principles of scientific literacy and focus particularly on the individual's participation in a scientific society. In the introductory paragraphs, the TIMSS 2015 frameworks states:

> … science is essential to becoming a knowledgeable and functioning individual as well as a contributing member of society... to become citizens who can make informed decisions about themselves and the world in which they live... maintaining good health habits, making informed financial decisions, and using effective problem solving skills. (Mullis & Martin, 2013, p. 3 & p. 29)

TIMSS aims to provide participating countries with information about student achievement in science against international benchmarks (Mullis & Martin, 2013).

The TIMSS 2015 Science Framework assessed 3 aspects of science: cognitive abilities, content knowledge and science practices (newly added in 2015). The cognitive abilities aimed to assess thinking skills in science and include "knowing, applying and reasoning" (Mullis & Martin, 2013, p. 55). Content knowledge in TIMSS was divided into four aspects: biology, chemistry, physics and Earth science (Mullis & Martin, 2013, p. 40). TIMSS described five science practices, or skills: asking questions based on observations, generating evidence, working with data, answering the research question, and making an argument from evidence (Mullis & Martin, 2013, p. 58). These science practices included skills from daily life and school that students use to conduct scientific inquiry. They are not subject specific but are fundamental to all science disciplines and are assessed within the context of the science content domains, using the thinking skills of the cognitive domains (Mullis & Martin, 2013).

Assessment items may assess content knowledge, cognitive skills and science processes within the same question, depending on what is being asked of the student (Mullis & Martin, 2013). An example of an assessment item from TIMSS is shown in Figure 1-4.



Diagrams 1 and 2 illustrate the same pair of eyes that have reacted to a change in an environmental condition. What is the environmental condition and how is it different for the eyes in Diagram 1 and Diagram 2?

Figure 1-4 TIMSS assessment item (IEA 2013)

The assessment item shown in Figure 1-4 is a short, open response question which aims to assess the cognitive ability, applying, within the content area of biology (IEA, 2013).

1.3.3 Impact of PISA on curricula and assessment

One of PISA's main claims is that it is policy oriented and is able to identify the characteristics of students, schools and education systems that perform well (OECD, 2016). As such, results are used by policy makers as the catalyst to shape reforms to curricula. This section outlines how PISA has influenced the science curricula of its participating countries. The focus of this discussion is on the Scottish and Irish curricula as these are discussed in later chapters of this thesis with the USA, Denmark and Australia given as examples to further highlight the influence of PISA globally.

Scotland

Different parts of the UK participate in separate adjudicated areas in PISA, allowing analysis and comparison to be carried out separately in England, Scotland, Northern Ireland and Wales. This is due to the differing education systems within the UK.

The Scottish Curriculum for Excellence (CfE) was developed with the findings of PISA in mind. Before implementation of CfE the Scottish Government commissioned a report by the OECD to appraise the Scottish secondary school curriculum. The Scottish Government (2010a) stated that:

> International education comparisons enable us to ascertain if we are on the right track in terms of our performance, that we have adopted the right policies and are making the best use of resources. (Scottish Government, 2010a, p. 1)

The Scottish CfE science courses aim to create "scientifically literate citizens with a lifelong interest in the sciences" (Education Scotland, 2010b, p. 253). The skills and attributes of scientific literacy as described in the CfE are wide ranging. The scientifically literate person has scientific values and respect for living things and the environment and an understanding of the risks and benefits of science. They use these when making informed personal decisions and expressing opinions. They have developed informed social, moral and ethical views of scientific, economic and environmental issues and self-awareness through reflecting on the impact, significance and cultural importance of science and its applications to society. They are able to read and understand essential points from sources of information including media reports, discussing and debating those scientific ideas and reflecting critically on information included or omitted from sources/reports including consideration of limitations of data (Education Scotland, 2010, p. 257). The Curriculum for Excellence science courses are intentionally aligned with the PISA vision of scientific literacy. The Scottish Government (2010a) states:

> The Curriculum for Excellence … is based on the concept of science as an important part of our heritage with its application as part of our everyday lives. This concept of science fits with that put forward by the OECD in PISA. (The Scottish Government, 2010a, p. 1)

CfE aims for students to be: successful learners, confident individuals, effective contributors and responsible citizens (The Scottish Government, 2008). The CfE science courses aim to stimulate curiosity, investigate the environment, provide experience of practical investigations and experiments, promote understanding of empirical methods, interpret evidence, convey understanding of the big concepts, understand the impact of science on society, consider social, ethical, economic and environmental issues (The Scottish Government, 2010b). The science curriculum allows students to develop the scientific skills and knowledge required in all sectors of the economy (Education Scotland, 2010, p. 253).

Assessment in CfE aims to support learning, help plan next steps in learning, inform learners and their parents, summarise achievements, monitor the education system and inform future developments (The Scottish Government, 2011).

Ireland

The Irish National Council for Curriculum and Assessment (NCCA, 2013) referred to PISA and TIMSS in its review of the Junior Cycle Curriculum:

> Ireland's performance in PISA … relative to the OECD average shows that Ireland has not shown any discernible improvement in students' science achievement. (NCCA, 2013, p. 11)

In 2011, primary school pupils in Ireland participated in Trends in International Mathematics and Science Studies (TIMSS) for the first time since it was originally conducted in 1995. In both the 1995 and 2011 TIMSS studies, Ireland scored significantly above the TIMSS average. However, it is worth noting that, despite intensive primary curriculum reform, achievement by Irish primary pupils in science is broadly similar to the Irish performance on TIMSS in 1995 (NCCA, 2013). The lack of progress in PISA and TIMSS performance has been one driving force behind Irish curricular changes.

The Junior Cycle science specification (NCCA, 2015) aims to develop scientific literacy in students. The Specification for Junior Cycle Science produced by the NCCA (2015) specifically refers to the PISA definition of scientific literacy and the three competencies (OECD, 2013; NCCA, 2015, p. 4). It also refers to developing students' knowledge *of* and *about* science, the knowledge types of scientific literacy in PISA 2006 (OECD, 2006; NCCA, 2015, p. 4). The specification focusses on skills development and problem solving and aims to develop positive attitudes towards science, scientific literacy, scientific habits of mind, literacy and numeracy, as well as a body of scientific knowledge (NCCA, 2015). Junior Cycle Science is divided into five strands: Earth and space, physical world, chemical world, biological world and Nature of Science. The Nature of Science strand is a unifying strand that permeates through the specific science disciplines (NCCA, 2015). This strand focuses on how science works, carrying out investigations, communicating in science, and science and scientists in society. It has no content knowledge of its own; instead the Nature of Science outcomes are intended to be visited throughout the course, when carrying out activities related to the other four strands (NCCA, 2015).

Assessment in the new Junior Cycle science specification aims to increase support for learners, through increased in-course assessment, in the form of classroom-based assessments, and focus less on the final exam (NCCA, 2015). There are two classroom-based assessments, the Extended Experimental Investigation and the Science in Society Investigation. The Extended Experimental

Investigation took place for the first time in April/May of 2018 and the Science in Society Investigation is planned for autumn/winter of 2018.

Other examples

The USA's Next Generation of Science Standards (NGSS) evidences PISA and TIMSS to justify curricular change:

> U.S. students have not ranked favourably on international comparisons of science achievement as measured by Trends in International Mathematics and Science Study (TIMSS) and Program for International Student Assessment (PISA). (Lee, Miller and Januszyk, 2014, p. 14)

NGSS refers to poor scientific literacy, evidencing PISA results:

> When it comes to … using scientific evidence, identifying scientific issues, and explaining phenomena scientifically as measured by PISA, U.S. students performed in the bottom half of the international comparison and did not show significant improvements (Lee, Miller and Januszyk, 2014, p. 14)

Denmark has also made significant educational reforms based on the findings of PISA.

> Danish public school is also facing significant challenges. The academic standards – especially in reading and Maths – are not sufficiently high. Danish students perform on the average within the OECD in Danish, Maths and natural sciences when leaving the public school. (The Danish Government, 2013, p. 1)

These reforms included the implementation of national tests in years 2-8 of the Danish Folkeskole, with reporting levels aligned with PISA reporting levels (The Danish Government, 2013).

The Australian Curriculum and Assessment Reporting Agency (ACARA) is an independent authority that runs the National Assessment Programme (NAP) in Australia, including PISA. The Australian education system does not have state run external exams so PISA is the only external assessment of science used by the Australian Government to assess students' science progress at secondary level:

> The Education Council agreed to use the Programme for International Student Assessment (PISA) as the national measure of performance for science literacy among secondary students. (ACARA, 2016)

1.3.4 Limitations of PISA assessment of scientific literacy to inform policy

While the influence of PISA on curricular policy is wide reaching. There are limitations to its usefulness in informing policy decisions. Criticisms of PISA tend to focus on the validity of the assessment, rather than the description of scientific literacy upon which it is based. PISA 2015 aims to assess the competencies and knowledge described in the PISA 2015 Framework (Table 1-1and Table 1-2) and evaluate education systems worldwide (OECD, 2013; OECD, 2018a). Therefore, two questions can be asked relating to the assessment's validity:

1. Does the assessment measure what we think it does? i.e. does PISA actually assess the competencies and knowledge it purports to assess?
2. Can we rely on the assessment as the basis of our decisions? i.e. can the results from PISA be used to evaluate education systems and inform policy decision making?

The first question relates to measurement validity, also known as assessment validity, and refers to the accuracy of the measurement or how well a test measures what it aims to measure (Phelan & Wren, 2006; Newton & Shaw, 2014). Alignment is closely related to validity and refers to the match between the assessment instrument and the curricular documentation (Webb, 1997). In the case of PISA, to be able to infer *valid* information about students' competencies, the assessment must be *aligned* to the PISA 2015 Framework. The PISA scientific literacy assessment is an assessment of scientific competencies and knowledge. Competencies are work or task related and describe behaviour (Whiddet & Hollyforde, 1999). However, the PISA assessment is a written or computer-based assessment, and although it now involves some simulations, it cannot represent the practical aspects of science performance upon which the competencies are based (Dolin & Krogh, 2010). It also relies on traditional reading and writing literacy skills to interpret questions and provide answers, particularly in the case of the short or open constructed responses, which are not directly related to performance of the competencies (OECD, 2013). It attempts to minimise this by using language that is clear and simple and aiming for a reading age no higher than the average 15-year-old (OECD, 2013).

PISA scientific literacy assessments are not directly linked to the school curriculum of participating countries. This presents difficulties in accurately measuring students' application of scientific content knowledge. Students sitting the assessment will have a variety of content knowledge due to differing curriculum focus in participating countries. Danish research suggests that there is a lack of correspondence between PISA content knowledge systems and Danish topic areas and that "large parts of PISA's physical systems might not have been taught in many classes in Denmark" (Dolin & Krogh, 2010, p. 582). PISA results show that many countries perform better in some content areas than others, for example students in the United Kingdom performed better in living systems compared to Earth and space and physical systems (OECD, 2006). This may be due to differing curricula between countries.

It is also difficult to ensure assessment items are unbiased in terms of gender, culture and linguistics, given the wide range of participating countries and therefore cultures. Bias may be present in terms of the situation within which the question is set and the type of content knowledge required (Gorur & Wu, 2015). PISA acknowledges that translation of assessments and questionnaires into the various languages also introduces the risk of bias (OECD, 2010). Therefore, PISA releases strict guidelines for the translation of assessment items into the language of instruction for each participating country.

The second question of PISA's validity relates to how the findings from PISA are used to extrapolate information for decision and policy making (Newton & Shaw, 2014; Gorur & Wu, 2015). PISA can give information on how a country ranks within a list of other countries but the situations behind these scores are complex and based on a multitude of confounding factors, e.g. socio-economic status or cultural differences such as media attention to science, that PISA cannot fully account for in its analysis (Eijkelhof, 2014; Gorur & Wu, 2015).

1.4 Development and assessment of scientific literacy using inquiry in the context of SSI

Section 1.3 discussed PISA and TIMSS assessments of scientific literacy and their impact on national curricular policy. As discussed in Section 1.1, scientific literacy can be considered as the skills and knowledge of science that allow a person to participate in and receive enrichment from society. This section explores the theoretical and educational policy background around how inquiry is used to develop these skills and knowledge of scientific literacy, with a particular focus on inquiry carried out using socioscientific issues (SSI) as the context. Firstly, a brief overview of the literature regarding inquiry as a pedagogical approach will be provided, including an overview of the use of SSI as the context for inquiry in the classroom. Finally, a definition of inquiry in the context of SSI will be provided, considering the literature discussed. Inquiry as a pedagogical approach is widely supported by educationalists as an effective method of teaching both skills and knowledge of science and SSI can be used as the contexts for student inquiry (Colburn, 2000; Olson & Loucks-Horsley, 2000; Wenning, 2005).

Inquiry can be understood in two distinct lights:

1. Inquiry is a set of knowledge, understanding, competencies and skills that students *learn*
2. Inquiry is an approach to *teaching*

(Bybee, 2002)

Inquiry as a set of skills and knowledge is well documented in curricula and policy documents that outline what students should learn in their science education (NRC, 1996; Csikos *et al.*, 2016; OECD, 2013). The range of skills and knowledge is so broad that it is impractical to attempt to summarise them at this stage of the thesis. In the first instance, PISA's competencies and knowledge can be considered as the skills and knowledge of inquiry (or science more generally) (Table 1-1 and Table 1-2) but as this thesis progresses the skills and knowledge of inquiry will be discussed further.

1.4.1 Inquiry as a pedagogical approach

Inquiry as an approach to teaching is:

- Student-centred and collaborative;
- Based on investigative approaches, including experimentation, secondary research and discussion;
- Often described according to levels of varying teacher-student control and intellectual sophistication;
- Assessed formatively and summatively.

(Harrison, 2015, Lederman, Lederman & Antink, 2013, Wenning, 2005, Colburn, 2000)

Broadly speaking, inquiry-based instruction is where students engage in "hands-on activities" in a student-centred way, with students involved in active-construction of learning" (Colburn, 2000, p. 42). Students engage in collaborative activities that allow exchange of ideas between peers and the teachers act as facilitators, rather than knowledge providers, by asking probing questions and encouraging students to reflect on their learning (Colburn, 2000; Harrison, 2015).

Inquiry is based on investigative approaches, which may include experimentation and secondary research (Wenning, 2005; Bencze & Sperling, 2012; Lederman, Lederman & Antink, 2013). Descriptions of inquiry usually describe variations of a systematic and sequential process which could be considered "the scientific process":

1. Stating the problem or question for investigation,
2. forming the hypothesis,
3. performing an investigation which includes experimentation and secondary research,
4. analysing data,
5. drawing conclusions.

(Olson & Loucks-Horsley, 2000; Bybee, 2002; Wenning, 2005)

However, Bybee (2002) describes the idea of this systematic series of steps that constitute scientific inquiry as a "prevailing misconception" because true scientific inquiry rarely follows such systematic, precise, rigorous and impersonal procedures (Bybee, 2002).

Other descriptions of inquiry highlight the role of carefully scaffolded student interaction and discussion (Linn, Davis & Eylon, 2004). When students are encouraged to listen to, analyse and build upon ideas from their peers this introduces them to perspectives that conflict with their current viewpoint and causes them to explicitly reflect on their views (Century *et al.*, 2002; Linn, Davis & Eylon, 2004). This is important because it exposes students to the kind of discourse that occurs in the scientific community and may go some way to dispelling the "misconception" of science as a rigid set of procedures to be followed (Bybee, 2002; Century *et al.*, 2002). However, care should be taken when designing such discussions to ensure that participation is not dominated by a few individuals or viewpoints (Linn, Davis & Eylon, 2004).

The collaborative approach to inquiry need not be seen as distinct from the investigative experimental and secondary research-based approach described in earlier paragraphs. Student discussion can be used at strategic points throughout a more traditional inquiry to support learning. For example, students may engage in discussion when they are faced with a phenomenon for the first time and this discussion may lead students to propose questions for investigation (Century *et al.*, 2002). Working with others while carrying out their investigation allows students to discuss methodological considerations such as the validity of sources of information from secondary research or methodological considerations relating to their experiment (Century *et al.*, 2002; Linn, Davis & Eylon, 2004).

Inquiry as a teaching approach can be described in terms of a hierarchy, which consists of levels that vary according to the level of teacher and student control, and the intellectual sophistication (Colburn, 2000; Olson & Loucks-Horsley, 2000; Wenning, 2005). As teacher control is relinquished, the students take more control and the level of intellectual sophistication increases.

Colburn (2000) describes four levels of inquiry: structured, guided, open and learning cycle. In a structured inquiry the teacher provides a hands-on problem or question and the students discover the relationships between variables or generate conclusions from the data collected (Colburn, 2000). In this type of inquiry, the locus of control is with the teacher and the level of intellectual sophistication is low. In guided inquiry, the materials are provided to students but they must devise their own procedures to solve the given problem (Colburn, 2000). In this inquiry control begins to shift from the teacher to the student as they are given more responsibility and this increases the level of intellectual sophistication. In open inquiry, students are provided with materials but they must devise their own problem and procedures to solve their problem. This involves a high level of student control and the level of intellectual sophistication is high (Colburn, 2000). In learning cycle type inquiry students must apply a new concept to a different context. The students follow guided inquiry procedures so the locus of control is shared between the teacher and student and the level of intellectual sophistication is intermediate (Colburn, 2000).

Olson & Loucks-Horsley (2000) also describe inquiry in terms of levels, varying according to the locus of control and level of intellectual sophistication (Table 1-3). Olson & Loucks-Horsley's (2000) description of inquiry focusses on the locus of control for each skill demonstrated. The more student self-direction and the less guidance provided by the teacher, the higher the level of intellectual sophistication. For example, at the lowest level of intellectual sophistication for engaging with scientific questions, the student takes little control and uses a given question. At the highest level of intellectual sophistication, the student generates their own question (Table 1-3). Wenning (2005) also describes inquiry in terms of locus of control and student responsibility (Figure 1-5).

Table 1-3 Features of inquiry and level of student self-direction (Olson & Loucks-Horsley, 2000, p. 29).

Essential Feature	Variations			
Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or another source	Learner engages in question provided by teacher, materials, or another source
Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyse	Learner given data and told how to analyse
Learner formulate explanations from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence and how to use evidence to formulate explanation
Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use sharpen communication	Learner given steps and procedures for communication

Discovery Learning	Interactive Demonstration	Inquiry Lesson	Inquiry Lab	Hypothetical Inquiry
Low		**← Intellectual Sophistication →**		**High**
Teacher		**← Locus of Control →**		**Student**

Figure 1-5 Wenning's hierarchy of inquiry (Wenning, 2005, p. 4)

Wenning (2005) describes discovery learning as the most fundamental form of inquiry. The teacher introduces a concept and uses questioning to guide students towards a pre-determined conclusion. The level of teacher control is high and the intellectual sophistication is low. Interactive demonstrations, as the name suggests, are demonstrations from the teacher, using scientific apparatus, where the teacher asks probing questions that lead students towards explanations and conclusions about the given situation. The level of teacher control is high and the level of intellectual sophistication is low (Wenning, 2005). In an inquiry lesson, the students are given an experimental procedure for a given question and encouraged to reflect on the inquiry processes (e.g. consider variables/evaluate method). Control is shared between the teacher and student and the level of intellectual challenge is intermediate (Wenning, 2005). Inquiry labs differ from inquiry lessons in that the students independently develop an experimental plan to collect data (Wenning, 2005). The locus of control is mainly with the student and the level of intellectual sophistication is high. Wenning's (2005) hypothetical labs are the most advanced form of inquiry described. Students generate their own hypotheses and test them.

The question of when and how the different levels of inquiry should be adopted in the classroom is a contested one. Some research suggests that inquiry approaches result in higher scores on content achievement tests (Colburn, 2000), while other research suggests that open approaches to inquiry teaching can have a detrimental effect on content knowledge acquisition and achievement. Somewhat contradictorily, the same study found that open approaches promote positive attitudes, interest and engagement towards science, another component of scientific literacy (Jiang & McComas, 2015). More teacher-led approaches to inquiry may increase content acquisition but decrease interest and engagement (Jiang & McComas, 2015). Therefore, it is suggested that the level of inquiry be thoughtfully chosen by the teacher depending on the students' situation and context, and the skills and knowledge to be developed (Jiang & McComas, 2015). Wenning (2005) suggests that for inquiry approaches to be effective, the hierarchy of levels should be attempted by students in order from lowest intellectual sophistication to the highest. Student should first be made aware of the inquiry processes implicitly through teacher-led demonstrations and then explicitly through their own practice (Wenning, 2005). Colburn suggests that the right mix of the different approaches including inquiry and non-inquiry methods will both engage students and increase achievement (Colburn, 2000). Like Wenning (2005), Colburn (2000) suggests that teachers gradually make a transition from the lower levels of inquiry to open inquiry at a pace that both students and teacher are comfortable with.

Assessment of inquiry can be summative or formative, and focusses on the assessment of skills and knowledge. Summative assessment approaches have been discussed in Section1.3, many of which aim to assess inquiry skills and knowledge. For example, PISA 2015 aimed to assess skills relating to design and evaluation of scientific inquiry (OECD, 2013). Wenning (2007) designed a summative test that claimed to be a valid and reliable diagnostic test of a range of inquiry skills. It was a written, 40-50 minute, multiple-choice test. Wenning (2007) claimed that the test could be used for "identifying weaknesses in student understanding, improving instructional practice, and determining programme effectiveness in relation to teaching inquiry skills" (p. 23). There are also curricular assessments that aim to summatively assess inquiry skills and knowledge, including the Scottish CfE National 5 Assignment and Irish Junior Cycle Science in Society

Investigation, which were briefly introduced in the introduction to this chapter and will be discussed further in Chapter 4.

Black *et al.* (2004) describe formative assessment as "assessment for which the first priority in its design and practice is to serve the purpose of promoting students' learning", as distinct from summative assessment which has the primary purpose of accountability. Formative assessment of inquiry in science classrooms is based on feedback and action as shown in Figure 1-6 (Sadler, 1989; Buck & Trauth-Nare, 2009; Harrison, 2015).

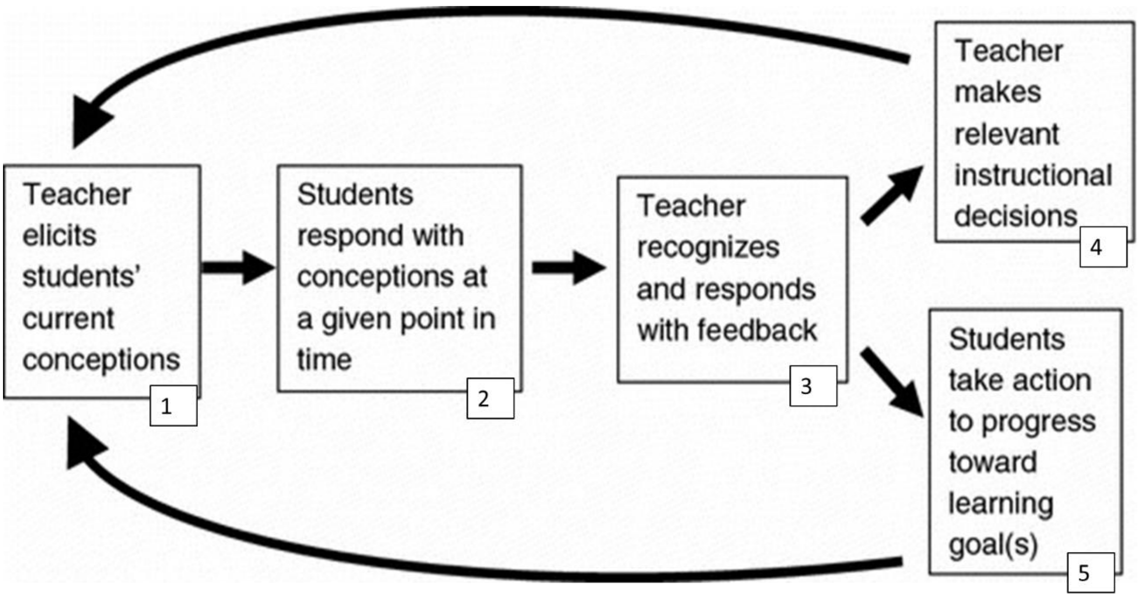


Figure 1-6 Formative feedback cycle (Buck & Trauth-Nare, 2009, p. 477)

Firstly, the teacher elicits students' current conceptions (stage 1) and students respond (stage 2). Students demonstrate their current conceptions in a range of ways, including: verbally through group and whole class discussion, performance of competencies and skills during a practical investigation, and written reports and explanations of findings. Feedback on these conceptions can then be given by the teacher, peers or student themselves. Whole class or group discussions, allow students to verbalise their current understanding, partial understandings or misconceptions (stage 2) which teachers can then provide feedback on (stage 3) (Harrison, 2015). A written scientific report or verbal presentation of findings may be critiqued by peers, self-assessed or given a written comment by the teacher (stage 3) (Black *et al.*, 2004). In peer and self-assessment, students learn by taking on the role of the examiner and this can be used to allow students to make assessment criteria explicit (Black *et al.*, 2004). Peer-assessment is valuable because students often accept critique from their peers that they may not take from the teacher and the comments will be in language that students themselves naturally use (Black *et al.*, 2004). Students should be facilitated to explicitly reflect, through discussion, performance and written work, not only on the content knowledge gained but on their understanding and performance of the processes of inquiry

(Bianchini & Colburn, 2000; Schwartz *et al.,* 2004). Schwartz *et al.* (2004) state that it is essential that students have explicit opportunities for reflection through journals and discussions and through the authentic context of a research setting (Schwartz *et al.,* 2004). In stage 3 of Figure 1-6, the teacher, peer or student provides feedback relating to their goals and what they need to do to reach them and in stage 4 the teacher adapts the teaching approach to allow the students to carry out the required actions (stage 5) (Black *et al.,* 2004; Buck & Trauth-Nare, 2009).

1.4.2 Inquiry in the context of socioscientific issues

SSI can be used to provide contexts for inquiry with the aim of developing the skills and knowledge of scientific literacy.

In this thesis, "authentic" SSI contexts are described as:

- Scientific topics with societal implications
- Controversial
- Contemporary
- Encourage activism

These aspects will be discussed in the following paragraphs.

SSI are scientific topics with moral, ethical or societal implications which can be used to provide a situated learning context for experimentation and investigation but also provide opportunities for dialogue, discussion and debate (Sadler, 2009; Zeidler & Nichols, 2009). Inquiry in the context of SSI can be described in terms of the approaches and levels of inquiry discussed in the previous section. However, there is likely to be less focus on experimental investigative approaches and more on explanations of science. The role of the teacher is to provide a scaffolded learning environment by providing students with a range of perspectives on the SSI (Zeidler & Nichols, 2009). In this way teacher would allow the students the space and opportunity to genuinely explore their own belief system about the SSI (Zeidler & Nichols, 2009). The role of the student would be to engage actively in exploring their own ideas and conceptions around the SSI (Zeidler & Nichols, 2009). Students may engage in interpretation, analysis and evaluation of conflicting data and evidence from a range of sources (Zeidler *et al.*, 2009). Students may also use information literacy skills to identify information sources, access information, evaluate information, and use this information effectively, efficiently and ethically (Julien & Barker, 2009).

SSI are controversial. This means that they involve a range of scientific, social or moral viewpoints, which may conflict with the students' own views. This makes them personally relevant to the students (Oulton, Dillon & Grace, 2004; Levinson, 2006). The SSI cannot be easily concluded even after thorough examination of available evidence due to the likelihood of differing interpretations of the same evidence by those with opposing views (Oulton, Dillon & Grace, 2004; Levinson, 2006). The SSI should also be contemporary, e.g. those in current media spotlight, which is likely to increase the relevance to the students (Zeidler *et al.*, 2009).

Some educationalists take inquiry in the context of SSI a step further, beyond students developing a viewpoint on the issue. They argue that students should also be facilitated to prepare for and engage in socio-political actions that they believe will make a difference (Hodson, 2010; Bencze & Sperling, 2012). Students who carry out their own experimental or secondary research inquiry are said to be more motivated to take action on the issue explored. This is because the more control the student has over the generation of the claims relating to SSI, the more engaged they become with the SSI (Bencze, 2017). PISA, in its 2018 Framework for Global Competence (OECD, 2018b), recommended that students should have opportunities to take "informed, reflective action and have their voices heard" (p. 11) and that schools are in a unique position to facilitate students to take action on important global issues. Hodson (2010) described four stages of the SSI based approach. At level 1, the students appreciate the societal impact of scientific and technological change and recognise that science and technology are culturally determined. This relates to students' knowledge of the Nature of Science (Figure 1-2). At level 2, students recognise that decisions relating to scientific and technological progress pursue certain interests, therefore benefits in some areas may be at the expense of other areas. Students at level 2 also recognise that which areas are the focus of scientific progress is linked to the distribution of wealth and power (i.e. culturally and socially linked). Again, this relates to students' knowledge of the Nature of Science (Figure 1-2). At level 3 students develop their own views and underlying positions in relation to the SSI explored. At the highest level, level 4, the students prepare for and take action on the SSI explored (Hodson, 2010, p. 199). At level 4, students are encouraged to carry out socially and environmentally responsible actions. "It is almost always much easier to proclaim that one cares about an issue than to *do* something about it" (Hodson, 2010, p. 201). Bencze (2017) described six actions that can be taken after conducting inquiry in the context of SSI in order to achieve Hodson's level 4. Students may choose to educate others, develop better inventions, boycott offenders, lobby power brokers, improve personal actions and provide services (Bencze, 2017, p. 34). These will be revisited in more detail in the findings of Chapter 5.

PISA (2018b) gives an example of "taking action" relating to SSI:

> A group of students decides to *initiate an environmental awareness campaign* on the ways in which their school contributes to *local and global waste and pollution*. … they arrange a *series of talks* on how to reduce waste and energy consumption ... design and strategically distribute *information posters* that help guide students to make better choices when buying products and when disposing of waste … introduce recycling bins and *energy conservation strategies on the school premises.* (p. 11)

This exemplifies actions described by Bencze (2017). Students educate others by raising awareness, giving talks around the school and making posters. They provide solutions and services by providing recycling facilities and energy conservation strategies.

There are challenges associated with using inquiry in SSI contexts. Sadler (2009) argues that advanced secondary school science classes should focus on preparation for summative exams and so a more teacher-led approach, focussed on content knowledge acquisition is more appropriate. However, as discussed in Section 1.2, science education should also develop the skills and knowledge of scientific literacy, which will have lifelong implications for the individual. However, these need not be conflicting aims as research suggests that use of SSI contexts increases content knowledge acquisition compared to non-SSI based learning (Zeidler *et al.,* 2009), suggesting that inquiry in the context of SSI may be a suitable approach for development of scientific literacy in *all* students.

Roberts (2005) describes how educational terms, such as inquiry, can be defined. These definitions can be descriptive or stipulative. Descriptive definitions explain terms in connection with their past and present usage and aim to take account of the variety of understandings. So far, Section 1.3 has provided a detailed, *descriptive* definition of inquiry. Stipulative definitions describe a term to be defined in a single context and don’t attempt to take account of all previous uses of a term. Stipulative definitions are useful when it’s necessary to take a stance on the definition of a term. Section 1.4.3 provides a concise, *stipulative* definition of inquiry in the context of SSI.

1.4.3 Stipulative definition of inquiry

Inquiry follows a set process of questioning, hypothesising, designing, carrying out and evaluating experimental and secondary research-based investigations, data analysis and interpretation and drawing final conclusions.

The terms *structured*, *guided* and *open* describe levels of inquiry (Table 1-4). Structured inquiry refers to inquiry in which the teacher makes most of the decisions and the student interprets information and draws conclusions. Guided inquiry is where the student is given a question for investigation and they choose how to investigate this question followed by data collection, analysis and conclusions. Open inquiry is where the student chooses a question for investigation, although the teacher may have given a topic. The student designs the method for investigation, gathers and analyses data and draws conclusions.

Table 1-4 Levels of inquiry according to locus of control and decision making

	Develop question	**State hypotheses**	**Propose method**	**Evaluate method**	**Interpret data**	**Draw conclusions**
Structured	Teacher	Teacher or student	Teacher	Teacher or student	Student	Student
Guided	Teacher	Student	Student	Student	Student	Student
Open	Student	Student	Student	Student	Student	Student

Guided discussion is a type of inquiry but it does not follow the set process of experimental and secondary research-based inquiry.

SSI can be used to provide contexts for inquiry. SSI contexts are:

1. Scientific topics with moral/ethical/societal implications
2. Controversial
    a) Include a range of viewpoints
    b) Cannot be easily concluded even after thorough examination of evidence
3. Contemporary
4. Encourage activism

(Colburn, 2000; Oulton, Dillon & Grace, 2004; Wenning, 2005; Levinson, 2007; Sadler, 2009; Hodson, 2010; Bencze & Sperling, 2012)

1.5 Development and assessment of scientific literacy in initial teacher education

Pre-service teachers are in the unique position of being both the undergraduate or postgraduate level *learner* and a trainee *teacher*. Initial teacher education needs to take account of these dual roles. PSTs should be facilitated to develop as both learners, developing their own skills and knowledge of scientific literacy, and as future teachers, developing skills and knowledge relating to teaching for the development of the skills and knowledge of scientific literacy in their own students (Topcu, Sadler & Yilmaz-Tuzun, 2010). There are three different ways that this can be achieved in initial teacher education: teaching only the scientific skills and knowledge required (PST as *learners*); teaching both the scientific skills and knowledge required (PST as *learner*) and the pedagogical approaches (PST as *teacher*) simultaneously; and teaching the scientific skills and knowledge required (PST as *learner*) and the pedagogical approaches (PST as *teacher*) separately. These different approaches are discussed in the following paragraphs.

Much of the research into initial teacher education programmes that aim to develop PSTs' ability to teach using inquiry approaches describe programmes that focus on the PST as a *learner* only (Topcu, Sadler & Yilmaz-Tuzun, 2010; Bencze & Sperling, 2012). This approach explicitly develops the scientific skills and knowledge of scientific literacy. However, the development of PSTs' pedagogical skills and knowledge is dealt with implicitly (Lederman *et al.,* 2001). Through increasing their scientific skills and knowledge, it is hoped that this will translate into improved classroom practice. However, research indicates that this approach does not directly translate into classroom practice. PSTs may have good scientific skills and knowledge but be unable or unwilling to implement these in the classroom (Lederman *et al.,* 2001; Buck & Trauth-Nare, 2009).

Another approach described in the literature is to treat the role of the *learner* and the *teacher* explicitly, and teach both simultaneously within the same initial teacher education programme (Bencze, 2010; Michalow, 2015). This approach addresses the PSTs' role as a *learner* and aims to develop the scientific skills and knowledge of the PSTs through explicit reflection and feedback relating to these skills and knowledge. At strategic points and throughout the programme or module, PSTs will also be asked to explicitly reflect on the teaching approaches used or described (as *teacher*).

The third approach is similar to the approach described in the previous paragraph because it treats the dual roles of the PST explicitly and addresses each role directly. However, in this approach doing both simultaneously is deemed too challenging for the novice teachers and the two roles are addressed separately (Lederman *et al.,* 2001). In this approach, the PSTs participate in lectures, labs or modules aimed to develop their scientific skills and knowledge as learners and separate lectures, labs or modules that aim to develop their skills and knowledge relating to implementing inquiry approaches in the classroom.

1.5.1 The PSTs' role as learner

Most of the research into inquiry in the context of SSI as an approach to developing the skills and knowledge of scientific literacy has focussed on the experience of the *learner*. Within this, most of the research has focussed on the development of scientific literacy at secondary school level, rather than undergraduate level. It is important that PSTs' have a sound basis of scientific knowledge and skills to be able to teach scientific inquiry to their students. This knowledge should comprise the "prominent concepts", "facts and principles" in science but also knowledge of the "processes and nature of science" (Roehrig & Luft, 2004, p. 4). Thus, the skills and knowledge shown in the Framework of Scientific Literacy described in Section 1.2.1 and Figure 1-2 not only apply to learners at secondary school level but also to PSTs who wish to develop these skills and knowledge in their own students.

There is little research with undergraduate level students into the use of inquiry approaches, specifically in SSI contexts, for the development of the skills and knowledge of scientific literacy. Grooms, Sampson & Golden (2014) explored the use of different levels of inquiry in the context of SSI with undergraduate science students (although not PSTs) and drew similar conclusions to the wealth of research at secondary school level. Similarly to much of the research into inquiry in the context of SSI, they looked at the development of skills relating to argumentation and found that these were effectively developed using more open inquiry approaches using SSI contexts (Grooms, Sampson & Golden 2014). The inquiry approach using SSI contexts has been shown to successfully develop PSTs' skills and knowledge of scientific literacy (Bencze, 2010; Topcu, Sadler & Yilmaz-Tuzun, 2010; Bencze & Sperling, 2012). This indicates that despite differences in age, prior science knowledge and context that the approaches described for use in secondary school contexts (Section 1.4) are suitable for university level teaching as well as secondary schools.

1.5.2 The PSTs' role as teacher

Section 1.5.1 highlighted the importance of a sound basis of scientific skills and knowledge that is used by PSTs in their teaching. However, research suggests that these skills and knowledge acquired by the PST as a learner do not necessarily translate into classroom practice (Lederman *et al.*, 2001; Roehrig & Luft, 2004). This indicates that initial teacher education should pay explicit attention to both roles of the PST: as *learner* and as *teacher*. As suggested in the introduction to this section this can either be done by considering each role simultaneously or separately.

In order to effectively develop the skills and knowledge of scientific literacy in their students, PSTs need skills and knowledge relating to pedagogical approaches to do this. Research suggests that inquiry approaches using SSI contexts are effective in developing scientific literacy. As described in Section 1.4 these approaches are student-centred and collaborative, use investigative approaches, are described according to levels and are assessed formatively and summatively. Inquiry teaching requires strong "student-centred beliefs" and a reflexive approach which is challenging for many experienced teachers let alone for PSTs who have yet to develop strong pedagogical skills and may have fragmented content knowledge (Roehrig & Luft, 2004, p. 20; Buck & Trauth-Nare, 2009). Even if a teacher possesses strong student-centred beliefs and skills and knowledge of science, there are many other barriers to the implementation of inquiry approaches to teaching in practice.

Barriers to the implementation of inquiry, specifically using SSI contexts in practice are wide ranging and include: lack of time, lack of materials and resources, lack of permission or support in school, lack of appropriate pedagogical skills and knowledge relating to these approaches, and lack of self-efficacy relating to implementing these approaches (Roehrig & Luft, 2004; Ratcliffe & Grace, 2003; Bencze, 2010). In the case of PSTs, the lack of pedagogical skills and knowledge, due to a lack of classroom experience, or lack of self-efficacy around their use, is a major restraint to the implementation of inquiry in the context of SSI. Additionally, PSTs may have personally been taught science in a didactic way, rather than through inquiry, and therefore may be conditioned, through their own educational experience, to use a more didactic approach (Bencze & Sperling, 2012). Some of these barriers that PSTs face may be addressed through initial teacher education (Lederman *et al.,* 2001; Roehrig & Luft, 2004).

Research suggests that PSTs' skills and knowledge relating to pedagogical approaches to develop students' scientific literacy can be increased through participation in initial teacher education that caters to their dual role as teacher and learner (Lederman *et al.,* 2001; Topcu, Sadler & Yilmaz-Tuzun, 2010). Activities should allow the PSTs to experience inquiry approaches and reflect on their development as *learners*. They should also be given opportunities to increase self-awareness of their own beliefs and conceptions of teaching, with a focus on inquiry in the context of SSI, through an explicit, reflective approach (Lederman *et al.,* 2001; Buck & Trauth-Nare, 2009). This means that teaching about the pedagogical approaches to inquiry in the context of SSI should be planned for, rather than developed as a result of participation in such approaches (Lederman *et al.,* 2001). This aims to make the tacit processes and gut instincts that experienced teachers often rely on explicit to allow the PSTs to more easily implement them into their practice (Buck & Trauth-Nare, 2009).

There is little research that addresses the specifics about how this should be carried out with PSTs in practice. Some recommendations regarding the development of PSTs' pedagogical skills and knowledge of inquiry in the context of SSI can be gleaned from what little research there is. As part of their initial teacher education programme, there should be explicit discussion of pedagogical approaches to inquiry in the context of SSI. PSTs should be required to plan lessons and schemes of work and develop instructional materials and design resources for implementing these approaches (Lederman *et al.,* 2001; Michalow, 2015). PSTs should also be required to demonstrate their ability to assess inquiry in the context of SSI by planning formative assessment approaches (Buck & Trauth-Nare, 2009). Research also suggests that this should be extended to in-school placement and that PSTs should be required to integrate inquiry approaches into their teaching in practice (Michalow, 2015).

It is important to recognise that even if a PST holds student-centred beliefs, has strong pedagogical skills and knowledge relating to inquiry approaches, self-efficacy relating to their use and strong knowledge and skills relating to scientific literacy (as a *learner*), this does not necessarily translate into classroom practice (Roehrig & Luft, 2004). Initial teacher education can only address some of the barriers PSTs face when implementing of inquiry in the context of SSI, e.g. increase pedagogical skills and knowledge as *teachers* and skills and knowledge of scientific literacy as *learners*. Literature recommends inquiry in the context of SSI as an approach for the development of scientific literacy. This is also advocated by policy. However, in teachers', including pre-service teachers', classroom practice complex barriers often prevent implementation of these approaches. This is observed as gaps between the research, policy and practice. The studies carried out in this thesis aim to contribute to the literature regarding the development and assessment of scientific literacy, with a focus on inquiry in the context of SSI. The case studies are based on practice in secondary school and initial teacher education and so aim to narrow these gaps between literature, policy and practice.

1.6 Chapter conclusions

This chapter aimed to provide an overview of the literature relating to the development and assessment of scientific literacy. The focus was mainly on secondary school contexts, where the majority of published research is carried out. Literature relating preparing teachers to develop and assess scientific literacy in their students was also discussed.

Scientific literacy has been described in the literature in a variety of ways. This chapter aimed to provide a Framework of Scientific literacy that took account of these varied descriptions and combined their central ideas into a single, holistic framework. This framework depicted scientific literacy as four individual and three societal aspects. Overall, scientific literacy can be described as the skills and knowledge of science (inner circle of Figure 1-2) that that influence the individual's interactions with society (outer circle of Figure 1-2).

There has been increasing curricular focus on the development and assessment of scientific literacy in countries around the globe (Scottish Government, 2010a; Lee, Miller and Januszyk, 2014; NCCA, 2015). This has been driven, in part, by international assessments such as PISA that claim to measure scientific literacy in secondary school students and provide international comparisons of achievement (OECD, 2013). However, the best way to teach for the development of scientific literacy remains contentious. Research suggests that using inquiry approaches, particularly those that use SSI as contexts, can develop a range of skills and knowledge that contribute to scientific literacy (Colburn, 2000; Wenning, 2005; Sadler, 2009; Zeidler & Nichols, 2009). These approaches have recently been included in curricula of various countries, aiming to increase secondary school students' scientific literacy. Scotland and Ireland have included curricular assessments that use inquiry in the context of SSI as an approach to the development and assessment of a range of skills and knowledge (NCCA, 2015; SQA, 2016).

However, most published research has been carried out in secondary school contexts and policy relating to the development and assessment of scientific literacy is also limited to secondary schools. From what little research there is exploring the use of inquiry in the context of SSI in tertiary level education, the approach is advocated as an ideal approach for the development of skills and knowledge of scientific literacy (Grooms, Sampson & Golden, 2014). Within the literature that focusses on the development and assessment of scientific literacy in tertiary level education, initial teacher education is unique. This is because while most tertiary level students are required to develop the skills and knowledge of scientific literacy as the *learner* only, PSTs must also be prepared as *teachers* (Topcu, Sadler & Yilmaz-Tuzun, 2010). This means that initial teacher education must cater for these dual roles.

This thesis explores the development and assessment of scientific literacy in secondary schools, in literature (Chapter 1) and in practice. First exploring the assessment of scientific literacy through summative, written exams (Chapter 3) and then the development and assessment of scientific literacy through inquiry in the context of SSI (Chapter 4). The findings from these studies are used to develop an initial teacher education module for pre-service science teachers (Chapter 5). The module aims to cater for their dual role by developing and assessing the skills and knowledge of scientific literacy as *learners* and preparing them as *teachers* to use inquiry in the context of SSI with their own students. Chapter 2 will now present the methodological approaches used in these studies and the theory and rationale for the chosen methodologies.

2 Methodology

This thesis presents five studies over three chapters (Chapters 3-5) that aim to explore in practice the literature discussed in Chapter 1. They used a variety of methodological approaches. Chapter 2 first outlines the theory and considerations relating to the chosen methodologies (Section 2.1) before providing a brief overview of the methodology employed for each study (Section 2.2).

2.1 Theoretical consideration for chosen methodology

Creswell & Plano Clark (2011) describe three elements of a research study that should be considered. These are: the researcher's paradigm worldview, methodological approach and methods of data collection and analysis. Figure 2-1 shows how the paradigm worldview of the researcher influences the design and research approach, which in turn influences the research methods.

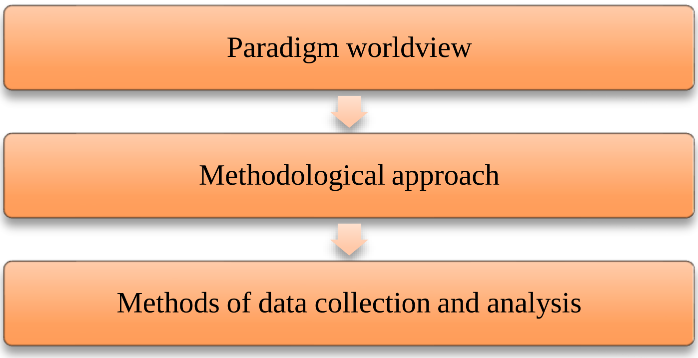


Figure 2-1 Elements that influence a research study (adapted from Creswell & Plano Clark, 2011, p. 39)

2.1.1 Researcher's worldview and methodological approach

The paradigm worldview of the researcher is what drives the researcher to choose their methodology. It is the basic set of beliefs or assumptions that the researcher approaches the study with and it is sometimes referred to as the researcher's ontology and epistemology. Ontology is how the researcher views reality and epistemology relates to the relationship between the researcher and that which is being researched (Creswell & Plano Clark, 2011).

Creswell & Plano Clark (2011) describe four worldviews that a researcher may possess: postpositivist (also known as positivist), constructivist, participatory and pragmatist. The postpositivist worldview is most often associated with quantitative approaches and traditional science. The worldview is characterised by deterministic thinking, based on cause and effect and a focus on empirical observation and measurement with the overall aim of verifying theories (Creswell & Plano Clark, 2011).

Constructivist worldviews are typically associated with qualitative approaches. Researchers with this view derive meaning of phenomena through differing views of participants. Social interaction is an important aspect of research in a constructivist view. The research is usually inductive and forms broad findings and understandings (Creswell & Plano Clark, 2011).

The researcher with a participatory worldview is more likely to use qualitative approaches but may also use mixed methods. The research is influenced by politics and aims to improve society by looking at issues surrounding empowerment and marginalisation. This view allows for collaboration with the participants of the research (those experiencing the injustice or other phenomena) (Creswell & Plano Clark, 2011).

The pragmatist worldview is more likely to be associated with mixed methods research and importance is placed on researching a worthwhile question and the consequences of the research. The use of multiple methods (mixed methods), whichever are appropriate to the question, is typical (Creswell & Plano Clark, 2011).

Creswell (2014) describes three methodological approaches to research: qualitative, quantitative and mixed methods research approaches and these are dictated by the researcher's worldview (Figure 2-1).

Quantitative approaches are used to test objective theories by examining the relationship among variables. Variables are measured to give numerical data that can be analysed using statistical procedures. The approach is generally deductive. The final written report has a set structure consisting of introduction, literature and theory, methods, results, and discussion (Creswell, 2014). Quantitative research is based on the postpositivist worldview that objective reality exists and can be discovered or, at least, approximated by the research (Denzin & Lincoln, 2005). Examples of quantitative research designs include experimental designs and non-experimental designs, including data collection methods such as surveys (Creswell, 2014).

Qualitative approaches explore the meaning individuals or groups ascribe to phenomena, usually a social or human problem. The aim of the qualitative approach is to "represent the world" so data is usually collected in a real-life setting (Denzin & Lincoln, 2005, p. 3). Data analysis inductively builds from the specifics to the general. Qualitative approaches value the role of the researcher's interpretations of data to describe a complex situation. The final report of findings is typically flexible and without a set structure (Creswell, 2014). Qualitative research is based on constructivist worldviews, where the premise is that objective reality can never truly be recaptured but rather interpreted by the research (Denzin & Lincoln, 2005). Examples of qualitative designs include narrative research, phenomenology, grounded theory, ethnography and case study (Creswell, 2014).

Qualitative research may be criticised by those working in more quantitative research disciplines such as the "traditional" experimental sciences for being "unscientific" (Denzin & Lincoln, 2005). These critics are likely to have a positivist worldview and assume that there is a stable, unchanging reality or truth that can be studied using empirical methods such as traditional scientific processes (Denzin & Lincoln, 2005; Creswell & Plano Clark, 2011). However, qualitative research values the individualised interpretations of the researcher and has processes in place to minimise subjective misinterpretations (Stake, 1995). Other criticisms of qualitative research are that it is too slow and expensive. Proponents of qualitative research would say that the phenomena themselves are slow to happen and to reach full understanding undeniably takes a long time (Stake, 1995).

Mixed methods approaches aim to combine qualitative and quantitative methodologies to obtain a more complete understanding of a research problem (Creswell, 2014). Mixed methods are typically associated with pragmatic and participatory worldviews, which choose the methodology based on suitability to the question.

Creswell & Plano Clark (2011) describe the core characteristics of mixed methods research:

- Collects and analyses persuasively and rigorously both qualitative and quantitative data based on research questions,
- Mixes the two forms of data concurrently by combining or merging them, sequentially by having one build on the other, or embedding one within the other,
- Gives priority to one or both forms of data,
- Uses these procedures in a single study or in multiple phases of a programme of study,
- Frames these procedures within a philosophical worldview and theoretical lens,
- Combines the procedures into a specific research design.

(Creswell & Plano Clark, 2011, p. 5)

Mixed methods are characterised by the collection of both qualitative and quantitative data, either simultaneously or separately. There is no expectation that both forms of data are given equal priority and it is likely that either qualitative or quantitative methods will take a lead role (Creswell & Plano Clark, 2011). Creswell & Plano Clark (2011) describe a range of examples of mixed methods designs. Convergent designs are where quantitative and qualitative data are collected simultaneously but analysed separately. Explanatory designs include the collection of quantitative data is first and then the results used to inform the design of qualitative data collection. Exploratory designs are the reverse of explanatory designs and qualitative data is collected first and the results are used to inform quantitative data collection. Embedded designs do not give equal priority to quantitative and qualitative approaches and one form of approach takes a lead role compared to the other. In studies with a transformative design, the research aims to address injustice or bring about change. In mixed methods multiphase design studies, qualitative and quantitative data is collected at different stages of the research and the studies are carried out over a number of years (Creswell & Plano Clark, 2011). Mixed methods designs can use a combination of the approaches described, for example a design can be embedded, using a mainly qualitative design, and convergent, where data is collected simultaneously but analysed separately.

Mixed methods are suited to research questions where one data source may be insufficient. For example, results of a quantitative survey may need to be explained using findings from qualitative interviews or focus groups, or findings from qualitative research may need to be generalised using quantitative survey methods (Creswell & Plano Clark, 2011).

Denzin and Lincoln (2005) criticise mixed methods research methods for being too focused on gathering and analysis of quantitative data, stating that "mixed methods takes qualitative research out of its natural home". They say it is incompatible with the participatory worldview because it excludes stakeholders from dialogue and active participation, which can only occur during in-depth qualitative data collection (Denzin & Lincoln, 2005). This criticism, however is unlikely to apply to embedded designs, where priority is given to qualitative data collection and analysis. A mainly qualitative, embedded design study would allow exploration of phenomena in-depth and give participants a voice, while also allowing some quantitative generalisation. An example of this may be an embedded, mainly qualitative case study design (Creswell & Plano Clark, 2011).

Case studies are a methodological approach that spans quantitative, qualitative and mixed methods. However, they are mainly associated with qualitative and mixed methods approaches (Luck, Jackson & Usher, 2006; Creswell & Plano Clark, 2011). Case studies can be used to explore and evaluate interventions or phenomena in real-life contexts (Baxter & Jack, 2008). The role of the researcher in case study research is to observe directly, ask others (the participants) and examine records and documents (Stake, 1995).

Stake (1995) describes different types of case studies that are used by researchers for different purposes: intrinsic, instrumental and collective case studies. Intrinsic case studies are ones where the researcher is interested in the case, in its own right, and the particulars of the case form the research. Instrumental case studies are those where the case study is explored to examine a broader research question. The use of this case study is to understand something other than the particulars of the case itself. Collective case studies consist of several instrumental case studies that work together to answer a research question (Stake, 1995). Case studies are generally carried out over seven sequential stages:

1. "Identifying the research as an issue, problem or hypothesis
2. Asking research questions and drawing up ethical guidelines
3. Collecting and storing data
4. Generating and testing analytical statements
5. Interpreting or explaining the analytical statements
6. Deciding on the outcome and writing the case report
7. Finishing and publishing"

(Bassey, 1999, p. 66)

However, progression through the stages is flexible and at times cyclical. The research questions and methods of data collection and analysis are likely to change as the case study progresses. If early questions or data collection methods are not working or if new issues emerge then the design can be changed (Stake, 1995; Bassey, 1999). Luck Jackson & Usher (2006) argue that case study research is in a unique position to span research paradigms and data collection approaches due to this flexibility. There are no universally agreed set of methods for data collection and analysis, instead methods are chosen for their usefulness and appropriateness to the research question (Luck, Jackson & Usher, 2006). This flexibility allows the researcher to choose the most appropriate methods of data collection for the research question rather than being bound by a traditionally quantitative or qualitative approach (Luck, Jackson & Usher, 2006).

One criticism of case study research is the perceived inability to generalise findings. Even a number of collective case studies are unlikely to provide a large enough sample to be representative of others (Stake, 1995). However, this criticism misses the point of case study research because case study research should focus on the particulars not the generalisations and the emphasis is on describing the uniqueness of the case (Stake, 1995). This is not to say that you cannot generalise from case study research, it is just not the main purpose. In educational settings, generalisations are needed in order to inform policy and best practice. Case studies in educational settings, in particular, explore such a complex social situation that it is difficult to infer correlation from case study findings. Researchers cannot state that that teachers should "Do X and students will learn Y" because there are many more variables than just "X" that influence Y (Bassey, 1999, p. 51). Instead, Bassey (1999) describes "fuzzy generalisations" (p. 51) that can be drawn. Bassey changes the wording slightly to "do X and your students *may* learn more" to show the element of uncertainty and give teachers the opportunity to explore the approach in their own settings (Bassey, 1999, p. 51). The aim of the case study is to report that something has happened in one setting and it *may* happen elsewhere (Bassey, 1999). In mixed methods case studies, this "fuzzy generalisation" may then be explored more widely using quantitative approaches.

2.1.2 Methods of data collection and analysis

The methods of data collection chosen by a researcher relate to their worldview and methodological approach chosen.

Quantitative methodologies and methods are likely to rely on collection and analysis of numerical data. Quantitative data collection methods are based on closed-ended questions with pre-determined responses of scales or categories. These include closed-ended interviews, closed-ended observations and closed-ended questionnaires (Creswell & Plano Clark, 2011). Quantitative data collection seeks to aggregate perceptions over multiple participants and the questions are closely linked to the research question and are inflexible (Stake, 1995). Quantitative analysis involves presentation of results in tables and figures and is likely to include statistical testing of data (Creswell & Plano Clark, 2011).

Qualitative data collection methods are open-ended and include open-ended interviews, open ended-observations, open-ended questionnaires, documents and audio-visual material (Creswell & Plano Clark, 2011). Data collection tools (e.g. interviews/questionnaires) in qualitative research tend to ask the participant to describe an episode or give an explanation rather than provide yes or no answers (Stake, 1995).

Qualitative methodologies may use a range of different analysis methods. Generally, qualitative analysis involves coding data and grouping coded data into themes (Creswell & Plano Clark, 2011). Coding is the classification of observations (e.g. open response survey and interview data, pictures, other documents) into categories, which may or may not be pre-determined (Stake, 1995). Although, collation of data (i.e. through coding) is likely, the extent may vary between studies. Some research questions can be answered through direct observation, interpretation and reporting of findings while other research questions will rely more heavily on coding or categorising data before reporting (Stake, 1995). In other words, researchers can either report their direct interpretations or aggregate instances into appropriate categories (Stake, 1995). Even when researchers report observations more directly, some form of aggregation is inevitable. The researcher is likely to deem direct observations that occur repeatedly as more important but in direct observation, single instances are not ignored. They are reported on if the researcher deems them to be credible accounts of the overall story (Stake, 1995). Coding can be used by the researcher in two ways. Reductive coding allows for indexing and grouping data together. It is a way of gathering a large amount of data into neat categories but is purely descriptive (Schreier, 2012). This type of coding is typically seen in content analysis. Conceptual coding is an analytical process used to create links between data and concepts (Schreier, 2012). This is typically seen in thematic analysis. Content analysis (i) and thematic analysis (ii) will be discussed in the following paragraphs.

(i) Content analysis

Content analysis is a form of document analysis that aims to reduce in-depth, qualitative data into a more manageable format through a highly systematic yet flexible approach to coding (Schreier, 2012). Content analysis is useful when exploring descriptive or comparative research questions because it results in a numerical measure of the data. This numerical data can then be used to describe the phenomena or compare different groups depending on the research question. Content analysis involves categorising (coding) data, thus reducing it from a mass of open-ended data to a representation of the chosen categories (Schreier, 2012, Bryman, 2004). The process is systematic in that every piece of data is treated in the same way and approached through the following set of sequential, yet at times cyclical, steps:

1. “Deciding your research question
2. Selecting your material
3. Building a coding frame
4. Dividing your material into units of coding
5. Trying out your coding frame
6. Evaluating and modifying your coding frame
7. Interpreting and presenting your findings”

(Schreier, 2012, p. 6)

Firstly, the researcher chooses a research question and selects material, (e.g. transcripts of extended interviews, newspaper and magazine articles) appropriate to the research question. A coding frame is built prior to commencement of coding, and reductive coding is carried out. The building of the coding frame is an iterative process where the categories, although pre-determined, can be changed and modified to better suit the data (see steps 3-6) (Schreier, 2012). In content analysis the extent to which the coding frame is pre-determined can vary. In deductive coding, the coding frame is almost wholly constructed prior to commencement of coding. In inductive or data-driven coding, the coding frame will be only partly built prior to coding and the data informs major modifications to the coding frame (Schreier, 2012).

There are four key requirements for building the coding frame in content analysis: Unidimensionality, mutual exclusivity, exhaustiveness and saturation (Schreier, 2012, p. 71). Unidimensionality is where each category in the coding frame captures only one aspect of your material. Subcategories should be “instances” of the main category and should not be repeated in different main categories. This creates mutually exclusive categories. Mutual exclusivity refers to the sub-categories in one dimension. A unit of coding can only be assigned to one of the sub-categories. This can be done through careful choice of units of coding (references/extracts from the data) and carefully defined categories and subcategories. Exhaustiveness means each unit of coding (reference/extract from the data) in your material is assigned to at least one subcategory in your coding frame. Saturation is the final requirement and ensures that each subcategory is used at least once so no subcategory remains empty. This happens naturally in a data driven coding framework (Schreier, 2012).

(ii) Thematic analysis

Thematic analysis is similar to content analysis in that coding is employed to analyse qualitative data. However, thematic analysis does not usually result in a numerical measure of the data and is more likely to be used for exploring research questions that aim to create theories and analyse real-life phenomena (Braun & Clarke, 2006; Schreier, 2012). Another key difference between thematic analysis and content analysis is the extent to which categories for coding data are pre-determined. In thematic analysis the categories, called themes, emerge from the data inductively, whereas in content analysis, the categories are, at least partially, pre-determined (Braun & Clarke, 2006; Schreier, 2012).

Braun & Clarke (2006) describe thematic analysis as a "method for identifying, analysing and reporting patterns (themes) within data" (p. 79). They set out rigorous procedures for qualitative data analysis, consisting of 6 sequential stages outlined below:

1. "Familiarising yourself with your data: Transcribing data (if necessary), reading and rereading the data, noting down initial ideas.
2. Generating initial codes: Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3. Searching for themes: Collating codes into potential themes, gathering all data relevant to each potential theme.
4. Reviewing themes: Checking in the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic map of the analysis.
5. Defining and naming themes: Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells; generating clear definitions and names for each theme.
6. Producing the report: The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis."

(Braun & Clarke, 2006, p. 87)

Software, such as NVIVO, designed for thematic analysis, can be used as an online database or filing system for researchers who have a large volume of data of different types, from a range of participants. Effective use of such software can allow for quicker coding and analysis, once the researcher is familiar with the software. It also allows the researcher to keep a clear record of coding decisions, such as the progression from initial to final themes (Braun & Clarke, 2013). While there are options for auto-coding of data, these are for purely descriptive coding (e.g. searching for a keyword) and the use of software in qualitative analysis does not usually replace the decision-making of the researcher. The software is a database that simply stores and reports back the input from the researcher. Braun & Clarke (2013) caution the use of software for those who are not "tech savvy" , stating that it can cause frustration and can take a long time to learn. They also warn that the technology may act as a barrier, lessening the researcher's immersion in the data.

While thematic analysis does not result in numerical findings to the extent of content analysis, aggregation in thematic analysis can be quantified by comparing the number of references/ extract from the data (quotes, snapshots of work, photographs, audio snippets) or the number of participants who refer to each theme. Using software, such as NVIVO, allows tabulation and graphical representation of the number of references or number of participants referring to themes.

Themes can then be compared according to the demographics of the study population, e.g. gender or role (e.g. student or teacher). This allows exploration of the complex relationships between the themes (QDA Training, 2015). These frequencies, however, cannot be used as the basis of statistical analysis or to further generalise findings due to the small number of participants in qualitative studies and the subjective nature of the coding decisions (QDA Training, 2015). Although these numerical comparisons may be useful, Braun & Clarke (2013) warn that meaningfulness cannot be directly related to the frequency of coding. It may be the case that a large theme is important to the case but smaller themes also tell an important story.

Qualitative methods of analysis, such as content and thematic analysis, aim to ensure that findings are reliable and valid. Reliability considerations focus on the consistency of coding between researchers and between different points in time. Validity considerations are concerned with ensuring the findings accurately represent the phenomena studied (Creswell & Plano Clark, 2011)

Intercoder agreement (or inter-rater reliability) is when different researchers working at different time points infer the same findings (Creswell & Plano Clark, 2011; Schreier, 2012). This is a measure of reliability of coding such as content or thematic analysis. The basic process involves having several individuals code the material and then compare the coding to see if they identified the same category or theme. Intercoder agreement is increased by highly systematic and consistent procedures for coding data (Creswell & Plano Clark, 2011). However, as stated by Moran (2017) in a graduate level workshop with a focus on thematic analysis, intercoder agreement is not always deemed appropriate in qualitative research due to the individualised nature of data interpretation.

Another measure of reliability is consistency of coding between different points in time by the same researcher. Schreier (2012) describes how to achieve a consistent approach to coding by clearly describing coding instructions, in the form of a coding frame or codebook, which describe how to recognise instances of the concept in the data (examples of coding frames can be found in Appendices C-F).

Validity in qualitative research refers to whether the researcher's findings can be considered accurate, credible and trustworthy (Creswell & Plano Clark, 2011). Triangulation is where different data sources are compared for evidence of convergence and corroboration. Triangulation can be carried out between data sources (e.g. written questionnaire and interview) and between individuals (e.g. different participants in the same study) (Creswell & Plano Clark, 2011). The aim is to find out whether the different data sources and participants tell a common story. However, the researcher should take care not to wrongly discount disconfirming evidence and data which diverges from the common story, because this is representative of the real-life situation where different experiences and viewpoints within the same situation are common (Creswell & Plano Clark, 2011).

Another opportunity to increase validity, which is particularly common for researchers with participatory worldviews, is member checking. This is where the researcher discusses the findings (e.g. themes) with the participants to check whether they are an accurate representation of their experience and draws on the participants' viewpoints before finalising the analysis and reporting of findings (Creswell & Plano Clark, 2011).

There is no particular classification of data collection procedures for mixed methods research. Mixed methods are generally associated with pragmatist worldviews, in which the researcher chooses the methods of data collection and analysis based on suitability to the research question. Mixed methods involves a mixture of quantitative and qualitative methods of data collection and analysis with varying focus on each methodology depending on the requirements of the study (Creswell & Plano Clark, 2011). For example, in embedded mixed methods designs the focus is on one methodological approach over the other. These may also be convergent design where quantitative and qualitative data are collected simultaneously, and analysis is carried out separately.

2.2 Methodology overview relating to this thesis

There are five studies presented in this thesis. This section will present the methodological considerations for each study, including the paradigm worldview of the researcher, methodology and data collection and analysis methods (Figure 2-2). This section aims to present a brief overview relating to the methodological considerations and full details will be given within each chapter.

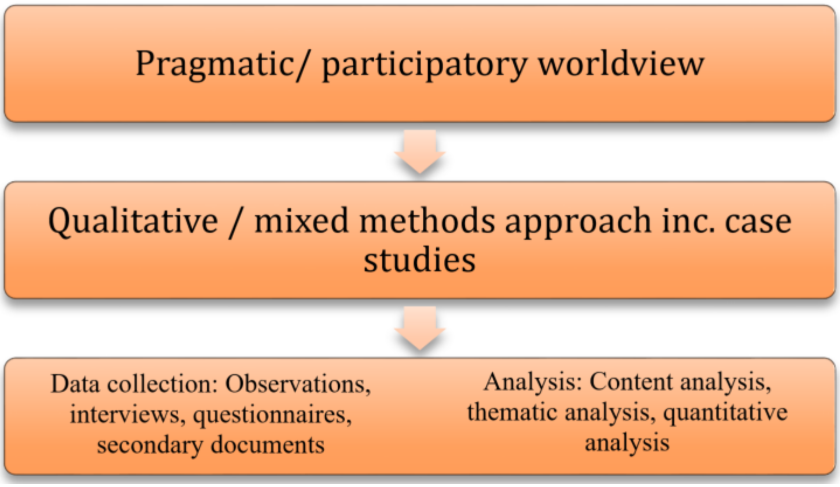


Figure 2-2 Influences on the research studies of this thesis (adapted from Creswell & Plano Clark, 2011, p. 39)

Firstly, it is important to define the researcher's paradigm worldview because this drives the choice of methodology and therefore the methods of data collection and analysis (Figure 2-2). This worldview is shaped by the researcher's own experiences within the area of research. At this point in the thesis it makes sense, therefore, to outline the researcher's own background, which influenced the studies in terms of choice of research topics and questions. Immediately prior to carrying out this research, the researcher was working as a full time secondary school biology and science teacher in Scotland. The researcher had begun their teaching career during a time of curricular upheaval, during the introduction of the Scottish Curriculum for Excellence (CfE) and had experienced first-hand, as well as observed in colleagues, the impact of large scale curriculum policy changes on teachers' practice. As was discussed briefly in Chapter 1, the introduction of the Curriculum for Excellence included changes to assessment, including the introduction of an assessment of inquiry in the context of SSI (including the National 5 Assignment). The researcher was responsible for external marking of this assessment and so became familiar with the assessment in both their classroom practice, administering the assessment with their own classes, and through marking for the Scottish Qualifications Authority (SQA). So, it can be seen how the researcher's own experiences of curriculum change in Scotland led to an interest in research in this area. Additionally, the researcher was based in Ireland and working within an Irish university during the research period so there were further influences in this regard. The Irish secondary school science curriculum was also going through major changes, which were still in development when the research presented in this thesis was in its infancy. Furthermore, the researcher was working part-time within the Irish university as a lecturer in initial teacher education for pre-service science teachers. This experience led to a focus on initial teacher education in third level, as well as in secondary schools. The researcher's own experience of curriculum change in Scotland, combined with influences from the Irish secondary and tertiary contexts within which the researcher was working led to the overall research question: *How can the teacher and student experience of the development and assessment of scientific literacy in secondary schools inform initial science teacher education?*

Figure 2-1 shows, in general, how the worldview of the researcher influences their chosen methodology and methods of data collection and analysis, while Figure 2-2 provides details of these in relation to the researcher and studies presented in this thesis. In this thesis, the worldview of the researcher remains the same throughout (they are the same person after all). The author, and researcher, of this thesis, has a pragmatic and participatory worldview. This means they focus on the consequences of the research and place primary importance on the research question. The methods of data collection and analysis are driven by the best methods to explore the research question (Creswell & Plano Clark, 2011). The participatory worldview drives the researcher to carry out research with the aim of improving society. They also involve the participants in decision-making around the study, using a collaborative approach (Creswell & Plano Clark, 2011). In this case the research aims to develop and assess scientific literacy in secondary schools and benefit society by doing so. The researcher strived to remain an objective observer and in most cases (Chapter 4) carried out observation of real-life phenomena with the assumption that had the researcher not been present the outcome would have been the same. In one study (PST case study described in Chapter 5) the researcher was also the teacher and so objectivity could not be assumed to the same extent. It is accepted by the researcher that one can never be truly objective and that there is a place, particularly in qualitative research, for the researcher's interpretations and insights. This subjectivity cannot be completely avoided because each researcher brings with them their own past experiences and views that colour their view of the observed phenomena.

In keeping with the researcher's worldview, all studies were carried out using either a wholly qualitative or mixed methods approach. Where mixed methods were employed, the focus was on qualitative approaches with quantitative approaches playing a supporting role. A brief overview of the chosen methodologies of each of the five studies will be presented in the remaining part of this chapter. More detailed methodologies will be presented within chapters three to five.

Before discussing, in detail, the methodology relating to the studies presented in this thesis, it is useful to present an overview of the five studies in terms of when each study was carried out. This is helpful to allow the reader to gain an insight into the journey of the researcher and how the findings from each study informed other studies. A timeline of the completion of the five studies, including pilot studies, over the years 2014 – 17 is shown in Figure 2-3. A further timeline (Figure 2-4) shows the progression of the main studies over the years 2016-17.

Figure 2-3 shows that the findings and conclusions from the studies described in Chapter 3, exploring the assessment of scientific literacy in written, summative exams, led to further questions around the development and assessment of scientific literacy through inquiry in the context of SSI. The following year, pilot studies exploring inquiry in the context of SSI were carried out with secondary school teachers and their students, and PSTs (focussing on their role as *learners* only). In the final year of data collection, studies were carried out with secondary school teachers and students in Scottish and Irish contexts. Data collection and initial analysis was carried out in the first semester of this year (Figure 2-4). In the second semester of this year an initial teacher education module was designed, implemented and evaluated based on the findings and conclusions from pilot studies and early analysis of the secondary school case studies carried out in the first semester (Figure 2-4).

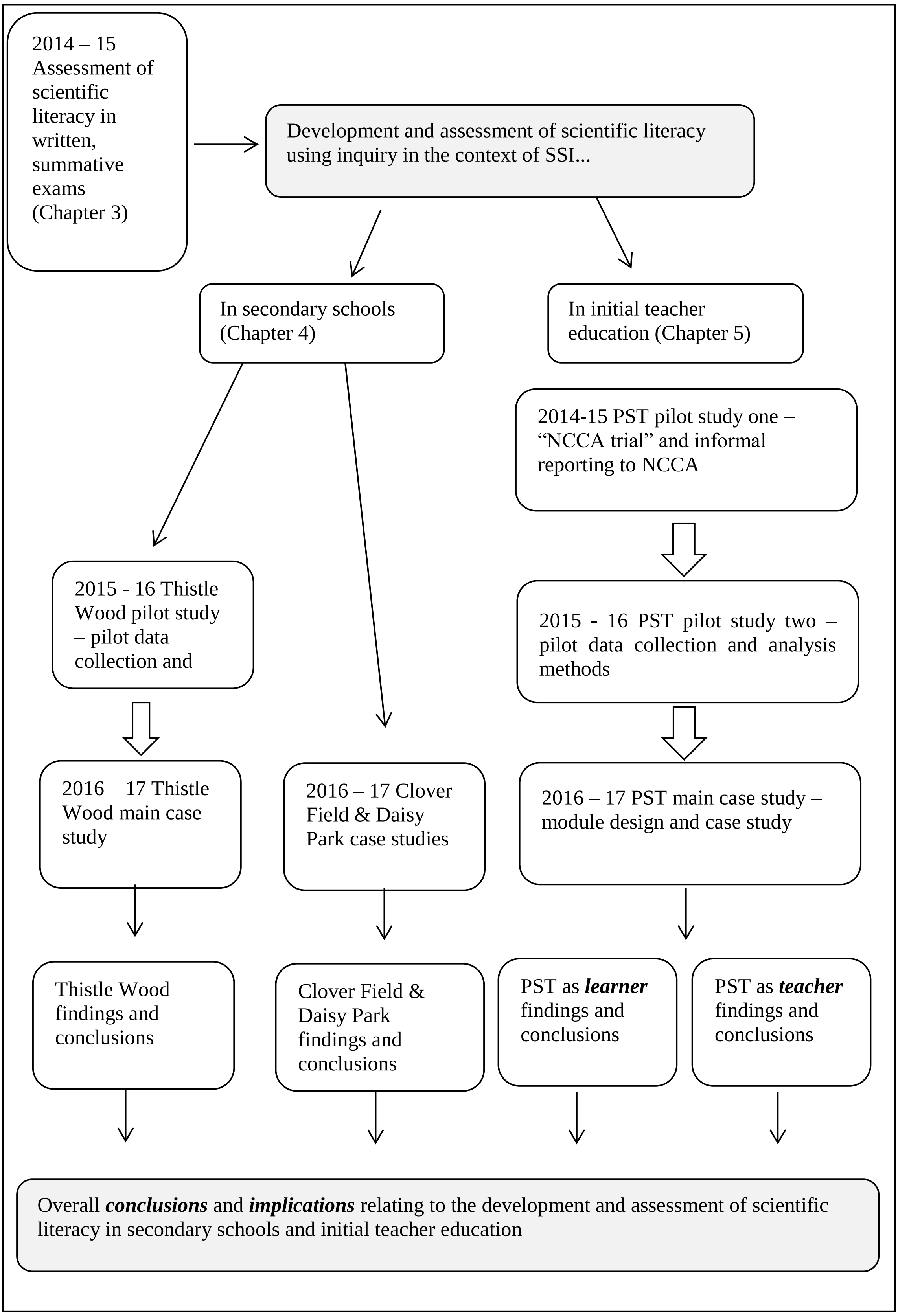


Figure 2-3 Timeline of the five studies presented in this thesis

Oct/Nov 16

Thistle Wood School - Assignment carried out/student & teacher questionnaire completed

Dec 16

Daisy Park School - Researcher observations of lessons/ student questionnaire completed

Jan 17

Clover Field School - Researcher observations of lessons

April/May 17

PST case study - designed and implemented/ questionnaires & student work collected

June 17

Thistle Wood/ Clover Field / Daisy Park Schools - teacher interviews carried out

Sept 17

PST case study - interviews carried out

Figure 2-4 Timeline of studies carried out over the years 2016/17

2.2.1 Assessment of scientific literacy in a PISA assessment item (Chapter 3)

This study aims to explore the assessment of scientific literacy in written, summative assessments and asks:

1. Which PISA sub-competencies and knowledge types are assessed in a PISA assessment item?
2. What level of scientific literacy is demonstrated by first year undergraduate science students when answering a PISA assessment item?

This study was carried out using a qualitative methodology. 30 first year undergraduate science students participated in the study and were asked to complete a PISA assessment item. Their written answers underwent document analysis using content analysis procedures, which are described in detail in the following paragraph (i).

(i) Content analysis used in this thesis

The research questions in this study are mainly descriptive and so can be answered using numerical comparisons (of competencies and knowledge types used/ of levels of scientific literacy). For this reason, content analysis was chosen and was carried out over a series of sequential steps adapted from Schreier (2012):

1. Decide the research question
2. Collect or select relevant material
3. Build an initial coding frame or use a pre-existing frame (e.g. PISA competencies)
4. Try out your coding frame
5. Evaluate/ modify the coding frame and produce a detailed “codebook”
6. Interpret and present findings

To explore which sub-competencies and knowledge types were evidenced in the student answers to a PISA assessment item, the stages of content analysis were followed as described. The research question was decided in advance of data collection (step 1). For step 2, 30 first year undergraduate science students were asked to complete a PISA assessment item which included an open-response element (see Figure 3-1). In step 3, the initial coding frame used was mainly pre-determined and taken directly from PISA’s description of the 15 sub-competencies and three knowledge types of PISA (Table 1-1 and Table 1-2). Coding was carried out deductively (step 4); the students’ open, written responses were coded according to the 15 sub-competencies and three knowledge types of PISA. Only two of the 15 sub-competencies and one knowledge type was identified in the data and so the initial coding frame was modified to remove any categories not observed and to give detailed coding instructions for these categories (step 5). The detailed codebook (or coding frame) can be seen in Table 3-1.

The level scientific literacy demonstrated in the student answers was also explored using content analysis but a different coding frame (codebook) was devised (Table 3-2). Step 1 and 2 had already been carried out to explore the sub-competencies and knowledge types. In step 3, the initial coding frame divided the data into three levels of answer. The coding frame (codebook) was then used for initial coding and modified to give detailed instructions for each of the three categories (levels) of answer (steps 4 and 5) (Table 3-2). In this case the coding frame was determined inductively as the three categories (or levels) were only partly pre-determined (three levels) and were described fully only after initial analysis of the data (steps 4-5).

Reliability of findings was increased by using the systematic procedures for analysis described on page 58. While intercoder agreement was not used in this study, reliability between researchers was considered as the coding frame (codebook) and any contentious coding decisions were discussed with the researcher’s academic supervisors and a consensus reached.

All studies involving human participants have been approved by the Dublin City University Research Ethics Committee (DCU REC). The primary aim of the REC is to promote the rights of study participants and avoid participant burden or harm. This study underwent “notification” type ethical review. The participants were all over the age of 18 and the information collected was not of a sensitive nature. As such the study was considered low risk. Individuals gave written consent to participate in the study.

2.2.2 Assessment of scientific literacy in curricular exams of Scotland and Ireland (Chapter 3)

As with the study described in section 2.2.1, this study was concerned with the assessment of scientific literacy in summative, written assessments. The study asks:

1. Which PISA competencies and knowledge types are assessed in the summative, written examinations of the Scottish curriculum?
2. Which PISA competencies and knowledge types are assessed in the summative, written examinations of the Irish curriculum?

The study used a qualitative methodology and employed content analysis of secondary documentation. The documents chosen for analysis were curricular exams from Scotland and Ireland.

Content analysis was carried out according to the sequence of steps as described in Section 2.2.1. In steps 1 and 2 of content analysis, the research question was determined and data was collected that was appropriate to the research question, in this case assessment examples from the Scottish and Irish curricula (Table 3-3). The initial codes were pre-determined (step 3) as the 15 PISA sub-competencies and three knowledge types, and as coding progressed, the coding frame underwent evaluation and modification to form a detailed codebook (steps 4-5). The final codebook (coding frame) can be seen in Appendix C.

This study considered reliability by obtaining a measure of intercoder agreement (inter-rater reliability). Two researchers were asked to code a sample of the assessment items and these categorisations were compared to the categorisations of the researcher. Cohen's Kappa was calculated to assess the reliability of coding between the researcher and two other researchers.

2.2.3 Thistle Wood School case study (Chapter 4)

Thistle Wood School case study, described in Chapter 4, explored the research questions:

1. What are the teacher and student experiences of carrying out the Scottish CfE National 5 Assignment?
2. Which PISA competencies are developed and assessed in the Scottish CfE National 5 Assignment?

The study took a mixed methods approach and was an embedded, mainly qualitative case study. The mixed methods design was convergent, meaning that the two data types were collected together and analysed separately. The case study can be described as instrumental, which means it was used to contribute information to an overall research. The teacher and student experience was explored using qualitative data collection and analysis due to the interpretive rather than descriptive or comparative nature of the research question. Exploration of the PISA sub-competencies used was descriptive and comparative and so was explored using quantitative data collection and analysis.

Nineteen secondary school science teachers participated in the main study and provided secondary documentation relating to 402 of their students (a pilot was carried out the previous year). Data was collected using a mixed methods questionnaire which included a series of open-response questions that aimed to gather qualitative data, followed by closed response questions, with an optional open response, that aimed to gather both quantitative and qualitative data. Examples of completed questionnaires can be found in Appendix A. Secondary documentation included: anonymised student work and student evaluations, also in the form of a mixed methods questionnaire; departmental lesson plans and schemes; teacher quality assurance materials, such as minutes of meetings and lesson evaluations; and researcher field notes. All data was analysed using thematic analysis and a detailed method is described in the following paragraphs (ii).

(i) Thematic analysis used in this thesis

Exploration of the teacher and student experience required the researcher to interpret rich qualitative data and so thematic analysis was chosen. Thematic analysis was carried out on the qualitative data gathered: open-response sections of teacher and student questionnaires, teacher interviews and secondary documentation. The method of thematic analysis used in this study was initially based on the method described by Braun & Clarke (2006) but was refined as a result of a pilot study. The final method of thematic analysis devised for use in the studies described in this thesis is outlined in Figure 2-5 and the following paragraphs. This method of thematic analysis was used in each of the case studies (Thistle Wood School, Clover Field School, Daisy Park School and PST case study).

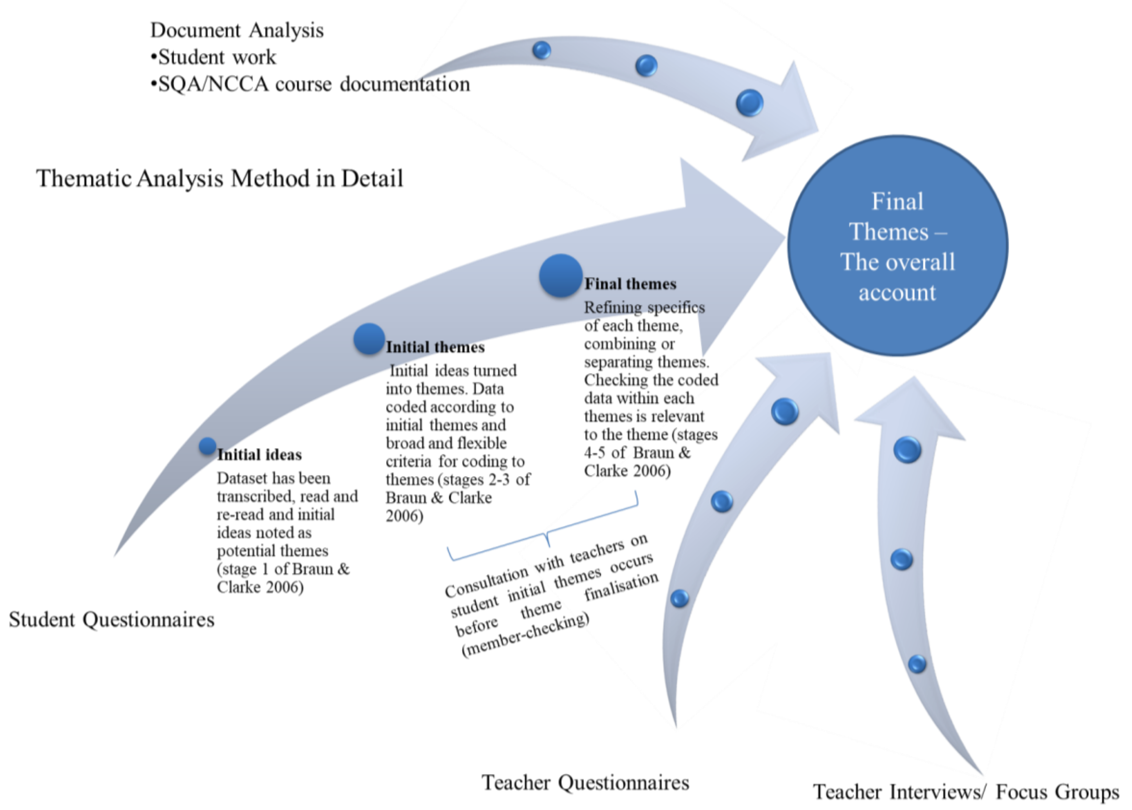


Figure 2-5: Thematic analysis method used in this thesis

Each type of data (e.g. questionnaires, interviews, documents) separately underwent a systematic process of analysis as shown in (Figure 2-5) before themes were combined to an overall account of the "case".

Firstly, the researcher read and transcribed (if necessary) the qualitative data and noted initial ideas and thoughts. This was known as the *initial ideas* stage. At this stage the "codebook" began to form with overall headings or themes and broad statements of what may be included.

Next, in the *initial themes* stage, the researcher formed themes from the initial ideas and began a process of systematic coding of data extracts (quotes, pictures, snapshots, video and audio extracts) into each theme. This coding process continued until all data from the data source (e.g. questionnaire) had been coded. It was possible at this stage to have a theme such as "other" or "miscellaneous" to allow all data to be coded. At this stage the codebook was detailed and inclusive but there may have been overlapping sub-themes or sub-themes that were too small (i.e. too few references or participants referring to it) or too large (i.e. contained multiple topics and would be better as separate sub-themes). At the end of this stage member-checking occurred, where the initial themes and sub-themes were discussed with the participants. The teachers were asked whether the themes represented the phenomena, in this case the experience of the National 5 Assignment, as they perceived it and any ambiguous answers or industry specific terms were checked for meaning. These conversations were used to inform the identification of the final themes.

Thirdly, the researcher reviewed the themes and sub-themes by checking all coded extracts fitted within the theme they were allocated. The “other”/ “miscellaneous” theme was checked and extracts were either coded into an appropriate theme or discarded if not deemed relevant. The themes were given clear descriptions and names, which were written up in a codebook. References that were found in more than one sub-theme of the same theme were placed into the most appropriate sub-theme and this decision this was noted in the code-book. By the end of this stage the codebook described clearly what should and should not be included in each theme and sub-theme, and the references/extracts within these matched the codebook.

The final stage of analysis was when all data sources were analysed together. The themes and sub-themes were combined for all data types. All references/extracts were re-checked against the allocated theme/sub-theme and the codebook to ensure consistent coding across all the data types. Appendix D shows the full, final codebook for Thistle Wood School case study.

There were three considerations for the final themes and sub-themes, adapted from content analysis procedures, that aimed to make the process more manageable and systematic:

1. Mutual exclusivity: The sub-themes within a theme are mutually exclusive and one unit of coding cannot be coded into multiple sub-themes.
2. Exhaustiveness: All data is assigned to at least one sub-theme. This applies to initial themes only as extracts from the “other”/ “miscellaneous” theme may be disregarded as irrelevant or not representative of the overall account before finalisation of the themes.
3. Saturation: All sub-themes have at least one relevant extract, no theme or sub-theme can be empty. In larger case studies (e.g. Thistle Wood School case study) the sub-theme should be present in more than one of the participants’ accounts.

(adapted from Schreier, 2012)

Triangulation was used to increase validity of findings by comparing findings between data sources, i.e. surveys and interviews with teachers, and between participants, i.e. students and teachers, teachers of different subjects, teachers of different roles. Validity was also increased as themes were checked with the participants, member-checked, to ensure they accurately represented their experience before being finalised.

Reliability was considered and increased through a systematic and consistent approach to coding. This was achieved through rigorous procedures as shown in Figure 2-5, including the development of a detailed “codebook” that outlined what should be included in each theme and sub-theme.

Inter-rater reliability was not used in this study as it was not deemed as appropriate given that the themes were interpretative. Instead themes were checked with the participants themselves. However, at appropriate stages in the analysis the working themes were subject to consultation with academic supervisors.

Data was also analysed quantitatively in this study. The percentage of teachers and students who responded "yes" to questions 7, 8 and 9 and who reported using each sub-competency in the N5 Assignment (part two of the questionnaire) was calculated (Appendix A). This information was displayed graphically.

This study underwent "expedited" ethical review. The participants in the study were teachers being questioned in their professional capacity about their professional activities and as such this aspect was considered low risk. Data collection methods were also considered low-risk: questionnaires and interviews with adults and document analysis. Surveys of student views of educational experiences are carried out as standard by teachers as part of quality assurance procedures in the participating school. The information collected was not of a sensitive nature but related to students under the age of 18, so this aspect was considered moderate risk. Note that all schools and participants have been given pseudonyms to ensure anonymity.

2.2.4 Irish case studies: Clover Field School and Daisy Park School case studies (Chapter 4)

This study explored the question: What are the teachers' and students' experiences of carrying out inquiry in the context of SSI in preparation for the Science in Society Investigation?

This study was comprised of two separate qualitative, instrumental case studies. Each case study followed one teacher, working within the Irish curricular context, and their students. Data collection was wholly qualitative and included observation of lessons, individual semi-structured interviews and secondary document analysis (teacher lesson plans and researcher field notes, student lesson evaluations and student work). Thematic analysis, as described in Section 2.2.3, was carried out on all data sources. This process of thematic analysis was carried out separately for each case study. Firstly, initial ideas were noted after familiarisation with the data and these were turned into initial themes. Data was broadly coded into these initial themes. These initial themes were discussed with the teachers (the participants) to ensure they represented their view of their own, and the students', experience. Final themes were then generated and all data was coded into these final themes. A final codebook was written at this stage, which can be seen in Appendices D and F.

Reliability was increased through rigorous, systematic coding procedures, i.e. detailed codebooks (Appendices D and F).

Validity was increased using triangulation between data sources (e.g. student work vs. student lesson evaluations) and between participants (teacher interview vs. student lesson evaluations), and member-checking of themes before finalisation.

The study underwent "expedited" ethical review for the same reasons as described for Thistle Wood School case study.

2.2.5 PST case study (Chapter 5)

This study aimed to contribute to the overall research question by asking:

1. What are the PSTs' experiences of carrying out inquiry in the context of SSI as *learners*?
2. Which PISA competencies are developed and assessed through inquiry in the context of SSI in this module (PSTs as *learners*)?
3. What are the PSTs' experiences of carrying out inquiry in the context of SSI as *teachers*?

This study was a mixed methods, mainly qualitative case study. The mixed methods design is convergent because the two data types are collected together and analysed separately. The case study is instrumental in that it is concerned with providing information towards a research question rather than for interest in the case itself. The participants in this study were eight PSTs in their second year of an undergraduate BSc in science education. Data was collected using a mixed methods questionnaire, open-ended interviews and secondary documentation including student work and researcher field notes. Data collection instruments used can be seen in Appendix A.

Thematic analysis was carried out on all qualitative data sources, using the method described in Section 2.2.3. First, initial ideas were noted after familiarisation with the data gathered. Initial themes were identified from these initial ideas and early coding took place. These initial themes were member-checked with a sample of the participants to ensure they represented their view of their experience as *learners* and as *teachers*. Final themes were then identified, and a final codebook was generated. This codebook can be seen in Appendix H. The instructions from the codebook were applied to the full range of data that had been collected, in a final round of coding.

Use of these systematic procedures increased reliability. To increase validity, triangulation was carried out between data sources (questionnaire/interview/student work) and between participants. Member-checking was also used to increase validity of the findings.

Some quantitative data was gathered and analysed. The percentage of PSTs who responded positively to questions 7, 8 and 9 and the 15 sub-competencies listed in the part two of the questionnaire was calculated and displayed graphically.

This study underwent “notification” type ethical review. The studies involved asking students about an educational experience. The participants were all over the age of 18 and the information collected was not of a sensitive nature. Individuals gave written consent to participate in the study.

2.3 Chapter Conclusions

This chapter aimed to provide a theoretical overview of the methodological considerations for the studies presented in this thesis. This thesis describes five related studies that were carried out over four years (Figure 2-3). The studies described in Chapters 3 and 4 describe the development and assessment of scientific literacy in secondary school contexts, with a focus on the curricula of Scotland and Ireland. These studies informed the design and implementation of an initial teacher education module for pre-service science teachers. The design of this module and a case study of eight PSTs who took part in the module is presented in Chapter 5. Chapter 2 aimed to provide a brief outline of the researcher's paradigm worldview, the chosen methodologies and methods of data collection and analysis used in the five studies.

Creswell & Plano Clark (2011) describe three elements that impact the design and implementation of a research study. These are: the researcher's paradigm worldview, methodological approach and methods of data collection and analysis. In the studies described in this thesis, the researcher's paradigm worldview is considered to be pragmatic, with elements of a participatory worldview. These two worldviews had a large influence on the chosen methodological approaches used in the studies. A researcher with a pragmatic worldview chooses the approach that best suits the research question, rather than being bound to one particular approach (Creswell & Plano Clark, 2011). The chosen methodological approaches in this thesis are either wholly qualitative or mainly qualitative mixed methods approaches. Case studies are used throughout the thesis and these are either qualitative or embedded (mainly qualitative) mixed methods approaches (Creswell & Plano Clark, 2011). These methodological approaches reflect the range of research questions posed in the various studies and the desire of the researcher to portray real-life educational situations and describe these in depth (Denzin & Lincoln, 2005). The methods of data collection and analysis used align with the methodological approach. Content analysis and thematic analysis were used to analyse the qualitative data collected. In some case studies (Thistle Wood School and PST case studies) some data was also analysed and presented quantitatively, as graphs.

Chapter 3 will now present two studies exploring the assessment of scientific literacy in secondary school contexts of Scotland and Ireland, using summative, written assessments.

3 Assessment of scientific literacy in summative, written exams

This chapter presents two studies that aim to contribute information towards the overarching research question: *How can the teacher and student experience of the development and assessment of scientific literacy in secondary schools inform initial science teacher education?*

The focus of this chapter is on summative, closed-book assessments taken under timed conditions, such as the end-of-year, curricular exams of many countries. These summative assessments are likely to be high-stakes, e.g. end of course examinations leading to qualifications, or perceived as such by the student, e.g. PISA may not be high stakes for the student but is perceived as such due to the nature of the test setting. These types of exams tend to rely on reading literacy skills. They involve students reading a question and constructing a written response (OECD, 2013). For ease of reference these will be referred to as summative, written assessments throughout this chapter.

PISA 2015 aimed to assess the competencies and knowledge of scientific literacy, described in the PISA 2015 Framework (Table 1-1 and Table 1-2). PISA 2015 was a computer-based assessment and some questions involved the use of simulations to attempt to represent practical tasks. To allow comparisons with previous PISA cycles, many of the questions remained the same as previous PISA cycles, i.e. standard, multiple-choice or constructed response items that relied on traditional literacy skills (OECD, 2016). From this point of view, despite the use of computers in the assessment, PISA remained a "written" assessment.

Chapter 1 discussed PISA's description of scientific literacy within the context of the variety of literature written on the subject. While the PISA definition of scientific literacy may not be universally accepted, it is no doubt a comprehensive and convenient description of scientific literacy. The studies described in this chapter use this definition and refer to the competencies and knowledge types of PISA throughout, as representative of the skills and knowledge of scientific literacy that allow participation in society. While the studies presented in chapters four and five use the PISA description of scientific literacy, they do not limit themselves to this definition in the way this chapter does.

This chapter has been kept purposefully short in comparison to chapters four and five. While this chapter provides important evidence relating to the assessment of scientific literacy through summative methods, the thesis' main focus is on the more novel approaches using inquiry in the context of SSI.

3.1 Assessment of scientific literacy in a PISA assessment item

PISA describes scientific literacy in terms of competencies and knowledge types (Table 1-1 and Table 1-2). The framework and assessment also describe performance of the competencies and knowledge in terms of levels of scientific literacy (OECD, 2013). PISA describes six levels of scientific literacy which are shown in Appendix B. A student performing at level 6 on the PISA 2015 reporting scale is deemed to be performing at the highest level of scientific literacy. Level 1b represents students who demonstrate the very minimal level of scientific literacy (OECD, 2013). Regardless of the level of scientific literacy, students are expected to demonstrate use of the competencies and knowledge types. A student with a high level of scientific literacy can demonstrate the competencies and knowledge types within complex and unfamiliar personal, local, national and global contexts. Those with low levels of scientific literacy demonstrate the competencies within familiar contexts only.

When demonstrating Competency 1 *explain phenomena scientifically* (Table 1-1), individuals with a high level of scientific literacy demonstrate advanced scientific thinking and reasoning requiring the use of models and abstract ideas. They develop arguments to critique and evaluate explanations, models, interpretations of data and proposed experimental designs. Those with a low level of scientific literacy may only develop partial arguments to questions and simply comment on the merits of competing explanations (OECD, 2013, pp. 48-49).

When demonstrating Competency 2 *evaluate and design scientific inquiry* (Table 1-1), those with high levels of scientific literacy clearly distinguish scientific and non-scientific questions, explain the purposes of inquiry, control relevant variables in a given scientific inquiry or any experimental design of their own, and demonstrate an ability to make appropriate judgments about the reliability and accuracy of any scientific claims. Those with a low level of scientific literacy distinguish some simple scientific and non-scientific questions, distinguish between independent and dependent variables in scientific inquiry or in a simple experimental design of their own (OECD, 2013, pp. 48-49).

When demonstrating Competency 3 *interpret data and evidence scientifically* (Table 1-1), an individual with a high level of scientific literacy draws appropriate inferences from a range of different complex data sources, provides explanations of multi-step causal relationships, transforms data representations and interprets complex data. Those with a low level of scientific literacy make a few inferences from different sources of data, describe simple causal relationships, transform and describe simple data, identify straightforward errors and make some valid comments on the trustworthiness of scientific claims, interpretations of data and proposed experimental designs (OECD, 2013, pp. 48-49).

This study will explore the competencies and knowledge types first year undergraduate science students demonstrate when answering a PISA sample question and compare these to the competencies and knowledge types stated by PISA as being assessed. The study will also explore the level of scientific literacy demonstrated. The study asks:

1. Which PISA sub-competencies and knowledge types are assessed in a PISA assessment item?
2. What level of scientific literacy is demonstrated by first year undergraduate science students when answering a PISA assessment item?

3.1.1 Methodology

This research was carried out qualitatively. Thirty undergraduate students were chosen to take part in this study. The students were in the second semester of their first year of university. The students all came from the Irish education system at secondary school and 19 of the 30 participants had taken chemistry at Irish Leaving Certificate level.

Students were asked to complete a written assessment item which was sourced from PISA's 2006 assessment, the last assessment prior to 2015 where science was a major domain (OECD, 2006). The question was modified from a "simple multiple choice" and a "constructed" response section was added (Figure 3-1). This additional constructed response element was added to allow students to explain the reasoning behind the multiple-choice answer given. This could then be analysed to show the level of scientific literacy of the student. The students were given 15 minutes to complete the assessment item and all students completed the question within this time.

Chemistry Question: Acid Rain

Below is a photo of statues called Caryatids that were built on the Acropolis in Athens more than 2500 years ago. The statues are made of a type of rock called marble. Marble is composed of calcium carbonate.

In 1980, the original statues were transferred inside the museum of the Acropolis and were replaced by replicas. The original statues were being eaten away by acid rain.

The effect of acid rain on marble can be modelled by placing chips of marble in vinegar overnight. Vinegar and acid rain have about the same acidity level. When a marble chip is placed in vinegar, bubbles of gas form. The mass of the dry marble chip can be found before and after the experiment.

A marble chip has a mass of 2.0 grams before being immersed in vinegar overnight. The chip is removed and dried the next day. What will the mass of the dried marble chip be? (circle your answer)

A Less than 2.0 grams

B Exactly 2.0 grams

C Between 2.0 and 2.4 grams

D More than 2.4 grams

In the space below, explain your reason for selecting this answer

Figure 3-1 PISA assessment item: acid rain (OECD, 2006)

According to PISA (OECD, 2006), the question intends to assess the competency using scientific evidence, which is equivalent to PISA 2015's competency 3 evaluate data and evidence scientifically. The knowledge category assessed was physical systems, which is equivalent to content knowledge in 2015. The percentage of students answering this question correctly in PISA 2006 was 66.7% (OECD, 2006).

The students' written responses were analysed using content analysis, using the method described on page 58 ((i) Content analysis used in this thesis).

When exploring the PISA competencies and knowledge types assessed, the initial coding frame chosen was pre-determined as the 15 sub-competencies and three knowledge types of PISA. Initial coding then took place; extracts from students' extended response answers were coded according to the PISA sub-competencies and knowledge types. Only two sub-competencies and one type of knowledge were observed so only these were included in the final coding frame "codebook" (Table 3-1)

When exploring the level of scientific literacy demonstrated by the students in their answers, the initial coding frame/ codebook was not pre-determined to the same extent. The initial codebook divided the data into three levels of answer and initial coding took place. This initial coding informed the development of a detailed codebook which described the characteristics of the different levels of answer (Table 3-2). The number of students achieving the different levels was compared quantitatively. A Mann-Whitney U test was carried out using SPSS to compare the level of answer given between those who had studied chemistry at leaving certificate or not. This test was chosen because the dependent variable (the score) was nominal (categories-1,2,3) rather than continuous.

3.1.2 Findings

Findings relating to the sub-competencies and knowledge types identified using content analysis will be presented. Findings relating to the sub-competencies and knowledge types and the level of scientific literacy demonstrated (i) and evidence from student work relating to performance at each level (ii) will be presented.

(i) Sub-competencies and knowledge types demonstrated

Twenty-nine out of the 30 participants correctly answered this question.

Content analysis of the student answers revealed that all correct answers, demonstrated the sub-competencies 3B analyse and interpret data and draw appropriate conclusions and 3C identify the assumptions, evidence and reasoning in science-related texts, both of which are sub-competencies Competency 3 interpret data and evidence scientifically. Correct answers also demonstrated content knowledge (see Table 1-1 and Table 1-2 for a reminder of the competencies and sub-competencies, and knowledge types). The codebook in Table 3-1 shows the criteria for identification of the two sub-competencies and knowledge type.

Table 3-1 Codebook for content analysis of competency and knowledge type

Competency/ Knowledge	**Justification**
3B: Analyse and interpret data and draw appropriate conclusions	Answers that make sense of the evidence given in the question to make claims and draw conclusions. Not solely relying on memory of scientific fact.
3C: Identify the assumptions, evidence and reasoning in science-related texts	Answers that identify the evidence and important information from the question, possibly using the same wording as the question or putting it into their own words. This evidence can then be used to draw a conclusion.
Content knowledge	Answers that use scientific terms not used in the question or explain a scientific concept not directly taken from the question.

The students used sub-competencies 3B and 3C when using evidence from the question, rather than only prior scientific knowledge, to make claims and draw conclusions. Students also used their content knowledge of science when they used scientific terms in their answers. The incorrect answer did not demonstrate any of the competencies or knowledge types.

(ii) Level of scientific literacy demonstrated

There was evidence of a range of levels of scientific literacy in the students' answers and all levels demonstrated the sub-competencies 3B analyse and interpret data and draw appropriate conclusions and 3C identify the assumptions, evidence and reasoning in science-related texts, and content knowledge of science (Table 3-2).

A Mann-Whitney U test was carried out using SPSS to compare the score of those who had studied biology, chemistry or physics at Leaving Certificate to those who had not. When comparing those students who had studied chemistry (n=18) at Leaving Certificate to those who had not (n=11), there was no significant difference (p=.414). There was also no significant difference in the scores of students who had studied biology or physics compared to those who had not. This result may not be surprising as all students had taken introductory modules in biology, chemistry and physics in semester one, prior to this study being conducted.

Table 3-2 Codebook for content analysis of level of answer

Level of answer	Number of students
Level 1: This is the lowest level of correct answer. These answers largely used the wording or similar non-scientific wording to the wording given in the question. Decreases in mass were attributed to the marble "dissolving" or being "eaten away" or "eroded". There was little further scientific explanation given.	17
Level 2: This is the intermediate level of correct answer. These answers used both the wording of the question or similar and added more scientific terminology of the students own. The explanations showed an understanding of a chemical reaction having taken place, causing the production of gas bubbles, and decreases in mass were attributed to this, although not explicitly. Some scientific explanation was given.	8
Level 3: This is the highest level of correct answer. The students used the wording given in the question but used scientific terminology to expand and explain this in their own words. The explanations showed an understanding of a chemical reaction having taken place, with the production of gas bubbles, and the creation of a product or using up of the reactants and decreases in mass were attributed to this explicitly. A good deal of scientific explanation was given.	4

Incorrect Student Answer

There was only one incorrect answer out of the 30 students who answered the PISA assessment item:

> acid rain = carbonic acid. They would remain the same because calcium carbonate reacts with carbonic acid but doesn't react with vinegar in the same way (Student 30)

This answer does not demonstrate the students' ability to draw conclusions (3B) because the conclusion drawn, and therefore the answer given, is incorrect. Their explanation showed that the student did not correctly use the evidence and reasoning given in the question (3C) and as such the conclusion drawn is incorrect. The student did not correctly identify the appropriate information (3C) from the text as they did not use the information given that "*The effect of acid* *rain on marble can be modelled by placing chips of marble in vinegar overnight"* or that the bubbles of gas referred to in the question indicated a chemical reaction taking place.

Student answers, exemplifying each of the three levels, are presented in the following paragraphs.

Level 1 Student Answers

Level 1 answers were the lowest level of correct answer and the majority (57%) of student responses were level 1. These answers demonstrated the two sub-competencies 3B and 3C and content knowledge but to a low level. These answers largely used the same wording as the question rather than using content knowledge to state scientific terms. The students used some content knowledge to provide a basic explanation of their reasoning. Conclusions drawn were correct (3B) and based on information given in the question (3C); the students recognised a decrease in mass and attributed it to the marble "dissolving", being "eaten away" or "eroded".

Student 29 correctly answered the question and provided a basic explanation for their choice:

> The statues were eaten away therefore less marble is present therefore less than 2.0 grams (Student 29)

Student 29 demonstrated their ability to use scientific evidence (3C) clearly by using the wording "eaten away", which was given in the question. They demonstrated their ability to interpret evidence and draw conclusions (3B) describing "less marble present" therefore "less than 2.0 grams" using the evidence and wording of the question itself.

Explanations from students 9 and 24 clearly show that the students identified the evidence and reasoning in the text (3C) and used this to draw a conclusion (3B):

> The acidic vinegar corrodes away more of the marble so there will be less marble remaining, therefore its mass is less (Student 9)

> The acidity of the vinegar will corrode the marble chip so bits of the marble chip will disintegrate meaning the marble chip will weigh less than its original value (Student 24)

However, these students did not recognise or discuss that a chemical reaction had taken place.

Level 2 Student Answers.

Level 2 answers were an intermediate level of correct answer and around one quarter (23%) of students in this study gave this level of answer. As with level 1 answers, these students used the wording of the question or similar. What characterised a level 2 answer, was that content knowledge was accessed to add more scientific terminology of the students own and the explanations showed an understanding of a chemical reaction having taken place. This reaction was explained by students as causing the production of gas bubbles (3C) and decreases in mass were attributed to this (3B), although not explicitly.

> The vinegar, which is similar in acidity level to acid rain will have reacted with some of the marble. The total mass would therefore decrease. A gas was produced (bubbles) (student 14)

> The acid and base react (the vinegar and marble) to produce the gas, by doing this you reduce the amount of marble (student 17)

These level 2 student answers clearly showed an understanding of the link between the occurrence of a chemical reaction, as shown by the bubbles of gas being produced (3C), and reduction in mass of the reactant (3B). The students did not simply use the wording given in the question, they used their scientific knowledge (content knowledge) to state scientific terms and expand upon the information given in the question. The students also demonstrated content knowledge of science through their discussion of bubbles of gas indicating a chemical reaction between the marble and vinegar.

Level 3 Student Answers

Level 3 student answers displayed the highest level of scientific literacy. The students performed the sub-competencies and demonstrated content knowledge to the greatest extent. A minority of students achieved a level 3 answer (13%).

When performing at level 3, the students used the wording given in the question and used content knowledge to give scientific explanations using scientific terminology. The explanations attributed the production of gas bubbles (3C) to a chemical reaction and discussed the creation of a product or using up of the reactants (content knowledge), causing a decrease in mass (3B).

> Because the acid in the vinegar reacts with calcium carbonate and produces a different product. As a result that means the mass of the marble chip will decrease due to being reacted (student 2)

> It will weigh less than 2 grams as bubbles of gas form when the marble is immersed in vinegar, meaning that a reaction is occurring in which the marble is being consumed, so the mass will decrease (student 25)

The students demonstrated their understanding of a chemical reaction having taken place to produce a new product and the associated decrease in mass of reactants explicitly. They demonstrated their ability to identify evidence and reasoning in the question text (3C) by referring to information given in the question. They drew appropriate conclusions (3B) by correctly stating that mass will decrease, followed by a short explanation. In these level 3 answers, students used their content knowledge of science to explain the underlying science using scientific terms not given in the question and discussed the chemical reaction in a higher level of detail than the level 2 answers.

3.1.3 Discussion

This study explored the assessment of scientific literacy using a PISA assessment item by examining the competencies and knowledge types (i) and level of scientific literacy demonstrated (ii).

(i) Competency and knowledge type

All correct answers (explanations) demonstrated Competency 3 interpret data and evidence scientifically, specifically sub-competencies 3B analyse and interpret data and draw appropriate conclusions, and 3C identify assumptions evidence and reasoning in science related texts. This matched with what PISA aimed to assess (OECD, 2006). Additionally, all correct answers displayed use of content knowledge of science, again this matched what PISA aimed to assess. The findings show that (at least) some of the competencies and knowledge types of scientific literacy can be assessed using summative, written exam formats.

The students' explanations allowed further exploration of how the competencies and knowledge were demonstrated. Students demonstrated sub-competency 3C when using information from the question. They then used this information to draw a correct conclusion (3B) which resulted in the correct multiple-choice response. Students drew on content knowledge to explain their conclusions and stated scientific terms not given in the question. This matches with how PISA expected students to answer this assessment item:

> The question asks students to *use information provided* to *draw a conclusion* … Several pieces of information from which a student can draw a conclusion accompany this question … the *student also must draw on knowledge* that a chemical reaction is the source of the bubbles of gas and that the reaction is drawing, in part, on the chemicals in the marble chip. (OECD, 2007a)

PISA states that in order to correctly answer the assessment item the students should know that a chemical reaction has taken place. However, most of the student answers in this study (all those at level 1) did not attribute the bubbles of gas to a chemical reaction and yet answered the question correctly.

In this study, the PISA assessment item was valid in the sense that it assessed in practice what PISA claimed it assessed.

However, the competency and knowledge assessed in this assessment item lends itself more to pen and paper assessments than the more practical competency, *evaluate and design scientific inquiry*, or the knowledge types procedural and epistemic knowledge. There is no evidence, therefore, of the assessment of these competencies in this study.

(ii) Level of scientific literacy

The percentage of undergraduate science students who answered this question correctly was higher than the percentage of 15-year-old students who answered correctly in PISA 2006 (OECD, 2006). This is unsurprising as the students in this study are older and have completed a higher level of education than PISA's intended recipients. They are also more invested in science in terms of their education and career, having chosen to study science to university level, and may be considering a career in science.

The PISA assessment item was simple multiple choice, so all students who answered this question correctly would have achieved this assessment item. However, in this study, the question was changed to include a constructed response element, allowing the students to elaborate the reasoning behind their multiple-choice answer. Analysis of these explanations evidenced a range of levels of performance.

Despite the high number of correct answers, most students in this study displayed the lowest level of scientific literacy. PISA asserts that regardless of the level of scientific literacy of the student, they can use the competencies and knowledge types. This was supported in this study, all correct answers used Competency 3, *interpret data and evidence scientifically*, and content knowledge to some extent.

In this study, answers that demonstrated a low level of scientific literacy correctly identified simple consequences of the situation and direct causes of decrease in mass: "vinegar corrodes away the marble…less marble… less mass" (student 9). Whereas those performing at a high level of scientific literacy identified a range of factors that led to the decrease in mass: "acid… reacts with calcium carbonate… produces a different product…mass of the marble chip will decrease due to being reacted" (student 2). This tallies with PISA's assertion that those performing at a low level of scientific literacy are able to only partially explain simple causal relationships while those working at a high level can explain multi-step causal relationships in scientific contexts (OECD, 2013 p48-49).

While most students performed at a low level of scientific literacy, this seems unlikely to represent their true level of scientific literacy. Indeed, it would be senseless to claim that the individual who answered the question incorrectly is scientifically illiterate based on a single assessment item. A more accurate measure of scientific literacy may be achieved if a wider range of competencies and knowledge types were assessed or the test was taken in a different format (e.g. practical assessment). This study indicates that scientific literacy, at least some competencies and knowledge types may be assessed in summative, written examinations. Additionally, if students are given the opportunity to explain their reasoning it is possible to gain some measure of the level of scientific literacy.

3.2 Assessment of scientific literacy in curricular exams of Scotland and Ireland

Scotland and Ireland recently introduced a revised secondary school science curriculum that aimed to develop and assess scientific literacy in students and specifically referred to performance in PISA as a key driving force behind these curricular reforms (NCCA, 2015, NCCA, 2013, Education Scotland, 2010). The Scottish National 5 CfE science courses are lower-senior phase secondary school courses, usually taken by students in their 4th year of secondary school but this is flexible. and were first assessed in 2014. Their predecessors were the Standard Grade science courses. The Irish Junior Cycle science specification replaces the previous Irish Junior Certificate science course. Students study the Junior Cycle in years one to three of secondary school and students will take the first exams in 2019, in their third year of secondary school.

Alignment refers to the match between assessment and curricular aims so in the case of the Scottish and Irish curricula, the aim to develop scientific literacy should be reflected in the assessment.

This study scrutinises the summative, written exams of the Scottish and Irish curricula to explore the assessment of scientific literacy, using the PISA definition (Table 1-1 and Table 1-2). The study will compare the assessment of PISA's competencies and knowledge types in the exams from the "old" and "new" curricula of Scotland and Ireland (see Table 3-3 for the "old" and "new" courses compared) and asks:

1. Which PISA competencies and knowledge types are assessed in the summative, written examinations of the Scottish curriculum?
2. Which PISA competencies and knowledge types are assessed in the summative, written examinations of the Irish curriculum?

3.2.1 Methodology

This study employed a qualitative methodology using content analysis of secondary documentation.

The analysis process was carried out over three phases. Phase one aimed to familiarise the researcher with the analysis process and build a detailed codebook. In phase two, content analysis was carried out on assessment items from the Scottish and Irish curricula. Phase three was used to estimate intercoder agreement (Creswell & Plano Clark, 2011). Phases one and three aimed to increase the validity and reliability of the analysis and findings, while phase two was the main content analysis coding stage. The three phases will be described in detail in the following paragraphs: phase one (i), phase two (ii) and phase three (iii).

(i) Phase one: Creating a codebook and familiarisation with coding

Phase one aimed to familiarise the researcher with the content analysis process and the PISA sub-competencies and knowledge types, and create a detailed codebook that could be used in phase two. Content analysis was carried out on PISA assessment items by categorising the questions according to the 15 sub-competencies and three knowledge types of PISA. These assessment items were categorised "blindly" by the researcher, i.e. without knowing which competencies and knowledge types the questions aimed to asses then the researcher's coding decisions were checked against PISA. If the coding decisions of the researcher matched those of PISA no further action was needed. If the coding decisions of the researcher disagreed with PISA, the assessment item was re-examined. This process is shown in Figure 3-2.

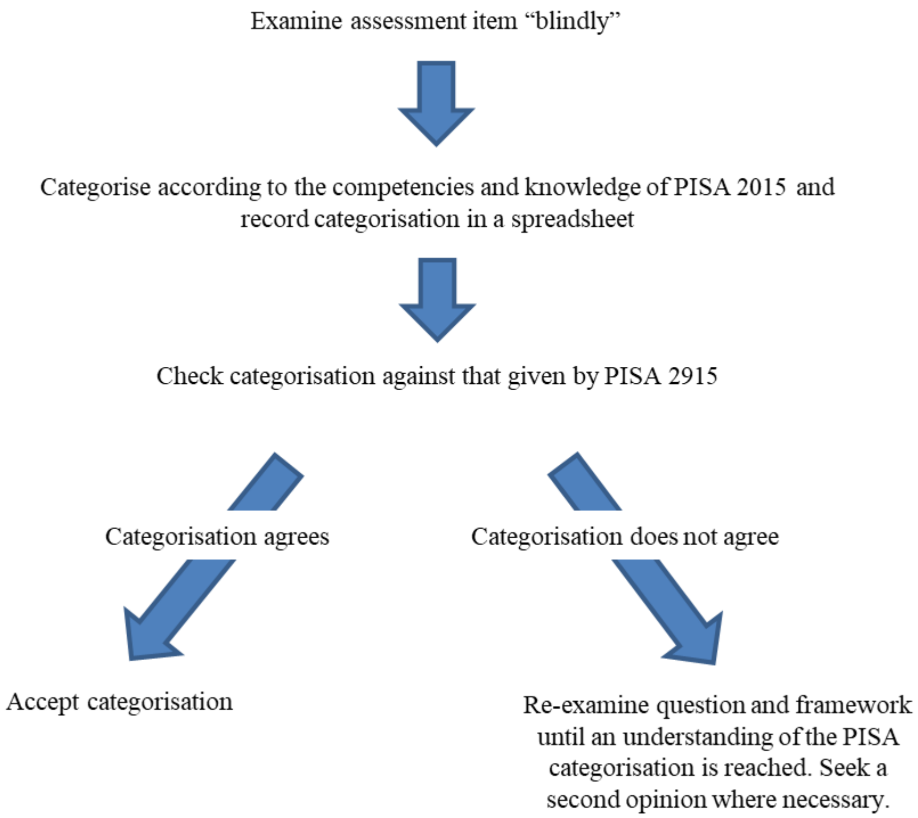


Figure 3-2 PISA content analysis familiarisation and building a codebook (phase one)

This phase was used to increase the validity by ensuring that the researcher's coding matched that of PISA. The creation of the codebook increased reliability. The codebook could be used by the researcher to ensure decisions were consistent throughout the coding process and given to other researchers to ensure consistent coding. The codebook can be seen in Appendix C.

There were some challenges faced during this initial coding exercise. PISA gave the overall competency assessed by each sample item rather than the sub-competency (A-E). Decisions regarding the allocation of sub-competencies were made by the researcher. Secondly, for items from PISA 2000 and PISA 2006, the framework differed slightly from that of PISA 2015 and decisions were made by the researcher regarding their 2015 equivalents.

(ii) Phase two: Content analysis of Irish and Scottish Assessment Items

In phase two, assessment items from the Irish and Scottish curricular exams were coded according to the 15 PISA sub-competencies and three knowledge types, using the codebook generated in phase one. Content analysis as used in this study was described in Section 2.2.1.

Table 3-3 shows the assessment items analysed, which were sourced from the past (and exemplar) exam papers of the Scottish and Irish secondary school curricula. Exam papers related to the "old" and "new" courses of each country as shown in Table 3-3. Two full exam papers were coded for each course with the exception of the "new" Irish Junior Cycle science specification where only seven questions, two from each science discipline and one nature of science, were published.

Table 3-3 Curricular assessments analysed

Context		Assessment items analysed
PISA		PISA 2015 Draft Science Framework and PISA 2000 and 2006 (OECD, 2013b, OECD 2000/2006).
Scotland	"old" – Standard Grade	2012 and 2013 Standard Grade past paper, Credit level, in biology, chemistry and physics from the SQA (SQA undated)
	"new" – National 5	National 5 Specimen Question Paper and 2014 paper from the Scottish Qualifications Authority (SQA) for biology, chemistry and physics (SQA undated)
Ireland	"old" – Junior Certificate	2014 and 2013 Junior Certificate Examinations, Science- Higher level, from the State Examinations Commission (SEC undated) -
	"new" – Junior Cycle	The sample questions provided in the NCCA's Draft Specification for Junior Cycle Science (NCCA 2014 p75-91)

To increase the validity and reliability of the categorisations, the codebook (Appendix C) and the full PISA 2015 Science Framework (OECD, 2013) were referred to often, including the sample questions, tables of competencies, and the detailed descriptions of the table contents.

Most assessment items assessed a combination of different competencies while in this study only one sub-competency (e.g. 1A only) was chosen for each question. The researcher used their judgement as to which single sub-competency or knowledge type was assessed most and advice of other researchers and academic supervisors was sought where necessary.

(iii) Phase three: Estimating reliability through intercoder agreement

This phase aimed to provide a measure of the reliability of the coding decisions made in phase two through calculating intercoder agreement (inter-rater reliability) (Creswell & Plano Clark, 2011). Two other researchers, a physics teacher (P1) and a chemistry teacher (C1), used the codebook produced in phase one to code nine assessment items. Due to limited length, only a sample of competencies and knowledge types could be included. These coding decisions were compared to the original categorisations of the researcher to give an estimate of inter-rater reliability. Cohen's Kappa was calculated to assess the reliability of coding between the researcher and two other coders. Kappa result should be interpreted as follows:

- ≤ 0 as indicating no agreement
- 0.01–0.20 as none to slight,
- 0.21–0.40 as fair,
- 0.41– 0.60 as moderate,
- 0.61–0.80 as substantial
- 0.81– 1.00 as almost perfect agreement (McHugh, 2012).

For the 15 sub-competencies the Kappa value between the main researcher and C1 was .250 (fair) and between P1 the Kappa value was .357 (fair). The Kappa value for coders one and two was .526 (moderate). For the three knowledge types the Kappa value between the main researcher and coder one (C1) was .609 (substantial) and between P1 the Kappa value was .609 (substantial). The value between coders one and two was 1.00, indicating 100% agreement in coding. Intercoder agreement for the 15 sub-competencies is therefore considered "fair" and for the three knowledge types is considered "substantial". This means that there was a substantial level of reliability when coding for the three knowledge types but the level of reliability for coding the 15 sub-competencies was slightly lower. This is unsurprising considering that there are more sub-competencies than knowledge types. The coding in this study was considered acceptably reliable based on the rigorous methods and "fair" to "substantial" level of intercoder agreement. A point of note is that intercoder agreement was slightly higher between the two teachers than the researcher and the teachers. It is possible that the two teachers who were less familiar with the PISA competencies and knowledge types had more similarities in coding due to some misinterpretations. However, because the researcher is more familiar with the PISA Framework, the researcher's categorisations were considered to have higher validity than those of the teachers.

3.2.2 Findings

This section presents the findings from content analysis of the Scottish and Irish curricular exams (phase two). Firstly, the sub-competencies and knowledge types from the “old” and “new” Scottish biology, chemistry and physics courses are presented. Secondly, the findings from content analysis of the Irish exams are presented in terms of the sub-competencies and knowledge types assessed. A reminder of the sub-competencies and knowledge types can be found in Table 1-1 and Table 1-2. The following paragraphs present: the sub-competencies (i) and the knowledge types assessed (ii) in the Scottish exams, and the sub-competencies (iii) and the knowledge types assessed (iv) in the Irish exams.

(i) Sub-competencies assessed in the Scottish curricular exams

Figure 3-3 to Figure 3-5 show the sub-competencies assesses in the "old" and "new" Scottish biology, chemistry and physics courses.

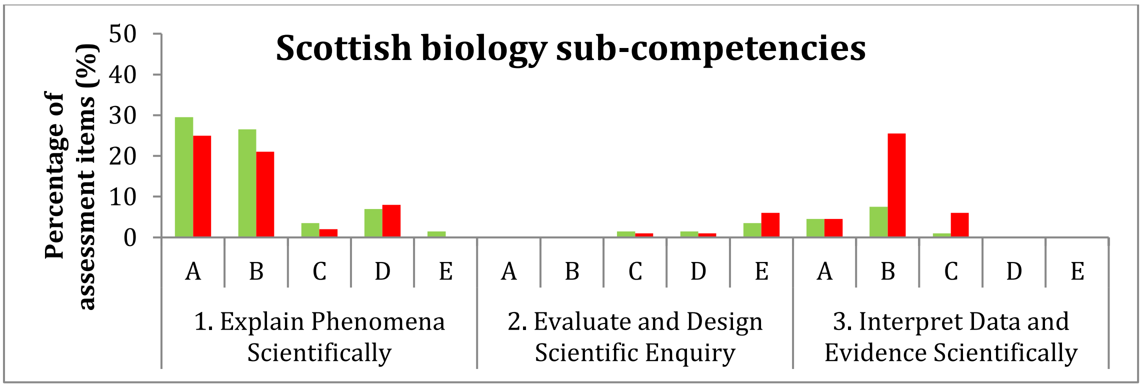


Figure 3-3 Sub-competencies types assessed in Scottish biology assessment items ("new" = green, "old" = red)

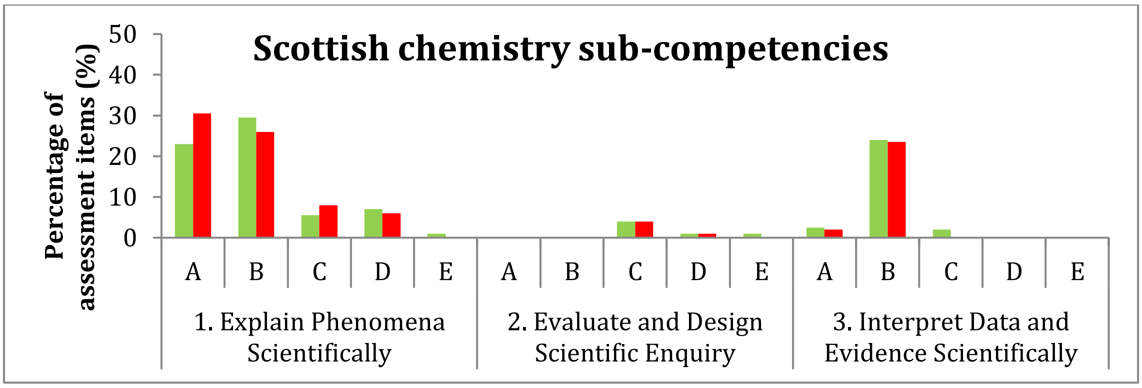


Figure 3-4 Sub-competencies assessed in Scottish chemistry assessment items ("new" = green, "old" = red)

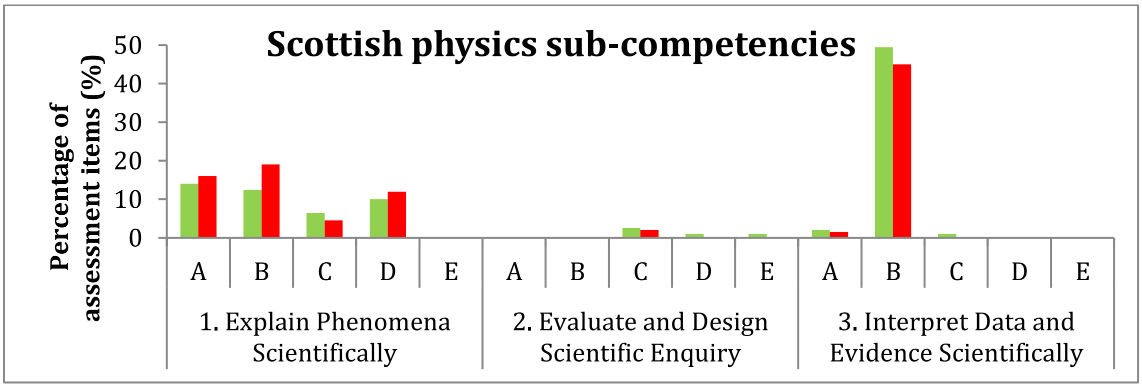


Figure 3-5 Sub-competencies assessed in Scottish physics assessment items ("new" = green, "old" = red)

The sub-competencies assessed most in both “new” and “old” biology assessment items are 1A and 1B (Figure 3-3). Sub-competency 3B is frequently assessed in “old” assessment items but not in “new”. All the sub-categories, A-E, of Competency 1 *explain phenomena scientifically* are assessed but some sub-competencies of Competency 2, *evaluate and design scientific inquiry*, and Competency 3, *interpret data and evidence scientifically*, are not assessed. 1E is present in “new” assessment items and absent from “old” (Figure 3-3).

The Figure 3-4 shows the which of the sub-competencies and knowledge types are assessed in the “old” and “new” Scottish chemistry courses. Sub-competencies 1A, 1B and 3B are all frequently assessed in the “old” and “new” Scottish chemistry assessments. Some sub-competencies are assessed in the new exams but not the old. These are 1E, 2E and 3C.

The Figure 3-5 shows the sub-competencies assessed in the Scottish physics assessment items. The most commonly assessed sub-competency in the “new” and “old” Scottish physics assessments is 3B. Sub-competencies assessed in the “new” assessment items and absent from “old” assessments are: 2D, 2E and 3C.

The following sub-competencies are not assessed in either “new” or “old” assessment items in any of the Scottish science subjects: 2A, 2B, 3D and 3E.

(ii) Knowledge types assessed in the Scottish curricular exams

The Scottish examination questions were also analysed according to the three knowledge types of PISA and the findings are shown in Figure 3-6 to Figure 3-8.

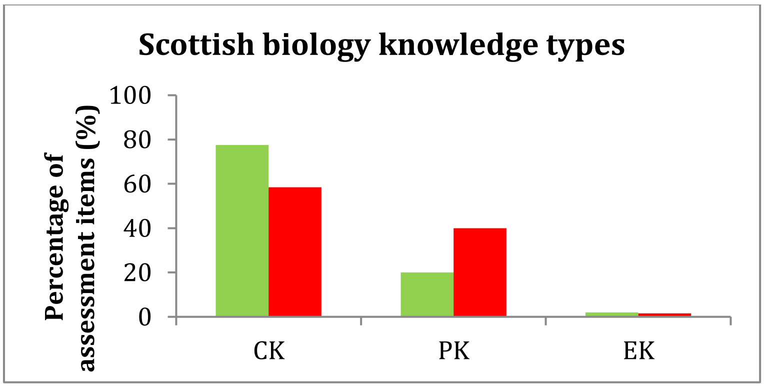


Figure 3-6 Knowledge types assessed in Scottish biology assessment items ("new" = green, "old" = red)

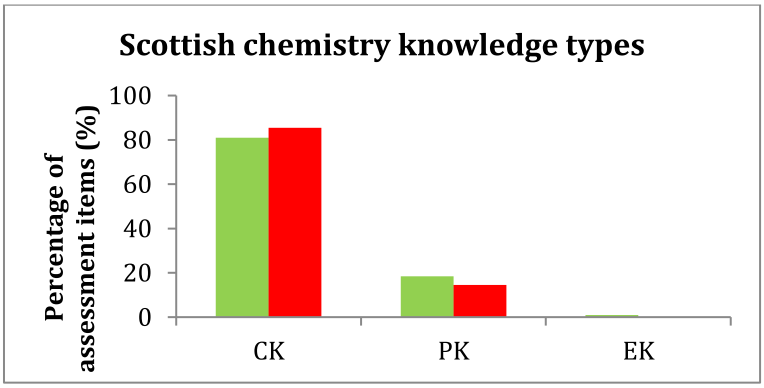


Figure 3-7 Knowledge types assessed in the Scottish chemistry assessment items ("new" = green, "old" = red)

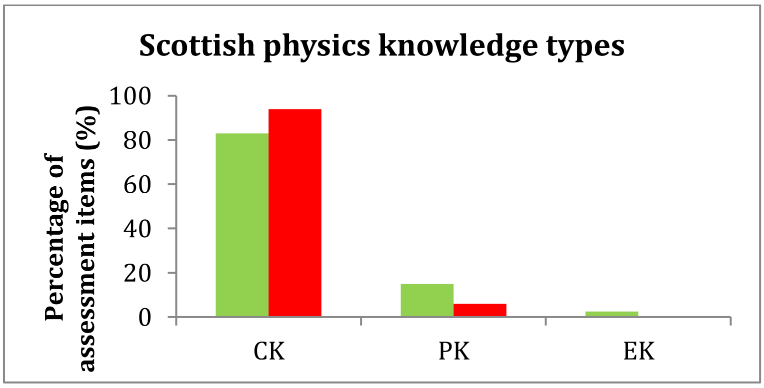


Figure 3-8 Knowledge types assessed in the Scottish physics assessment items ("new" = green, "old" = red)

The “new” and “old” biology assessment items mainly assessed content knowledge (CK). Procedural knowledge (PK) is assessed in less than half of questions and epistemic knowledge (EK) is assessed in a very small proportion of questions in both the “new” and “old” Scottish biology courses (Figure 3-6).

Content knowledge (CK) is the most assessed knowledge type in both “new” and “old” Scottish chemistry assessments. Procedural knowledge is assessed in around one fifth of questions and epistemic knowledge (EK) is assessed in a very small proportion of questions in the “new” assessments and not assessed in “old” assessments (Figure 3-7).

In the “new” and “old” Scottish physics assessments, the most commonly assessed knowledge type is content knowledge (CK). Procedural knowledge (PK) is assessed in a small proportion of assessments and slightly more in the “new” assessments. Epistemic knowledge (EK) is assessed in a small proportion of questions in the “new” assessments only (Figure 3-8).

(iii) Sub-competencies assessed in the Irish curricular exams

The analysis of Irish assessment according to the 15 PISA sub-competencies of scientific literacy are presented in this section. Figure 3-9 to Figure 3-11 show the sub-competencies assessed in the Irish Junior Cycle science exams.

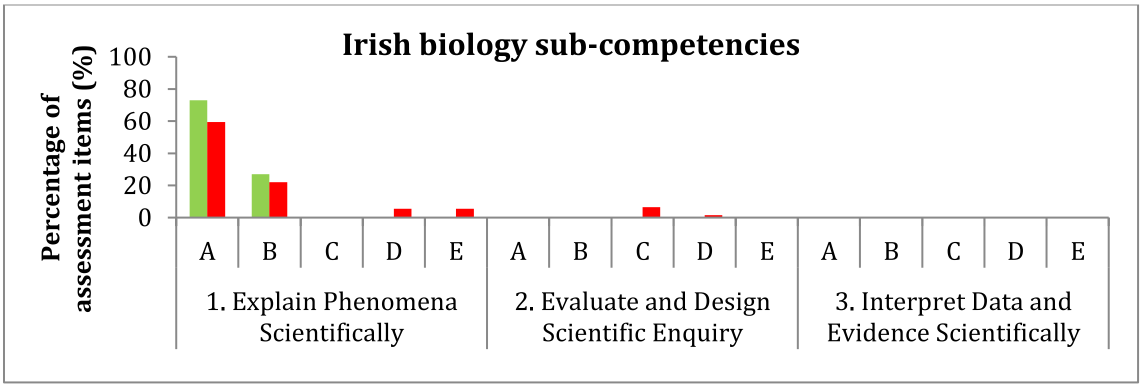


Figure 3-9 Sub-competencies assessed in Irish biology assessment items ("new" = green, "old" = red)

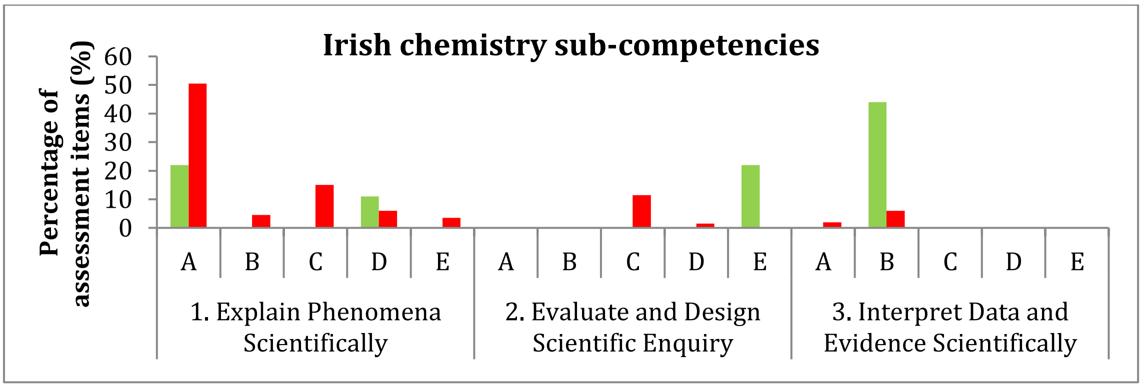


Figure 3-10 Sub-competencies assessed in Irish chemistry assessment items ("new" = green, "old" = red)

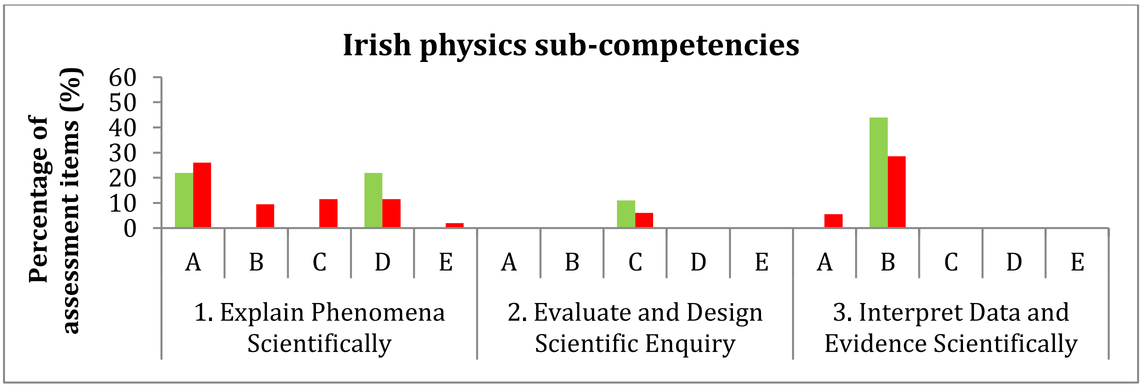


Figure 3-11 Sub-competencies assessed in Irish physics assessment items ("new" = green, "old" = red)

The Irish Junior Cycle science specification assesses all three science subjects in one exam, which were analysed separately in this study. Only seven questions were available for the “new” Junior Cycle, compared to two full exam papers for the “old” Junior Cycle. Comparisons between the “new” and “old” curricula therefore cannot be made to the same extent as the Scottish assessments.

The most commonly assessed sub-competency in the “new” and “old” Irish biology assessments is 1A, followed by 1B. These two sub-competencies are the only sub-competencies assessed by the “new” Irish assessment items. None of the sub-competencies of Competency 3 *interpret data and evidence scientifically*, are assessed in either “old” or “new” (Figure 3-9)

The most frequently assessed sub-competency in the “new” Irish chemistry assessment is 3B. In the “old” Irish assessment items it is sub-competency is 1A. Sub-competencies 2A, 2B, 3C, 3D and 3E are not assessed in the “new” or “old” chemistry curricular exams (Figure 3-10).

The most commonly assessed sub-competency in the “new” and “old” Irish physics exam questions is 3B, followed by sub-competency 1A. Sub-competencies 2A, 2B, 2D, 2E, 3C, 3D and 3E are not assessed in either the “new” or “old” physics curricular exams (Figure 3-11).

One question from the “new” Irish curricular exam aimed to assess NOS. This question assessed 3 sub-competencies equally: 2C, 3D and 3E.

(iv) Knowledge types assessed in the Irish curricular exams

The Irish assessments were also categorised according to the three knowledge types of PISA. The results are shown in Figure 3-12 to Figure 3-14.

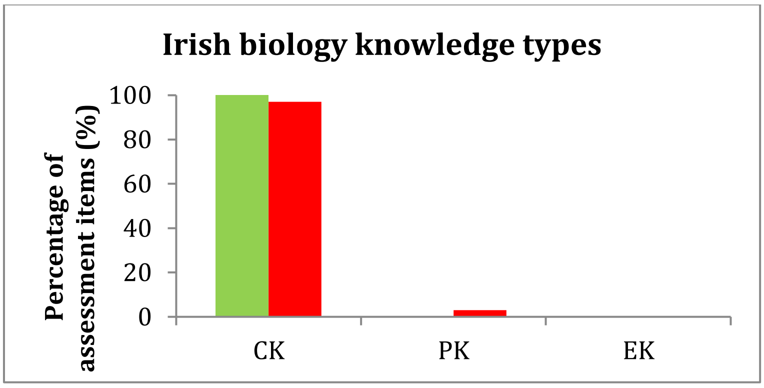


Figure 3-12 Knowledge types assessed in the Irish biology assessment items ("new" = green, "old" = red)

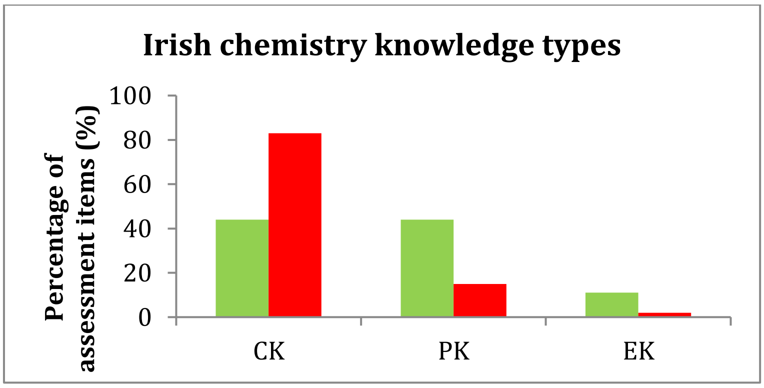


Figure 3-13 Knowledge types assessed in the Irish chemistry assessment items ("new" = green, "old" = red)

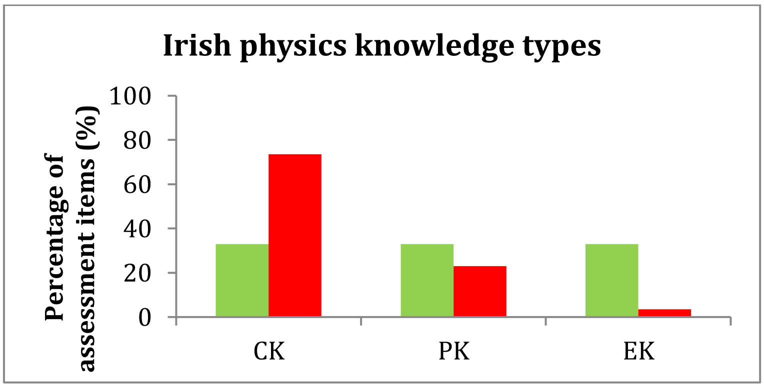


Figure 3-14 Knowledge types assessed in the Irish physics assessment items ("new" = green, "old" = red)

The most commonly assessed knowledge type in the “new” and “old” Irish biology exams was content knowledge (CK). Procedural knowledge was assessed in a small proportion of the “new” assessment items and epistemic knowledge (EK) was not assessed (Figure 3-12).

The “new” Irish chemistry assessment items assessed both content knowledge (CK) and procedural knowledge (PK) equally and Epistemic knowledge to a lesser extent. The “old” Irish chemistry assessment items assessed mainly content knowledge (CK), followed by procedural knowledge (PK) and epistemic knowledge (EK) least (Figure 3-13).

The “new” Irish physics assessment items assessed content knowledge (CK), procedural knowledge (PK) and Epistemic knowledge (EK) equally. The “old” Irish physics assessment items assess mainly content knowledge (CK) and epistemic knowledge (EK) least (Figure 3-14).

The “new” Irish curricular exam question that aims to assess NOS, assessed epistemic knowledge (EK) the most and procedural knowledge (PK) second. Content knowledge (CK) was not assessed.

3.2.3 Discussion

The “new” Scottish CfE National 5 biology, chemistry and physics courses and “new” Irish Junior Cycle science specification aim to develop and assess scientific literacy in students (NCCA, 2015, Education Scotland, 2010). This study explores whether this aim is reflected in assessment.

Comparisons between the “new” and “old” science courses can be made in terms of the number and range of sub-competencies and knowledge types of scientific literacy assessed. Comparisons can also be made in terms of the balance of the assessment. Webb (1997) describes the importance of balance in assessment and recommends that a conscious decision is made in terms of emphasis on different topics. When PISA describes the competencies and knowledge it gives each the same emphasis and so it can be assumed that each is considered equally important in the development and assessment of scientific literacy (OECD, 2013). This would be represented as a balanced coverage of the competencies and knowledge types in assessment.

In this study this was not found to be the case. This study found that some sub-competencies and knowledge types were frequently assessed in the summative, written exams of Scotland and Ireland, while some sub-competencies and knowledge types were infrequently assessed or not assessed at all.

This section will discuss the findings relating to the assessment of scientific literacy in the summative, exams of Scotland (i) and then discuss the findings from Ireland (ii). Comparisons will be made between “old” and “new” courses to look for evidence of increased assessment of scientific literacy in the “new” courses and the balance of the assessments will also be discussed.

(i) PISA competencies and knowledge types assessed in the summative, written exams of the Scottish curricula

The “new” biology, chemistry and physics courses assessed a wider range of sub-competencies compared to the “old” courses. Additionally, the “new” exams assessed all three knowledge types whereas epistemic knowledge was previously absent from chemistry and physics. This indicates that the Scottish curriculum is making steps towards increased assessment of scientific literacy in summative, written exams. Despite this progress, there was evidence of imbalance in the assessment; some sub-competencies were overrepresented while others were absent from all exams.

Competency 1 *explain phenomena scientifically* was over-represented, in terms of the sub-competencies assessed, compared to the other two competencies, while Competency 2, *evaluate and design scientific inquiry*, was under-represented. Most sub-competencies from competency 3 were under-represented but 3B was over-represented. In the Scottish curriculum the following sub-competencies were not assessed in either the “old” or “new” exams: 2A, 2B, 3D and 3E. These sub-competencies relate to scientific inquiry, particularly secondary research based inquiry. They centre around proposing questions for investigation and critical evaluation of evidence.

In terms of knowledge assessed, the exams focussed overly on content knowledge, less so on procedural knowledge and very little on epistemic knowledge. Again, the underassessed components relate to knowledge used in scientific inquiry.

Overall, this indicates a focus on scientific explanations, data analysis and recall and application of scientific knowledge over experimental and secondary research based scientific inquiry.

(ii) PISA competencies and knowledge types assessed in the summative, written exams of the Irish curricula

In Ireland, the range of sub-competencies assessed in the “old” science assessments was wider than in the “new” assessments. However, this is more likely to be due to the fewer number of available assessment items for the “new” curriculum, giving a smaller sample, rather than genuine differences. The “new” assessment items, despite being fewer, assessed a wider range of knowledge types. This indicates progress in terms of the balance of assessment of knowledge of scientific literacy, with a shift away from exams that focus overly on recall of content knowledge, towards the inclusion of assessment of procedural and epistemic knowledge.

However, there was evidence of imbalance in the assessment with some sub-competencies overrepresented and others not assessed. The sub-competencies 1A and 3B were more frequently assessed than other sub-competencies. 2A, 2B and 3C were absent from the Irish assessments. The "new" Irish assessment item that aims to assess NOS stood out because it focussed on proposing methods of inquiry and critical evaluation of evidence, using procedural and epistemic knowledge. These aspects were underassessed elsewhere. However, there remains a disproportionate focus on recall and application of scientific knowledge and data analysis over experimental and secondary research based scientific inquiry.

It is important to conclude this section by acknowledging that assessment in Scotland and Ireland does not solely rely on a summative, written exam. The "new" curricula include assessments of inquiry in the context of SSI, the Scottish National 5 Assignment and the Irish Science in Society Investigation. These assessments aim to assess a range of inquiry skills and knowledge and it is likely that they will assess different sub-competencies and knowledge types than those identified in the summative exams. This is the focus of Chapter 4.

3.3 Chapter conclusions and implications

This chapter presented two studies that explored the assessment of scientific literacy in summative, written assessments. Overall the studies showed that scientific literacy can be assessed using summative, written assessments. Additionally, the first study showed that if students are given the opportunity to explain their reasoning then it is also possible to determine the level scientific literacy demonstrated. This study also provided validity to PISA's framework and assessment. The assessment item did assess what PISA purported it to assess. However, the first study was based on a single assessment item and this assessment item assessed students' ability to identify evidence in text (3C) and analyse and interpret this evidence or data to draw conclusions (3B), using content knowledge. This didn't provide any evidence of assessment of a wider range of sub-competencies or knowledge types, particularly those associated with scientific inquiry.

The second study explored the assessment of scientific literacy in the "new" curricula of Scotland and Ireland. These curricula aim to assess scientific literacy and so the assessment items were analysed for evidence of this. In this study there was evidence of assessment of a range of sub-competencies and knowledge types of PISA. There was also evidence of increased assessment of scientific literacy in the "new" curricula of both countries. However, some sub-competencies and knowledge types were assessed frequently while others were assessed infrequently or absent altogether. The skills assessed in the summative, written assessment items in this study tended to focus on recall and application of scientific knowledge and interpretation of data, using scientific content knowledge. There was little evidence of the assessment of inquiry skills such as proposing investigatable questions and ways of exploring a scientific question, or skills associated with secondary research including critical evaluation of evidence.

The curricular assessment of Scotland and Ireland includes other forms of assessment that may assess a different range of skills and knowledge from the assessments explored in this chapter. For example. the Scottish National 5 Assignment and the Irish Junior Cycle Science in Society Investigation aim to assess skills and knowledge of inquiry in the context of SSI. The rest of this thesis is focussed on assessment of scientific literacy through inquiry in the context of SSI and how the skills and knowledge of scientific literacy can be developed and assessed using this approach. Chapter 4 will present two studies exploring the development and assessment of scientific literacy through inquiry in the context of SSI in the Scottish and Irish curricula.

The studies presented in Chapter 3 used the PISA sub-competencies and knowledge types as a convenient description of scientific literacy. The studies presented in later chapters continue to use the PISA description (Table 1-1 and Table 1-2) but do not limit themselves to this definition. Scientific literacy is considered to be the range of skills and knowledge that an individual has developed that allow them to participate in and receive enrichment from society (Figure 1-2). The studies described in Chapters 4 and 5 contribute towards a greater understanding of the skills and knowledge that contribute to scientific literacy.

4 Teacher and student experience of inquiry in the context of SSI in the Scottish and Irish curricula

This chapter explores the development and assessment of scientific literacy in secondary schools with a focus on approaches that use inquiry in the context of SSI. In Scotland and Ireland, the secondary school curricula include assessments of inquiry in the context of SSI. This chapter presents three case studies that explore the teacher and student experience of carrying out inquiry in the context of SSI. Holistically, the chapter explores how teachers interpret curriculum documentation (that aims to develop and assess scientific literacy) and use it to shape their classroom practice with secondary school students.

Section 4.1 presents a case study of inquiry in the context of SSI in the Scottish CfE. Since 2014, the Scottish CfE National 5 science courses have assessed the skills and knowledge of inquiry in the context of SSI through the National 5 Assignment. The case study presented in this section follows a science department in one Scottish school, named Thistle Wood School, as they carry out the National 5 Assignment with biology, chemistry and physics classes. Students carried out an experimental and secondary research inquiry into a range of topics including: uses of enzymes (biology); alcohols as fuels (chemistry); spacecrafts, seat belts and X-rays (physics).

Section 4.2 presents the curricular landscape within which the case studies are set. The secondary school science curricula of Scotland and Ireland both mandate assessment of inquiry in the context of SSI and this is the thread that ties the case studies of this chapter together. While the Scottish case study followed teachers in their third year of implementation of the National 5 Assignment, at the time of writing this thesis the Irish assessment had not yet taken place. Therefore, this section presents the Scottish journey from a curriculum policy point of view, comparing this to practice in Thistle Wood School, and highlights potential lessons for Irish curriculum policy makers.

Section 4.3 presents two case studies set in the Irish curricular context: Clover Field School case study and Daisy Park School case study. In Ireland the curricular mandated assessment of inquiry in the context of SSI, the Irish Junior Cycle Science in Society Investigation, will be implemented in winter of 2018. At the time of this case study, teachers in Ireland were focussed on the development of skills and knowledge of students in years one and two of secondary school, to prepare them for the assessment in their third year. Clover Field School and Daisy Park School case studies explore the teachers' and students' experience of inquiry in the context of SSI in preparation for the Irish Junior Cycle Science in Society Investigation. The case studies follow two individual teachers, in two separate schools, and their classes. In Clover Field School, the students carried out an experimental inquiry into the preferences of woodlice, followed by a discussion around the ethics of use of animals in science and animal rights. In Daisy Park School, the students carried out a discussion and secondary research inquiry into two topics related to local traffic congestion and pollution and global climate change.

While Chapter 3 limited the definition of scientific literacy to PISA's description i.e. the three competencies and 15 sub-competencies, and three knowledge types (Table 1-1 and 1-2). Chapter 4 uses both the PISA description of scientific literacy but also aims to contribute towards a broader description of scientific literacy. This broader description states that scientific literacy encompasses a range of skills and knowledge of science, and these lead to benefits to the individual in terms of their interaction with society and benefits to society. This broader description of scientific literacy is revisited in Chapter 6.

4.1 Thistle Wood School case study

This research is a case study of the implementation of the National 5 Assignment in one Scottish school. The study explores the teacher and student experience of carrying out inquiry in the context of SSI for the National 5 Assignment and asks the following:

1. What are the teacher and student experiences of carrying out the Scottish CfE National 5 Assignment?
2. Which PISA competencies are developed and assessed in the Scottish CfE National 5 Assignment?

4.1.1 Methodology

This is a mixed methods embedded, mainly qualitative, instrumental case study. This means that the case study is "instrumental" in providing information for the broader research question: *How can the teacher and student experience of the development and assessment of scientific literacy in secondary schools inform initial science teacher education?*

It can be used alongside other instrumental case studies that all provide various information towards the overall research question, different pieces of a jigsaw so to speak. It is embedded in that it is mainly qualitative in approach but there are some quantitative data collection and analysis methods used. The case is a school, or more specifically a department within a school and the participants are the teachers. The student voice is heard through secondary documentation from the teacher. Thistle Wood School is a large, mixed gender, non-denominational school, which has been rated "excellent" in all aspects in its most recent HMIE inspection (reference omitted for anonymity). The case study was carried out over two years, with year one being the pilot study and year two being the main study.

In the pilot year, six biology teachers participated and provided secondary documentation relating to 150 students. The main study included seven teachers of biology, six chemistry and six physics teachers (total 19 teachers). These teachers provided anonymised documentation relating to their students, which included 155 biology, 136 chemistry and 111 physics students (total 402 students). The students were in their fourth year of secondary school (aged 14-16). Five of the seven biology teachers participating in the main study had participated in pilot study the previous year. A summary of the participants is shown in Table 4.1 and the data collection methods are shown in Table 4.2.

Table 4-1 Participants from Thistle Wood School

Participant Alias	Subject	Role	Participation year	Questionnaire	Group interview
Amanda	Biology	Teacher	Pilot and main	Y	Biology
Beth	Biology	Teacher	Pilot and main	Y	Biology
Charlotte	Biology	Head of dept.	Pilot and main	Y	Head of dept.
Danielle	Biology	Teacher	Pilot and main	Y	Biology
Eve	Biology	Head of dept.	Pilot and main	Y	Head of dept.
Helen	Biology	Teacher	Main	Y	Biology
Ida	Biology	Teacher	Main	N	Biology
Julie	Chemistry	Head of dept.	Main	Joint	Head of dept.
Ken	Chemistry	Teacher	Main	Joint	No
Olive	Chemistry	Teacher	Main	Joint	Chemistry
Mark	Chemistry	Teacher	Main	Joint	No
Nadia	Chemistry	Teacher	Main	Joint	Chemistry
Linda	Chemistry	Teacher	Main	Joint	No
Phil	Physics	Head of dept.	Main	Anon.	No
Richard	Physics	Teacher	Main	Anon.	Physics
Simon	Physics	Teacher	Main	Anon.	No
Tim	Physics	Teacher	Main	Anon.	Physics
Victor	Physics	Teacher	Main	Anon.	Physics
Will	Physics	Teacher	Main	Anon.	No

Table 4-2 Data collection methods used in Thistle Wood School case study

Data collection method	Pilot Study	Main Study
Observation of lessons	✓	X
Questionnaires	✓	✓
Individual interviews (with teachers)	✓	X
Focus group interviews (with teachers)	X	✓
Secondary documentation		
Departmental lesson plans/ schemes	✓	✓
Teacher quality assurance documents: minutes from meetings, lesson evaluation (teacher)	✓	✓
Student work (student)	✓	✓
Student questionnaire (student)	✓	✓
Researcher field notes (teacher and student)	✓	✓

The questionnaire was a mixed methods style questionnaire (see Appendix A). Five open response questions gathered data relating to the teacher and student experience (Q1-5 of part one of questionnaire) and questions with both closed and open-response options gathered data relating to the PISA competencies used (Q6-8 of part one and part two of questionnaire). Teachers in biology and physics submitted individual responses to the questionnaire but in chemistry the teachers conducted a focus group and submitted a single, joint response.

Interviews and focus groups were open-ended with all questions being open response (see Appendix A). Secondary documentation included a range of materials collected from the teachers and heads of department. Secondary documents relating to the students were anonymised student work and student evaluations (also in the form of a mixed methods style questionnaire see Appendix A). Other secondary documents included departmental lesson plans and schemes, teacher quality assurance materials, such as minutes of meetings and lesson evaluations, and researcher field notes.

Analysis was carried out qualitatively using thematic analysis to explore the teacher and student experience of the National 5 Assignment, using the process outlined on page 61 ((i) Thematic analysis used in this thesis). NVIVO software was used because of the large volume of data to be stored, organised, analysed and compared. The software allowed comparison of themes according to the number of coded references each sample group made to each theme and sub-theme. In this way, it could be investigated how different groups (e.g. teachers vs. students, biology vs. chemistry vs. physics) emphasise the different themes. As noted in Chapter 2, the number of references may be indicative of focus or emphasis on a particular theme but should not be used as a quantitative measure of the importance of a theme. For this reason, emphasis on themes will be discussed in general terms.

Some data was analysed quantitatively. Two parts of the questionnaire asked teachers and students to report which of PISA's competencies/sub-competencies were used when carrying out the National 5 Assignment. In the first part of the questionnaire teachers and students were asked "When carrying out the Assignment, did you give scientific explanations/evaluate and design scientific investigations/explain scientific data and information? Yes/No". In the second part of the questionnaire teachers and students were asked to tick which sub-competencies they had used. The percentage of teachers and students who responded "yes" to questions 6 to 8 of the questionnaire (Appendix A) was calculated to provide evidence of student use of the overall PISA competencies. The percentage of students who reported using sub-competencies and teachers who reported students using each sub-competency in the N5 Assignment (part two of the questionnaire) was calculated and displayed graphically.

(i) Changes to methodology as a result of the pilot study

As a result of the pilot study, there were a number of changes made to the data collection methods and materials and the analysis method was refined. The results of the pilot study were used to inform changes to the questionnaires, some questions were omitted and others were added. Observations were used in the pilot year but not in the main study. After discussion with the participants it was decided that the work involved for the participants in setting up and carrying out video observations was not worthwhile given the limited additional evidence provided. Observations in the pilot year showed that any evidence provided by the video was also provided by the teacher lesson plans and notes. Individual interviews were carried out in the pilot year whereas in the main study, group interviews were carried out. The higher number of participants in year two made it unfeasible to carry out individual interviews as this would have required the two co-operating heads of department to co-ordinate a number of full days of interviews and this was deemed unreasonable in terms of workload and time for the co-operating teachers.

4.1.2 Findings

The results of the pilot study were presented at the ESERA conference in 2017 (Chadwick, McLoughlin & Finlayson, 2017) but have been omitted here for brevity. While they informed the methods of data collection and analysis and gave the researcher insight into the teacher and student experience, the findings of the main study are more comprehensive.

This section presents findings relating to the teacher and student experience of the National 5 Assignment in biology, chemistry and physics. Results relating to student use of the competencies and sub-competencies of PISA are then presented.

Table 4-3 shows the themes from thematic analysis of all data sources. The sub-themes are displayed in order of the number of references to the sub-theme, from highest to lowest, which is an indication of their focus or emphasis by the teachers and students.

Table 4-3 Thistle Wood School themes

Theme	Sub-theme
Skills	Present and analyse data
	Explain scientifically
	Research
	Present information
	Self-management
	Plan, carry out and evaluate experiments
	Propose investigatable questions
Knowledge	Recall and apply scientific knowledge
	Implications of scientific knowledge for society
Pedagogical approach	Open inquiry
	Direct instruction
	Supervision

The codebook for thematic analysis of data gathered from Thistle Wood School case study can be found in Appendix D. This gives a description for each theme and sub-theme shown in Table 4-3.

Figure 4-1 shows the progression from initial themes to final themes using the method of analysis described in Section 2.2.3. This is shown for information and only the final themes will be discussed.

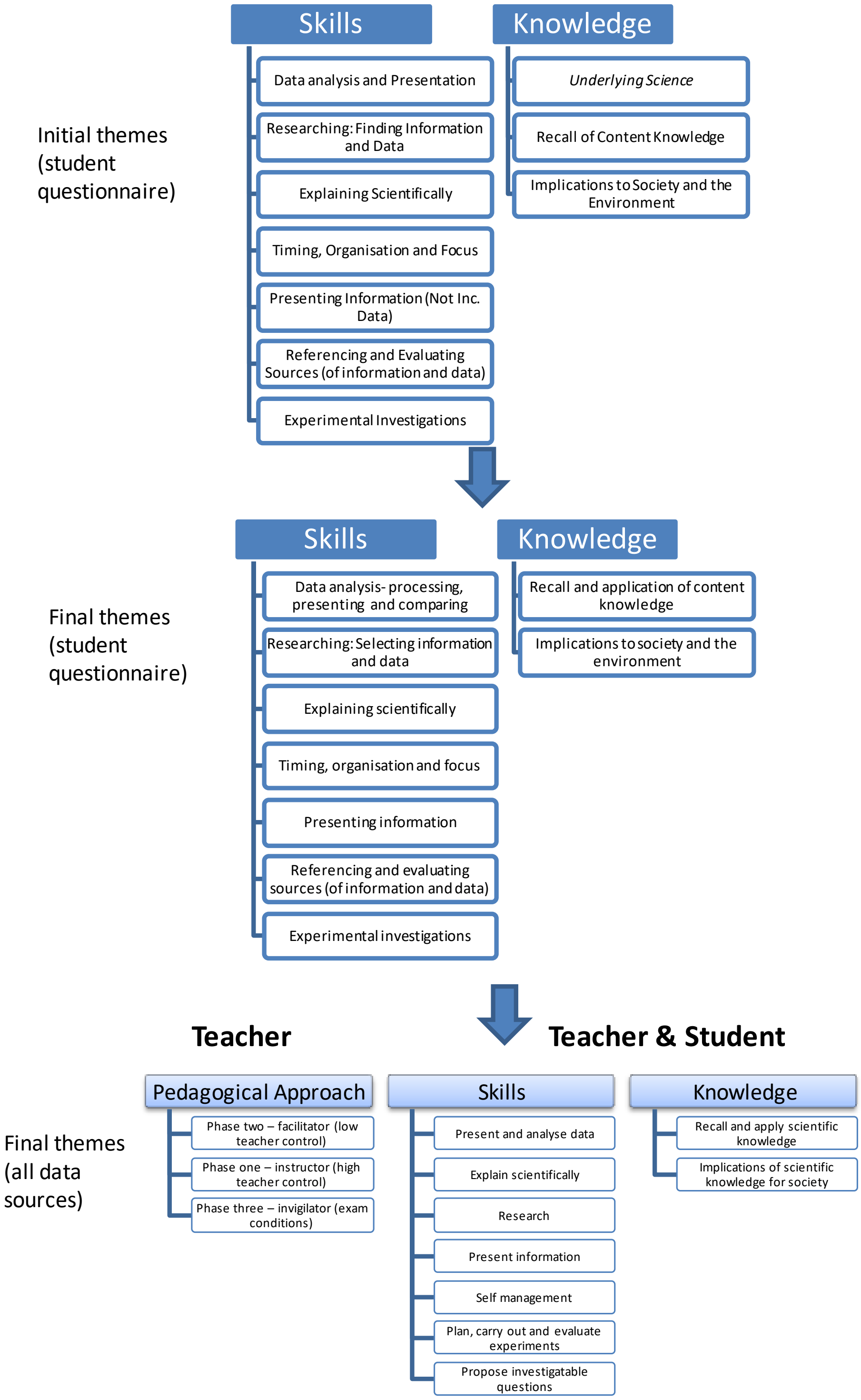


Figure 4-1 Development of themes in Thistle Wood School case study

Three overall themes were identified from thematic analysis: Skills, knowledge and pedagogical approach. The *skills* and *knowledge* themes relate to the student experience and were identified from data relating to the teacher (teacher questionnaire/ lesson plans and schemes) and student (student questionnaire/student work). The *pedagogical approach* theme relates to the teacher experience and was only identified in teacher data sources (teacher questionnaire/ lesson plans and schemes).

The following paragraphs will present each of the three themes and their associated sub-themes. Extracts from questionnaires, interviews and secondary documentation evidencing each sub-theme will be presented.

(i) Teacher experience: Pedagogical approach

This theme was evidenced from teachers' questionnaires and interviews, and document analysis of lesson plans and quality assurance documentation. The teachers' experience focussed on the *pedagogical approach* to the inquiry and was consisted of the same themes with similar emphasis in all three science subjects. The *pedagogical approach* theme consisted of three sub-themes: *open inquiry* (b), *instruction* (a) and *supervision* (c). The same three sub-themes were evident in biology, chemistry and physics. The sub-themes are discussed in the following paragraphs, not in order of emphasis but in chronological order.

(a) Stage one – Instruction

In the *instruction* stage, the teachers introduced the National 5 Assignment to the students through teacher-led instruction. The teachers made use of PowerPoints and paper-based materials ("handbook", "prep sheets", "candidate guide") to "talk them [the students] through the different sections in the Assignment" and provided a "step by step guide". In this stage, students also engaged in whole class and group discussions, to discuss questions such as "What makes a good aim?" and "What makes a good source?". Students also became familiar with the assessment criteria ("marking instructions") through "marking last year's Assignments". These exemplar Assignments were high scoring reports to "show the students this is what they are aiming for". The initial *instruction* stage lasted one to two hours.

(b) Stage two – Open inquiry

In the *open inquiry* stage, the students were given more control over their approach to the Assignment. The teachers referred to students "working independently" and "on their own". Students carried out "research" into their topic (see the *research* sub-theme for full details). In physics, students were given "a choice in what they are doing" for the topic of the Assignment. At this stage in chemistry and physics students carried out an experiment. Whereas in biology, students "were using an experiment, the enzyme experiment that they had already done", rather than carrying out an experiment. The evidence from student work suggests that all experimental investigation was structured (given method) rather than open (see Table 1-4 for a description of the levels of inquiry used in this thesis).

During the *open inquiry* stage of the Assignment the teachers acted as the facilitator. Teachers discussed how they balanced the support they gave the students with the need for the students to take responsibility: "making sure pupils understand the guidance and have an appropriate aim" (Charlotte), "not telling them what to write… you can't tell them if its right or wrong" (Beth).

The teachers also described teaching the Assignment to students of different abilities:

> [I] might steer students towards difficult topics if I felt they would cope with the challenge and would enjoy it. Other students I might steer towards topics that were straight forward (Victor).

Amanda described how the students of different ability responded to the *open inquiry* approach adopted at this stage of the Assignment.

> Some of the students in my class really rose to the challenge and enjoyed having that responsibility and they really coped well with it and got a lot of satisfaction out of it. But I do think there were others for whom it was such a challenging task that it just demotivated them and they just dropped off the radar. There were a few in the class who were really challenged by it. (Amanda)

Whereas Beth described how the "high flyers", high ability students, would get "really frustrated" with the *open inquiry* approach, which was reiterated by Ida who said "my high ability students really struggled with it and were getting really anxious with it".

(c) Stage three –Supervision

The focus of the teachers when talking about this stage of the Assignment was timing and "independent" student work, i.e. "not asking any questions". The students wrote a report of their findings under "exam conditions".

(ii) Student experience: Skills

The student experience was described by the teachers and by the students themselves. The same two themes, *skills* and *knowledge*, were identified. Teacher and students from all three subjects emphasised *skills* over *knowledge*, as determined by the number of references to each theme:

> Biology is the context, but before that there is the numeracy, literacy and health and wellbeing. These are the skills that students should be developing. (Charlotte)

The *skills* theme consisted of seven sub-themes and the *knowledge* theme consisted of two sub-themes (Table 4-3) and this was consistent across all three subjects. However, the following paragraphs highlight some differences in emphasis on the sub-themes between teachers and students from the three subjects. Sub-themes can be ranked to compare the emphasis on the different *skills* and *knowledge* (Table 4-4).

Table 4-4 Skills sub-themes by emphasis (student reported)

	Biology student	Chemistry student	Physics student	
Most important ----------------least important	Explain scientifically	Present and analyse data	Present and analyse data	Most important ----------------least important
	Present and analyse data	Explain scientifically	Research	
	Self-management	Research	Explain scientifically	
	Research	Self-management	Present information	
	Present information	Present information	Self-management	
	Propose investigatable questions	Plan, carry out and evaluate experiments	Plan, carry out and evaluate experiments	
	Plan, carry out and evaluate experiments	Propose investigatable questions	Propose investigatable questions	

Students from all three subjects (biology/chemistry/physics) emphasised the sub-themes *explain scientifically* (blue) and *present and analyse data* (red). All students focussed little on the sub-themes *plan, carry out and evaluate experiments* (grey) and *propose investigatable questions* (orange). There was varied emphasis on *research* (green). Physics students emphasised *research* relatively highly, chemistry students less so and biology students the least.

Due to a smaller number of participants, and that a single joint response was provided by chemistry teachers, the number of references to different sub-themes by teachers cannot be ranked in a meaningful way. Instead the emphasis will be discussed more generally. Biology teachers emphasised *research* the most and placed little emphasis on *self-management*, *propose investigatable questions* and *plan, carry out and evaluate experiments*. Chemistry teachers also mainly focussed on *research* and focussed little on all other sub-themes. Physics teachers emphasised *research* most highly and focussed little on *data analysis and presentation*, *explain scientifically*, *propose investigatable questions* and *self-management*.

The following paragraphs describe in detail the seven skills that were identified as forming the student experience of the National 5 Assignment and give evidence from teacher questionnaire and interviews, teacher lesson plans/ schemes and student questionnaires and student work to support the identification of each skill.

(a) Present and analyse data

> Processing the data is probably the biggest part because that's where most of the marks come from. (Charlotte).

This sub-theme contains references to presentation of raw data and analysis of gathered data, described as "processing data", and student work showing raw data and presentations of analysed data (tables and graphs). The representation of data was limited to "tables" and "graphs". Teachers described what they meant by "processing":

> Take information from a table and put it into a graph using units, labelling, scales (Nadia),

> If you've got a set of data here what units is it in? Their scale has to be good and their data points have to be plotted precisely (Tim).

However, some teachers pointed out that this skill could be done with little or no understanding of the data itself or use of scientific knowledge, and simply performed through procedural knowledge of the processes: "they [the students] could process the data without having to understand it" (Helen), "processing data, that's not biology, that's numeracy" (Charlotte).

There was evidence in all samples of student work, from all subjects, of this skill. Below is a typical example taken from a biology report. Firstly, the student presented their experimental data as a table and then processed it into a graph.

Temperature (°C)	Height of foam produced (mm)
0	0
20	10
37	42
80	0

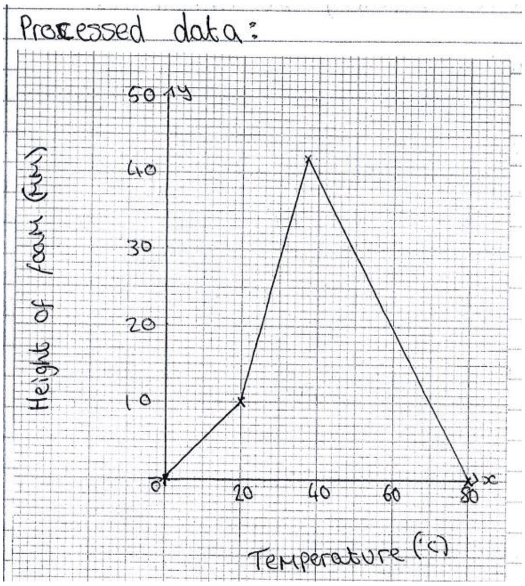


Figure 4-2 Student work showing data presentation and analysis (table of results) (biology student work sample one)

Student work showing this sub-theme also included students' calculations in chemistry and physics but not in biology.

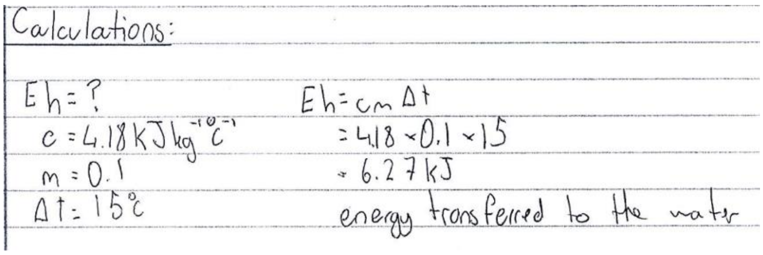


Figure 4-3 Student work showing data presentation and analysis (calculations) in chemistry (chemistry student work sample one)

(b) Explain scientifically

This sub-theme is characterised by students using their scientific knowledge to explain the science underlying their inquiry. The teachers described students "drawing conclusions". However, Danielle went further and described:

> …being able to read something that might be quite complex and put it into their own words. They know they’re not allowed to plagiarise anything so turning that into something that is going to make sense to them. (Danielle)

Students described their scientific explanations as “drawing a conclusion” that “linked back to the aim”, “writing my background information in my own words”, explaining in “detail” or giving “enough detail”. Students also described using a “diagram” to aid their explanations.

Student work relating to this theme included: students’ explanations of the “application of biology/chemistry/physics” and the “effect on the environment/society”, the “underlying biology/chemistry/physics” and conclusions. However, the aim or references to forming an aim would be coded into *propose investigatable questions* rather than *explain scientifically*. Examples of student work showing each of these is shown below. The first quote shown is from a chemistry student, describing the application of use of alcohol as a fuel and describing the effect on the environment.

> Application: Alcohols are used as fuels in vehicles due to their flammability.
>
> Effect on the environment/society: Ethanol, the alcohol used in cars, is more beneficial for the environment. It is better because the cars that use ethanol as fuel produce less Carbon monoxide and Carbon dioxide. Ethanol is also cheaper therefore most people want to use it. (chemistry student work sample four)

Most of the students’ work showing underlying biology described the science behind the chosen topic of inquiry and students tended not to evaluate by making a judgement, or discuss by including a range of arguments for and against the topic:

> A homologous series is a group of hydrocarbons with similar chemical properties and the same general formula. Alcohol is a member of a homologous series... Combustion is when we burn alcohols to produce energy. Fermentation is the breaking down of glucose to form ethanol and Carbon dioxide. (chemistry student work sample four)

Towards the end of their reports, the students stated a conclusion. This aimed to address the aim stated at the beginning of the report. Chemistry student four’s conclusion is given below, in which they use scientific explanations to attempt to answer their research question or aim. The student’s aim was descriptive and so their conclusion gave a scientific description rather than a discussion.

> Aim: Whether the length of a Carbon chain in an alcohol has an effect on the amount of energy released when burned…
>
> Conclusion: As I have found from my investigation, the length of the carbon chain affects the amount of energy released. As the Carbon chain length increases so does the energy released. (chemistry student work sample four)

(c) Research

This sub-theme included student and teacher references to carrying out "research", "selecting sources" of information and data, and choosing evidence and data from the selected sources: "I learned how to research efficiently when I was looking for evidence" (student questionnaire). The teachers talked about what was expected of the students when researching. Nadia described research:

> being able to access the internet... or books, not just the internet. There's a big range of material out there that they can go and find. (Nadia)

Olive described the challenges associated with carrying out research:

> They struggled with finding appropriate sources. If they were doing a topic about alcohols being used as fuels they might find a table about the uses of alcohols but it wasn't something that they could link back to their first source. If they were looking for a second source it either needed to back up or go completely against their first source. (Olive)

Students evaluated their sources of information in terms of relevance to their topic and reliability. Olive's explanation above relates to the relevance of the source to the student's topic of investigation. Relevance was described in terms of how closely the information related to the students' question for investigation: "[this source] is relevant because it shows that enzymes work best at lower temperatures" (biology student work sample one), "… shows the amount of carbon atoms and the energy produced which is the aim of this investigation" (chemistry student work sample four), "… shows the amount of new cases of cancer each year" (physics student work sample three).

The reliability of the source as described by the teachers and students related to the author and publisher of the material. Students referred to "trusted source(s)" (e.g. "BBC") and stated that they would trust a source written by "scientists". Students described why their source of evidence was reliable and relevant:

> This reference is reliable because it is from a Northern Ireland government website (ni.gov.uk) the ending of the link which is in brackets shows this. The link is relevant to this because it shows the number of people who wear seat belts (physics student work sample two).

In biology and chemistry, compared to physics, the range of sources of evidence used was narrower. Students used sources such as SQA past papers and BBC bitesize that were specifically aimed at school students. This meant the scope for evaluation of sources was also narrower and students explanations were simpler: "This source is taken from an SQA past paper and is therefore reliable" (biology student work sample three). This may indicate a more teacher led approach to the research stage of the Assignment in biology. This also limited the opportunity of biology and chemistry students to evaluate their sources in a meaningful way and resulted in comments like "Source two is reliable because it was provided by my teacher" (chemistry student work sample four).

In physics, the range of sources was wider, e.g. census information, government websites, WHO and Victor explained this:

> We are not allowed to give them a source [of data/evidence]. The most we can do is give them, maybe, five or six sources, from which they have to select. (Victor)

In physics, the students' explanations of reliability were the most in depth and their evaluations focussed on the source of the information, the authors and the publishers:

> This source is reliable because it is written and checked by many qualified and professional scientists (physics student work sample six).

Student work showing the product of student research tended to be placed in the *skills* sub-theme *explain scientifically* because students summarised and put the research into their own words in their final report. As this student put it "I liked that the research was all my own because it helped me to understand what I was writing about." (student questionnaire).

(d) Present information

This sub-theme is evidenced by student and teacher references to writing and structuring scientific reports, and student work showing presentation of information without any evidence of scientific explanations, for example presentation of references without evaluation. This does not include presentation of data, which is dealt with in the skills sub-theme *present and analyse data.* Students stated: "I learnt how to structure a scientific report" and "how to properly reference" (student questionnaire). Teachers referred to "report writing" and "referencing sources". The following student work typifies the student work evidence for this sub-theme:

www.askwillonline.com/2011/04/what-are-differences-between-biological.html (4.10.16)
http://www.bbc.co.uk/schools/gcsebitesize/science/addapapre2011/enzymes/enzymesanddigestion4.shtml
http://www.bbc.co.uk/schools/gcsebitesize/science/addocr21c/lifeprocesses/reactionsrev2.shtml
Research resource pack: use of enzymes
National qualifications Biology assignment pupil research pack Thistle Wood High School
Dickson and Moffat, 2013, how to pass National 5 Biology, Hodder Gibson

Figure 4-4 Student work showing present information (biology student work sample one)

(e) Self-management

In this sub-theme students talked about managing their time and organising their work. Students referred to “working under pressure” and “time limits” (student questionnaire).

Teachers also talked about the timings of the Assignment and students’ organisational skills:

> [the students] are a bit shocked at their time management...some of them had to work on how much time they were using and how they were using their time, and organising themselves as well as organising the Assignment ... they carried it out like they had all the time in the world (Olive)

> The main thing that pupils gain from it [the Assignment] is the confidence to work on their own, not as part of a group, and to take responsibility for their own piece of work, their own research, rather than a group activity (Amanda)

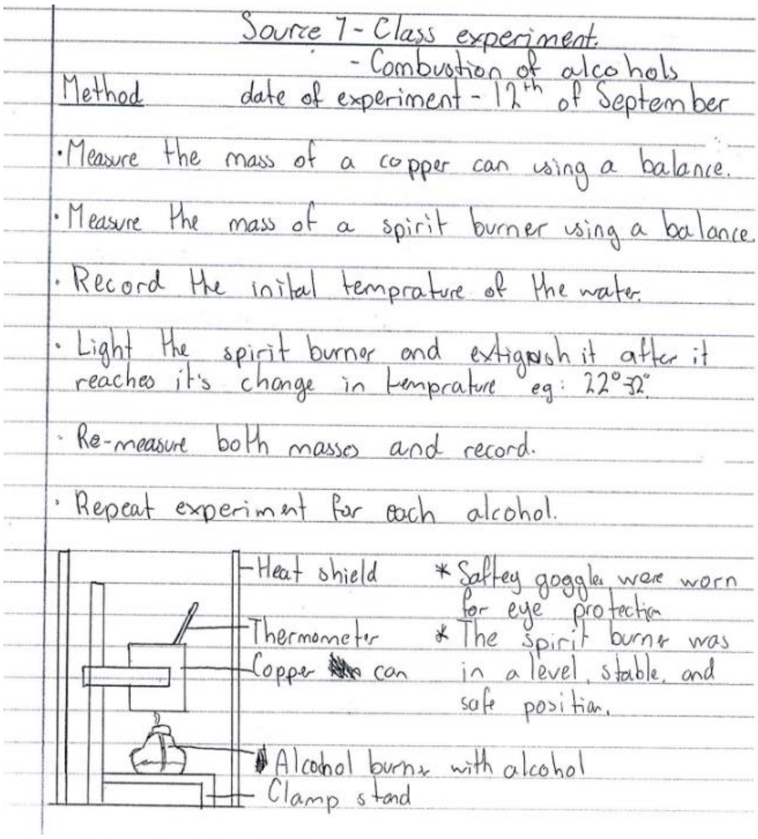
The students also talked about their feelings towards the Assignment process and these were mixed. One student stated that “it is serious, hard and you have to concentrate” (student questionnaire), while another student commented “It went well for me as I was able to do the assessment fairly easily and enjoyably” (student questionnaire).

The teachers also talked about the students’ feelings towards the Assignment, and again this was mixed. Victor quite bluntly stated: “overall, I think they learn that it is stressful”. Amanda was more positive and stated that some students gain “confidence” through completing the Assignment.

Due to the nature of the sub-theme, there was no evidence in student work.

(f) Plan, carry out and evaluate experiments

This sub-theme is evidenced by student and teacher references to planning and carrying out experiments, e.g. “[I] learnt how to create an experiment to collect data” and “carried out an experiment and recorded data” (student questionnaire), and references to evaluating experiments, e.g. “[I would] do more repetitions of the experiment I did myself” and “it was tricky to keep all other variables constant” (student questionnaire). Student work from chemistry included full experimental write-ups:



Source 7 - Class experiment.
- Combustion of alcohols

Method date of experiment - 12th of September

- Measure the mass of a copper can using a balance.
- Measure the mass of a spirit burner using a balance.
- Record the inital temprature of the water.
- Light the spirit burner and extigwsh it after it reaches it's change in temprature eg: 22°-32°
- Re-measure both masss and record.
- Repeat experiment for each alcohol.

Figure 4-5 Student work showing plan, carry out and evaluate experiments (experimental method) in chemistry (chemistry student work sample one)

Student work from biology included the results from experiments but this would have been included in the *present and analyse data* sub-theme rather than this sub-theme.

(g) Propose investigatable questions

This sub-theme is evidenced by references to the "aim" of the investigation or experiment and student work showing the "aim". All student work included an overall aim for the Assignment.

There were only two variants of aims stated across the nine samples of student work in biology:

> To investigate the effect of enzymes in biological detergents regarding the environment (biology student work sample one).

> To investigate the effect of temperature on enzymes in biological detergents (biology student work sample two).

In chemistry, as with biology, only two variants of aims were evident in student work.

> To investigate why alcohols being used as fuels are beneficial for the environment (chemistry student work sample one)

> Does increasing the carbon chain length of a fuel increase the amount of energy released? (chemistry student work sample three).

In physics, the range of topics chosen by students was wider and so were the aims stated. Two examples are shown below:

> To find the best material for a heat shield using the specific heat capacities of materials as a guide (physics student work sample one)

> To find out if wearing a seatbelt in vehicles reduces injuries and fatalities (physics student work sample five)

(iii) Student experience: Knowledge

There was evidence of two sub-themes within the *knowledge* theme. In this theme, students and teachers talk about knowledge that was gained during the Assignment process and the theme also includes examples of student work. There is overlap between the two knowledge sub-themes and the skills sub-theme *explain scientifically,* the students gave explanations justified with scientific knowledge.

(a) Recall and apply scientific knowledge

This sub-theme is evidenced by statements of knowledge or fact by the student without relating it to *implications for society (or the environment)*: "I learnt the difference between biological and non-biological detergents", "Alcohols release different amounts of energy" and "[I] learned how satellites orbit and about the link between orbital distance and period of satellites" (student questionnaire).

Student work demonstrated this sub-theme when students stated their conclusions:

> In conclusion, for both manmade and natural satellites as the orbital radius increases so does the orbital period. (physics student work sample eight)

Student work also included explanations of the "underlying biology/chemistry/physics" of the topic of investigation. These explanations were often over a page in length and focussed on the science behind the topic of investigation.

(b) Knowledge: Implications for society (and the environment)

This sub-theme is evidenced by references to scientific knowledge and its impact on society or the environment, and student work containing explanations showing scientific knowledge and relating this to impact on society or the environment.

Students talked about the knowledge they had gained: “Bio washing powders use enzymes because they use less energy which are better for the environment as they cause less pollution” (student questionnaire).

Students gave scientific explanations of the application of biology/chemistry/physics and its effect on the environment or society.

> Application: Scientists put enzymes in washing powders.
>
> Effect: This has a positive effect on the environment. This means that clothes are washed at a lower temperature, which uses less electricity. Therefore, less fossil fuels are burned and this means less greenhouse gases will be released into the atmosphere. (biology student work sample one)

In the following example, while the question (aim) does not clearly relate to implications for society, the explanations given by the student do link to implications for society:

> Aim: To investigate how the altitude of a satellite, man-made or naturally occurring, affects its orbital period.
>
> Application: Man-made satellites are useful for many purposes: weather forecast, communication and observation of the Earth.
>
> Effect on society: As we can use man-made satellites to forecast weather it means we can predict what is going to happen and prevent disasters … communicate quickly and enables us to socialise more … stay informed. This means we could stay safe and on alert, which would be a huge benefit to society. (physics student work sample six)

Victor described how students used scientific knowledge to explain the implications for society:

> [students] quite often confuse that [underlying biology] with what effect does it have [implications for society]. So what effect does sun cream have? It reduces the chance of you developing some kind of skin cancer. But that’s not physics, the underlying physics is that it reduces the harmful radiation that can penetrate the skin (Victor)

Victor described how students should clearly link their explanations of implications for society to the underlying science.

(iv) Student experience: PISA competencies used in the Assignment

This sub-section presents the students’ use of the three PISA competencies and 15 sub-competencies (a reminder of these can be found in Table 1-1 p9) as identified by both teachers and students. The percentage of students from biology, chemistry and physics that reported using the competencies and sub-competencies of PISA are displayed quantitatively and due to a smaller sample, the findings from teachers are discussed more generally.

Figure 4-6 shows percentage of students from the three science subjects that reported using each of the PISA competencies (questions 6-8 of the questionnaire - Appendix A).

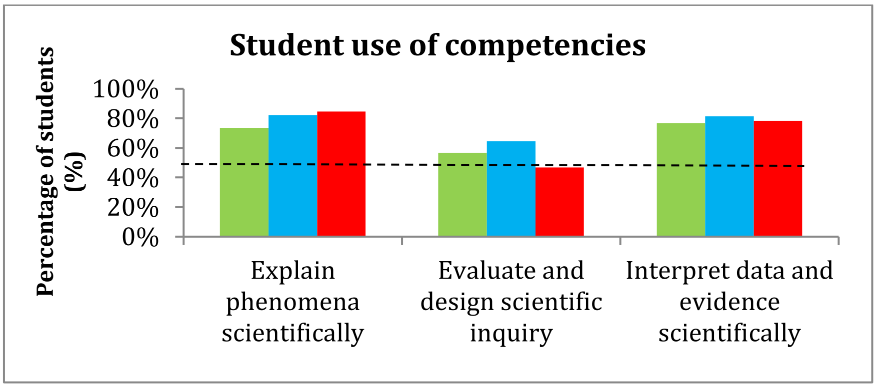


Figure 4-6 Student use of PISA competencies (student reported) Biology (green) n=155, chemistry (blue) n=136, physics (red) n=111

Students from biology, chemistry and physics all reported using Competency 1 *explain phenomena scientifically* and Competency 3 *interpret data and evidence scientifically* more than Competency 2 *evaluate and design scientific inquiry*.

Figure 4-7 show the percentage of students from all three science subjects who reported using each sub-competency in the Assignment (part two of the questionnaire – Appendix A).

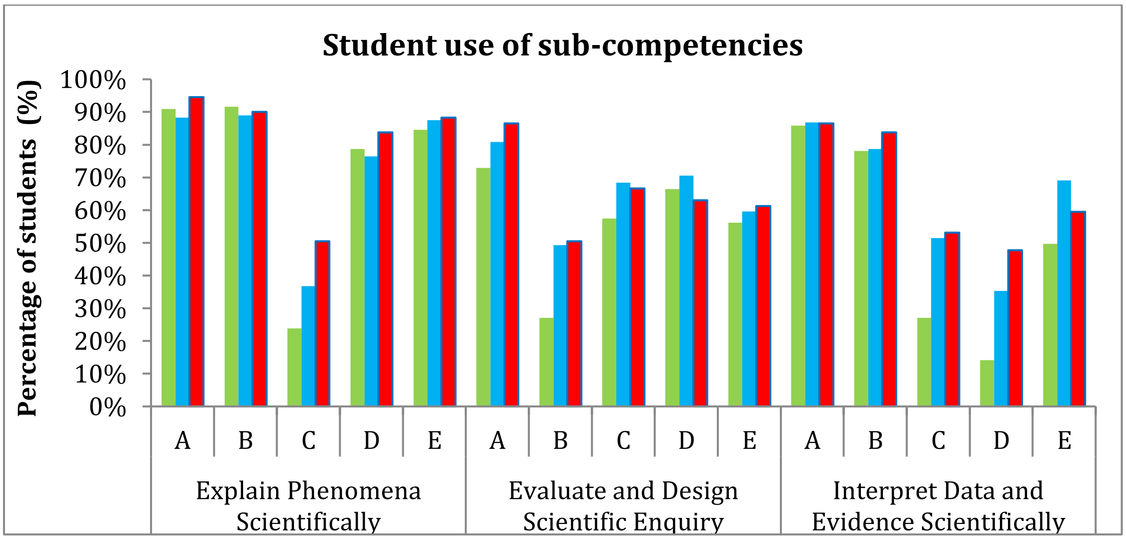


Figure 4-7 Percentage of students using each sub-competency (student reported) Biology (green) n=155, chemistry (blue) n=136, physics (red) n=111

All of the 15 sub-competencies were reported by the students as being used during the National 5 Assignment. Sub-competencies 1A, 1B, 1E, 3A and 3B were frequently reported as being used by students from all three subjects (>80% of students). Sub-competencies 1C, 1B and 3D were infrequently reported as being used by students from all three subjects (<50% of students).

Teachers were also asked to report which competencies and sub-competencies their students used when completing the Assignment. However, there were some methodological considerations that affected interpretation of the results. Firstly, there was a smaller number of teachers than students and while they provided rich qualitative data through in their response to the questionnaire and interview, this cannot provide a meaningful quantitative measure. In addition, a single joint response questionnaire was provided by chemistry teachers meaning that a percentage could not be calculated. This resulted in six biology teacher responses (one biology teacher did not complete the questionnaire), six physics and only one chemistry response. Finally, five of the seven biology teachers participating in the main study had participated in pilot study the previous year. There was evidence that this made the biology teachers more familiar with the competencies and sub-competencies because it affected their reports of student use. For these reasons, the teacher reports of which competencies and sub-competencies of scientific literacy were used in the National 5 Assignment will be discussed more generally.

In biology, when discussing the overall competencies (Q6-8 of the questionnaire – Appendix A) four out of six teachers stated that their students used Competency 1 *explain phenomena scientifically*, three teachers stated that their students used Competency 2 *evaluate and design scientific inquiry* and five out of six teachers stated that their students used Competency 3 *interpret data and evidence scientifically*. In chemistry, the teachers (in a joint response) reported that all three competencies were used. In physics, five out of six teachers felt that Competency 1 was used, only two out of six stated that their students used Competency 2 and all six teachers stated that Competency 3 was used.

Table 4-5 shows the sub-competencies identified by the teachers as being used by students. The following paragraphs highlight the key findings from part two of the teacher questionnaire from biology, chemistry and physics relating to student use of PISA's 15 sub-competencies.

Table 4-5 Student use of sub-competencies (teacher reported)

Competency or Knowledge type		Bio (n=6)	Chem (n=6)	Phys (n=6)
A	Recall and apply scientific knowledge	6	✓	6
B	Identify, use and make models, diagrams, graphs etc.	2	✓	2
C	Make predictions	0	✓	3
D	Use your science knowledge to explain why or how something happens	1		2
E	Explain how science impacts society (personally, nationally or globally)	6	✓	6
A	Identify what question the investigation aims to find out	2	✓	4
B	Choose between questions that can be investigated through science and those that can't	3		3
C	Plan an investigation to explore a scientific question	2	✓	4
D	Evaluate investigations	2	✓	4
E	Describe and evaluate how scientists make investigations and data fair, reliable, objective and fit into a wider context.	2	✓	5
A	Transform data from one representation to another e.g. table to graph	6	✓	6
B	Analyse and interpret data and draw conclusions	6	✓	6
C	Identify the assumptions, evidence and reasoning in scientific reports, articles etc.	0	✓	1
D	Choose between arguments which are based on science and those which are not	1	✓	4
E	Evaluate scientific arguments and evidence from different sources (e.g. newspaper, internet, journals)	4	✓	4

All six biology teachers reported that the students used the sub-competencies 1A, 1E, 3A and 3B. Fewer (3 or less) biology teachers stated that their students used 1B, 1C, 1D, 2A, 2C, 2E, 3C and 3D.

Chemistry teachers stated that 13 of the 15 PISA sub-competencies were used by students in the Assignment. They did not report the use of sub-competencies 1D offer explanatory hypotheses or 2B distinguish questions that are possible to investigate scientifically.

All physics teachers stated that their students used the sub-competencies 1A, 1E, 3A and 3B. Fewer (3 or less) physics teachers stated that their students used the sub-competencies 1B, 1D, 2B and 3C.

There was evidence when comparing the findings from the pilot study and the main study that the biology teachers' decision making had been affected by participation in the pilot. This was evidenced by a decrease in teachers' reports of the sub-competencies used (Figure 4-8).

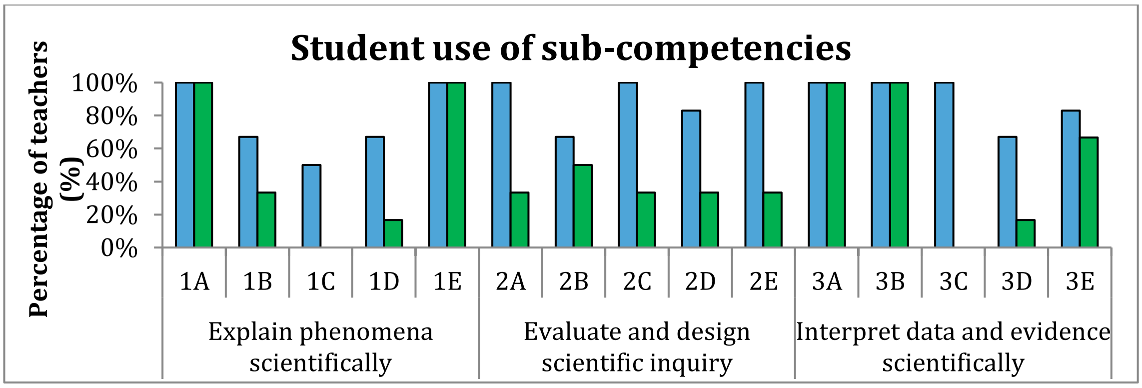


Figure 4-8 Percentage of students using each sub-competency comparison of year one and two (teacher reported) (year one =blue, year two = green)

The biology teachers were more negative in the main study than they had been in the pilot year and were more negative than the chemistry and physics teachers who only took part in the main study (they stated fewer sub-competencies).

4.1.3 Discussion

Thistle Wood School case study focused on a science department in one Scottish school and asked:

1. What are the teacher and student experiences of carrying out the Scottish CfE National 5 Assignment?
2. Which PISA competencies are developed and assessed in the Scottish CfE National 5 Assignment?

In this discussion, the teacher and student experience are explored qualitatively and this is compared to the competencies and sub-competencies used. First, an overview of the teacher and student experience is presented. Next the SSI contexts used as the context for the inquiry are discussed. The skills and knowledge that make up the student experience of the inquiry in the context of SSI are discussed and these are then compared to the competencies and sub-competencies of PISA used in the Assignment.

(i) Student and teacher experience of the National 5 Assignment

Overall, the teacher experience was dictated by the curricular documentation and was discussed as the *pedagogical approach* to the Assignment. The student experience was discussed in very similar terms by the teachers and students as the skills and knowledge that were used, developed and assessed through the Assignment.

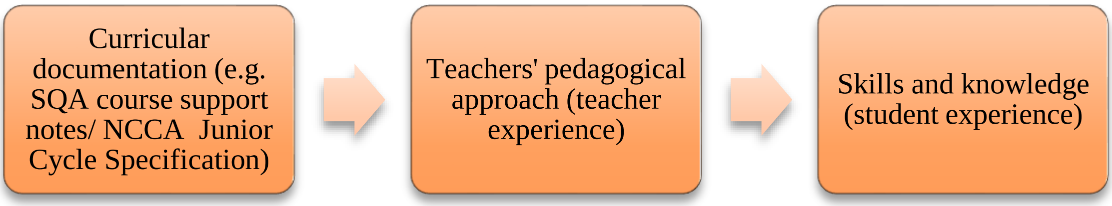


Figure 4-9 Curricular impact on teacher and student experience of the National 5 Assignment

Thus far, the curricular documentation that teachers used in planning the Assignment has not been fully discussed. The findings from the case study give a clear indication of the pedagogical approach used by the teachers and this was identified from the evidence gathered and analysed. The curricular documentation was examined by the researcher after analysis had been completed to compare the approach taken by the teachers to the approach outlined by the curricular documentation. This comparison will be discussed in detail in Section 4.2 of this chapter but as the Figure 4-9 shows, it was evident that the curricular documentation strongly influenced the teachers' approach which in turn influenced the students' experience.

(a) Overview and pedagogical approach

Figure 4-10 gives an overview of the teacher and student experience of carrying out the National 5 Assignment, an assessment of inquiry in the context of SSI.

When carrying out the National 5 Assignment, the teachers began with direct *instruction* that aimed to provide students with the information required to carry out the Assignment. The teachers followed a standard PowerPoint (which varied slightly between but not within subjects) which outlined the Assignment process. Some teachers described this as a "step-by-step" instruction. Some teachers also gave students exemplar Assignments to examine in groups. These exemplars represented high quality, high scoring Assignments. Resources such as SQA marking instructions and resources booklets, with sources of information and data, were handed out and discussed at this stage. This direct *instruction* took one to two hours of class time.

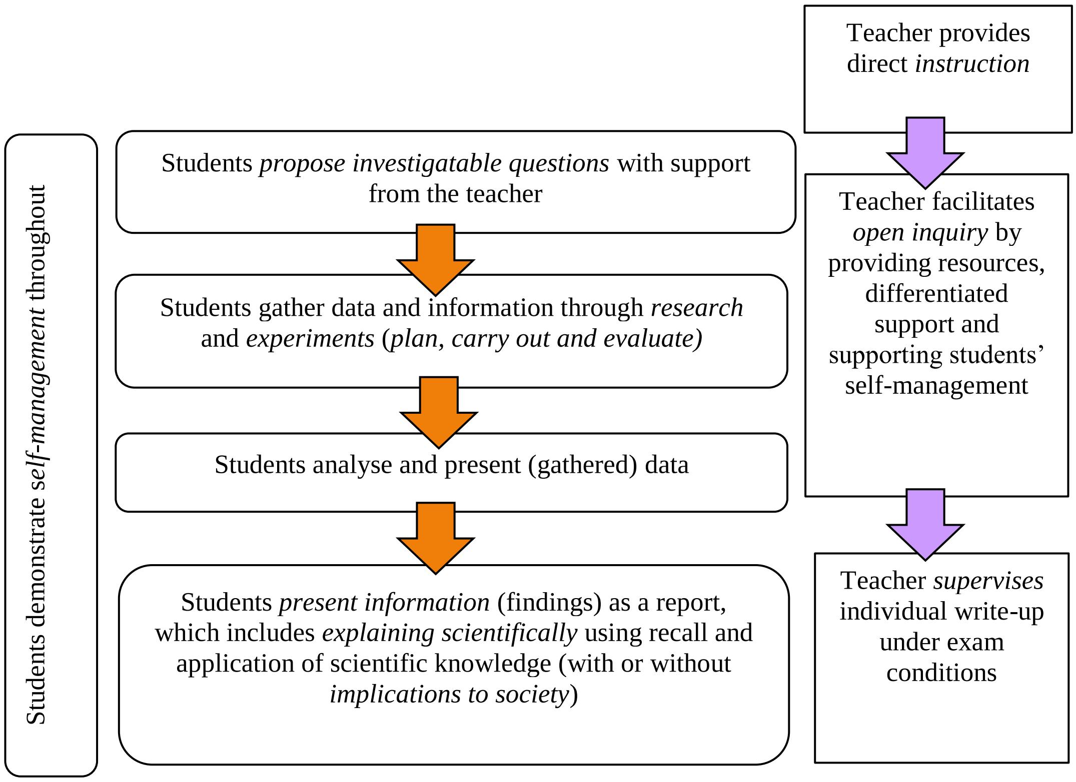


Figure 4-10 Overview of Thistle Wood School case study

The next stage of the Assignment shifted the control from the teacher to the students. The teacher stepped back into the role of facilitator of *open inquiry*. Students *proposed investigatable questions*, referred to as the "aim" of their inquiry. They then carried out *research* by findings and using a range of sources and selecting information and data from those sources. Some students were facilitated to carry out an experiment during this stage of the Assignment while other students simply used data from an experiment carried out previously. Students had an opportunity to practice data analysis and presentation at this stage with the teacher's support. In this stage the teachers encouraged the students to "work independently" but they were "able to ask questions". They were also provided with "SQA documents/marking criteria" for support. The pedagogical approach during this stage was identified from thematic analysis as *open inquiry*. However, there is evidence from student work that the approach taken may have been closer to guided inquiry. This is because while the teachers talked about ensuring students "have an appropriate aim" without "telling them what to write", the student work indicated that the aim (the question for investigation) was teacher directed. Regardless of this distinction, the teachers acted as facilitators of learning balancing the support they were giving the students with the need for the students to take responsibility for their learning. This open approach and flexibility in support allowed some scope for differentiation, but this was ultimately limited by the structured assessment criteria.

In the final stage of the Assignment, the teacher's role once again changed. The teachers *supervised* the students as they wrote a structured scientific report under exam conditions.

(b) SSI Context

SSI were defined in Chapter 1 as scientific topics with moral, ethical and societal implications that are controversial, contemporary and encourage activism. The National 5 Assignment is an ideal opportunity to carry out an inquiry in the context of SSI. The range of topics and the extent to which these were explored as SSI varied according to subject.

In biology only one topic was used as the context for the inquiry: the effects of use of enzymes in biological detergents on the environment. While there was an opportunity for students to discuss a variety of points of view in relation to this topic, many students incompletely discussed the SSI by focussing on the positive effects only:

> [use of enzymes in detergents] has a positive effect on the environment. Clothes are washed at lower temperatures which uses less electricity. Therefore, less fossil fuels are burned and this means less greenhouse gases will be released into the environment (Biology student work sample one)

This is a full description of the positive effects of the use of biological detergents but does not address any controversial elements to their use and is therefore an incomplete discussion of the SSI. Only one of the nine items of student work discussed both the benefits and drawbacks of the SSI:

> A positive effect would be that since enzymes allow reactions to happen at a lower temperature … less fuel is needed to heat the washing machine and therefore less pollution is released into the environment. A disadvantage … is that enzymes can sometimes irritate sensitive skin (Biology student work sample four)

Biology student work sample four discusses both sides of the SSI and discusses both global contexts (pollution in the environment) and personal contexts (personal health and wellbeing).

In chemistry, as with biology, only one topic of investigation was chosen: the effect of alcohols as fuels on the environment. Similarly to biology, most chemistry students presented only the benefits of using alcohol as a fuel (cleaner fuel/ less expensive to produce and buy) and therefore did not fully discuss the SSI. However, the conclusion shown below discusses both the positives and negatives of the SSI:

> Alcohols can provide a high energy alternative to coal, oil and gas. We may be able to slow down global warming and decrease air pollution... However, alcohols, such as ethanol are mainly produced from sugar cane... Growing sugar cane requires land, which may result in destruction of forests and habitats to increase production of the crop (chemistry student work sample five)

Student five discussed the benefits and drawbacks of the SSI in global/national contexts (pollution and "global warming"/ deforestation and habitat destruction).

Given the limited number of SSI contexts observed in student work from biology and chemistry, it is likely that the topics, and resulting questions for investigation, were dictated by the teacher. Beth stated that "we give them a rough aim and everyone's aims are very similar. They're all doing detergents and enzymes". This explains why the range of aims were limited.

In physics, the students researched a range of topics:

1. Use of different materials in heat shields of spacecrafts
2. Effects of altitude on the orbit of a space craft
3. Effectiveness of seat belts in cars
4. Health effects of exposure to X-rays

Topics 1 and 2 were descriptive and did not give the students the opportunity to discuss SSI. Three of the eight samples of student work discussed the use of different materials for heat shields. This topic was described by students rather than discussed. Conclusions simply related to the best materials for use and explanations were generally scientific, without considerations for the implications for society. Effects of altitude on the orbit of space craft was used as a topic in two of eight the samples of student work from physics. Students described the implications of use of satellites (the application) on society (GPS, TV etc.) but did not discuss any controversy or moral or ethical concerns. It may have been possible for this to be treated as SSI but it was not.

The seatbelt topic was discussed from multiple points of view. One conclusion stated "wearing a seatbelt in vehicles does reduce injuries and fatalities" but also discussed statistics around those who choose not to wear a seatbelt. Reasons against wearing a seatbelt were not discussed however, leaving discussion of the SSI somewhat incomplete.

One student explored the health effects of exposure to X-rays as SSI. Both the benefits and drawbacks were discussed.

> X-rays help show and diagnose medical problems. They can also be used in radiotherapy to damage harmful cells. However, they can also cause damage to useful cells. When exposure X-rays increases radiation to harmful levels you run the risk of getting a radiation burn. They make use of ionising radiation which can cause harm to the body. (physics student work sample three)

While students from all subjects discussed societal implications and considered to some extent different points of view (benefits and drawbacks) relating to SSI, the other criteria for SSI were not addressed. Topics did not have obvious moral or ethical implications or these were not addressed by students. Some topics may have been considered contemporary, e.g. use of alcohols as fuel sources, but others seem to have been chosen mainly for their relation to the content of the National 5 biology, chemistry and physics courses. Students were not facilitated to take action as a result of their inquiry, over and above writing a scientific report.

(c) Skills and knowledge

The following paragraphs highlight the seven *skills* used, developed or assessed when carrying out the Assignment and how (and if) these were situated within the SSI context. Discussion of these skills by teachers and students was the major focus of the student experience.

Presentation and analysis of data was a large focus of the Assignment and was described as "processing" by the students and teachers. "Processing" suggests that the skill can be done with mainly procedural knowledge (OECD, 2013) and this matches with the descriptions given by the students and teachers. The skill was carried out without reference to the SSI context or discussing the implications for society. For example, the table and graph presented by biology student one and the calculation performed by chemistry student one (Figure 4-2 and Figure 4-3) present data with no explanation to link this to the SSI.

Another important skill developed and assessed is the ability to explain the science behind the topic of investigation. This was also where most of the students' scientific knowledge was demonstrated and the SSI context was explored in most depth. However, when the students gave scientific explanations, most of the knowledge evidenced was *recall and application of scientific knowledge* without referring to the implications for society or the environment, i.e. the SSI context.

Students carried out *research* and this was mainly discussed as a process of finding sources of data and evidence, selecting the information from these sources and then evaluating the sources. Research involves using multiple resources and, crucially, thinking "critically about the information found" (McMaster University Libraries, 2016, 1.22 -1.31). Searching is looking for "information or facts" whereas research involves "putting different pieces of information together to find patterns, correlations and connections" (McMaster University Libraries, 2016, 0.46 - 1.00min). There is some evidence that the students engaged in authentic research (rather than just searching) in their evaluations of the sources of evidence. However, the evaluations focussed on a limited number of factors (relevance and reliability). There was clear evidence here that the *pedagogical approach* taken by the teacher affected the students' ability to carry out this skill. Biology and chemistry teachers exercised more control over the students' research by providing resource packs with a limited range of resources. Teachers classed this as "research" whereas the students did not. In physics, the teachers allowed students more choice in their sources and this is reflected in the student's discussion of their experience. Biology and chemistry teachers who provided resource packs with a limited number of sources and did not encourage wider research had students whose evaluations were more limited and less in depth. In addition, those students did not emphasise the skill, i.e. they did not recognise the importance of research in the Assignment. Conversely, teachers who encouraged students to find their own sources of data and evidence had students whose evaluations were more in-depth and discussed more factors relating to the source. These differences may explain why physics students put more emphasis on *research* than the biology and chemistry students. This is one occasion where the teachers' view of the student experience contradicts that of the student. This skill was not situated within the SSI context.

Evidence from student work showed that students in different subjects engaged with planning and carrying out experiments differently. The extent to which students demonstrated this skill in their student work varied between subjects. In chemistry, students carried out a full experiment and included a full experimental report in their Assignment write ups. In physics some students carried out or included data from a previous experiment while others completed a wholly research-based investigation. However, in biology all students included data from a previous experiment as one of their sources of data but did not carry out an experiment at the time of the Assignment or include an experimental method. None of the students, however, *planned* an experiment; they were given a set experimental method. Therefore, students focussed little on *planning, carrying out and evaluating experiments* in their questionnaires. This is in contrast to some of the teachers, where physics and chemistry teachers emphasised experimental investigations relatively highly. It is likely that the students felt a lack of ownership over the experiment and therefore did not focus on it when discussing their experience of the Assignment. Performance of this skill was not situated within the SSI context and did not involve use of scientific content knowledge.

Students proposed questions for investigation, in the form of aims. Some of these aims were clearly situated within the SSI context which allowed students to further discuss the SSI context in their conclusions. Many of the aims, however, did not reference an SSI context, meaning the SSI were not embedded but was limited to a paragraph or two explaining the application/effect.

In biology some of the overall aims related to the SSI explored: "To investigate the effect of enzymes in biological detergents regarding the environment" (biology student work sample one). Other aims were descriptive: "To investigate the effect of temperature on enzymes in biological detergents" (biology student work sample two). The range of different aims was limited, these were the only two chosen by students and all related to one topic for investigation.

In chemistry, as with biology, the aims were either related to the wider SSI, e.g. "To investigate why alcohols being used as fuels are beneficial for the environment" (chemistry student work sample one), or descriptive, e.g. "Does increasing the carbon chain length of a fuel increase the amount of energy released?" (chemistry student work sample three). As with biology, all student studied the same topic.

In physics, the range of topics chosen by students was wider and so were the aims stated. Again, some aims related to wider SSI while others could be answered in a more descriptive way. For example, the aim “To find the best material for a heat shield using the specific heat capacities of materials as a guide” (physics student work sample one) is purely descriptive, whereas the aim “To find out if wearing a seatbelt in vehicles reduces injuries and fatalities” (physics student work sample five) can relate to wider SSI.

(ii) PISA competencies and sub-competencies used in the Assignment

This section discusses the PISA 2015 competencies and sub-competencies that were used, developed and assessed in this Assignment (see Table 1-1 for a reminder of the competencies). Students and teachers were asked directly which competencies and sub-competencies were “used”. This data can be used to support the qualitative findings as many of the competencies and sub-competencies align with the skills that have been identified inductively through qualitative methods.

There was a high level of agreement between students from different subjects as to which competencies and sub-competencies were used in the Assignment, indicating a consistent experience across the three subjects. This aligns with the findings from the qualitative aspects of the study where the same themes for student experience were identified in the three subjects.

When referring to the overall competencies, the students reported using Competency 1 *explain phenomena scientifically* and Competency 3 *interpret data and evidence scientifically* to a similarly high extent. This aligns with findings from the qualitative aspects of the case study where high emphasis was placed on giving scientific explanations and data presentation and analysis.

Students from all three science subjects reported using competency 2 evaluate and design scientific enquiry less but there was variation seen between the science subjects for this competency. Chemistry students reported using competency 2 the most and physics students the least. This tallies with qualitative findings showing that low emphasis is placed on experimental investigation overall. The varied emphasis between the subjects likely results from chemistry students completing an experimental investigation as part of the Assignment while physics students did not.

All the sub-competencies of scientific literacy are reported by students as used in the Assignment. Students were most likely to consider that they used: *Recall and application of scientific knowledge* (1A); *Identify, use and generate explanatory models and representations* (1B); *Offer explanatory hypotheses* (1D); *Explain the potential implications of scientific knowledge for society* (1E). This supports the evidence from thematic analysis that students used two types of scientific knowledge: *recall and application of scientific knowledge* (equivalent to 1A) and *knowledge of the implications for society and the environment* (equivalent to 1E). Students reported using sub-competencies 1A and 1E to a similarly high extent and all teachers reported students using both sub-competencies. This is somewhat at odds with the previous findings that *recall and application of scientific knowledge* (equivalent to 1A) was demonstrated more than *knowledge of implications for society and the environment* (equivalent to 1E). It can be asserted therefore that the students and teachers recognised the importance of using knowledge to explain the implications for society and the environment but they did not put this into practice when carrying out the Assignment. This is likely to be due to the narrow focus of the Assignment that does not reward students for situating the demonstration of skills within the SSI context.

Students from all three subjects were less likely to consider that they: Made predictions (1C); Distinguished scientific questions (2B); Identified the assumptions, evidence and reasoning in science-related texts (3C); Distinguished between arguments which are based on scientific evidence and theory and those based on other considerations (3D). Sub-competencies 3C and 3D relate to research as described by the teachers and students. Biology students were least likely to state that they used these sub-competencies and physics students were most likely (although still only around half of students). This matches earlier findings that biology students did not focus on research in their discussion of the Assignment because they did not feel ownership over their research as it was overly teacher-led. Physics students who were given more freedom, emphasised the importance of research in both the quantitative and qualitative aspects of the case study. The sub-competency 3E also relates to the student experience of research and only around half of students in biology and physics and a little more in chemistry felt they had used this skill.

Teachers from different subjects showed marked differences in the competencies and sub-competencies they reported their students using in the Assignment. Teachers' overall responses were more negative compared to the students and only 5 sub-competencies had a high number of positive responses. These were: *Recall and apply scientific knowledge* (1A); *Explain the potential implications of scientific knowledge for society* (1E); *Transform data from one representation to another* (3A); *Analyse and interpret data and draw appropriate conclusions* (3B); and *Evaluate scientific arguments and evidence from different sources (e.g. newspaper, internet, journals)* (3E). 1A and 1E match the two knowledge sub-themes discussed previously and 3A clearly matches the skill *present and analyse data*.

There was only one sub-competency that teachers from all three subjects agreed was not used. This was 1D *evaluate ways of exploring a given question scientifically* which relates to students evaluating experimental investigations. This was not emphasised in the qualitative aspects of the case study either.

There was much more variability in the response of teachers compared to the students. This resulted in a high number of sub-competencies where there was disagreement between the subjects. Chemistry teachers were more positive and biology teachers were more negative. In chemistry, the teachers discussed the sub-competencies and submitted a joint response. This resulted in more sub-competencies being positively identified as being used. Biology teachers became more aware of the PISA competencies and sub-competencies through their participation in the pilot and were less likely to report them being used. This shows development of the teachers' knowledge and understanding through participation in this study. There was no evidence of genuine differences between the different subjects in use of the competencies and sub-competencies.

4.1.4 Conclusions and implications: Thistle Wood School case study

The pedagogical approach to the National 5 Assignment was dictated by curricular documentation (SQA, 2016) and this will be discussed in more detail in Section 4.2. This meant that the teacher experience, which focussed on the *pedagogical approach* to inquiry was consistent between teachers of all three subjects. The teachers first prepared students to carry out the Assignment using direct *instruction*, then facilitated students to carry out a secondary research and (to a varied extent) experimental *open inquiry*. While teachers discussed this stage of the Assignment as *open inquiry* the evidence from student work suggested that the teachers exercised control over the choice of aims for investigation. Therefore, in practice the inquiry was actually guided (see Table 1-4 for levels of inquiry). Finally, the students wrote a report of their findings under exam conditions, *supervised* by their teacher.

The consistent *pedagogical approach* resulted in a consistent student experience across the three science subjects. The student experience focussed on the skills and knowledge developed and assessed and this was reported by both the teachers and the students themselves. Teachers and their students focussed on *presentation and analysis of data* and *explaining scientifically*, using scientific *knowledge*. However, this knowledge tended to be stated outwith the SSI context of the inquiry and did not discuss the *implications of scientific knowledge for society*.

While many of the topics chosen could be discussed in terms of benefits or drawbacks for society, very few students described their chosen topic as SSI, by discussing and evaluating different sides of an argument. Many of the topics did not have obvious moral or ethical implications and the students were not encouraged to take further action, above and beyond their final scientific report.

There are areas of disconnect between the way the teachers and students talked about the student experience. One area of inconsistency was when talking about carrying out *research*. All teachers placed high importance on student-led *research* whereas this was variable between the students from the three science subjects. This was likely due to the differing approaches used in the three subjects. In physics, where students placed high importance on research, the students were given more flexibility and freedom to choose a range of sources. However, in biology and chemistry the research was restricted to a few sources chosen by the teacher. This limited biology and chemistry students' opportunity to evaluate their sources in a meaningful way.

Another difference in the student experience between the subjects was the extent to which they engaged in experimental inquiry. Chemistry students carried out an experiment using structured inquiry procedures (Table 1-4) and included a full experimental write up in their Assignment. In biology, the students included experimental data but this was from an experiment that had been carried out previously. In physics some students carried out or included data from a previous experiment while others completed a wholly research-based investigation. Interestingly, students from all science subjects placed little emphasis on experimentation as part of their inquiry. This is likely to be because of the structured inquiry approach taken. The teacher controlled most of the decision making relating to the experiment and the students did not feel a sense of ownership over the experimental aspects of the Assignment.

Similar low emphasis was given to the skill *propose investigatable questions.* Evidence from student work shows that the teachers had a high level of control over the choice of aim for the inquiry and so it is likely that the lack of emphasis on this skill is because students did not feel that this was a skill that they had developed.

In terms of the PISA competencies and sub-competencies used (Table 1-1), the quantitative study showed consistency across the three science subjects. This matches with the findings from qualitative analysis where themes and emphasis on themes was largely consistent between the three subjects. The teachers and students in the three science subjects reported using competency 2 evaluate and design scientific enquiry less. This ties in with the low emphasis on students planning and evaluating experiments.

Overall, the National 5 Assignment as carried out in Thistle Wood School is an assessment of skills and knowledge that contribute towards students' scientific literacy. The skills broadly relate to presenting and analysing data and giving scientific explanations with varied emphasis on students carrying out authentic research. The knowledge applied when carrying out these skills relates to recall and application of scientific knowledge both with and without making clear the implications for society and the environment. The Assignment has the potential to allow students to engage with SSI but this was rarely seen in practice. How the skills and knowledge developed and assessed contribute towards scientific literacy will be further discussed in Chapter 6.

4.2 How curricular documentation shaped the teacher and student experience: A shift away from SSI

Figure 4-9 outlined how the curricular documentation relating to the National 5 Assignment impacted the teachers' pedagogical approach. This in turn impacted the student experience, in terms of the skills and knowledge developed and assessed. Section 4.2 examines the curricular documentation published by the SQA, relating to the National 5 Assignment. It attempts to unpick how the Assignment was proposed to be carried out and compare this to the practice observed in Thistle Wood School.

The SQA outline the pedagogical approach to the National 5 Assignment and the skills and knowledge it aims to assess in a number of documents. Each subject outlines the assessment in their *General Assessment Information* document (SQA, 2016). Each subject also has *Course Support Notes* that include exemplar student work and topics (SQA, 2013a, b; 2014d). The documentation varies only slightly between the three science subjects to take account of subject specific topics and differing content knowledge, but the proposed approach, skills and knowledge outlined are the same between the three subjects. In addition to these documents, the SQA also provides *Course Reports* that are published after exams each year (SQA, 2014a, b, c). The reports provide information on the performance of candidates which can be used by teachers to prepare candidates for assessment. The SQA intends the reports to be "constructive and informative and to promote better understanding" of assessment (SQA, 2014a, p. 1). The curricular documents examined in this section include the *General Assessment Information*, *Course Support Notes* and *Course Reports* for National 5 biology, chemistry and physics.

An important point of note, and one that has not been discussed so far in this thesis, is that in the year following Thistle Wood School case study, the SQA (2017b) proposed changes to the National 5 Assignment that affect how it would be carried out in schools. Thistle Wood School case study was carried out in the year 2016-17 and changes were proposed by the SQA that would come into force from 2017-18. These changes were an outcome of the SQA's own evaluation of the first four years of implementation of the Assignment and these will be discussed in Section 4.2.2.

The final part of this section of the chapter (Section 4.2.3) will explore the curricular documentation relating to inquiry in the context of SSI in Ireland and give the researcher's recommendations for practice and policy based on the first four years of implementation in Scotland.

4.2.1 SQA approach compared to Thistle Wood School

Section 4.2.1 presents the approach to the National 5 Assignment as intended by the SQA and compares this to the approach observed in practice in Thistle Wood School. The pedagogical approach, SSI contexts, and skills and knowledge are discussed.

(i) Pedagogical approach

The SQA (2016) states that the Assignment is to be conducted by schools under specified conditions and then externally marked by the SQA. These specified conditions relate to the pedagogical approach and are outlined in the following paragraphs.

The pedagogical approach is described by the SQA (2016) as consisting of two stages: a research stage and a communication stage. This is as opposed to the practice observed in Thistle Wood School where an additional stage, the *instruction* stage, preceded the *open inquiry* (research) and *supervision* (communication) stage. The Assignment is recommended to take no more than eight hours (SQA, 2016). There is no further guidance of how much time each stage of the Assignment should take.

While the SQA (2016) does not specify an *instruction* stage explicitly, they state that the requirements of the assignment should be made clear to candidates at the outset and describe the importance of sharing the "Instructions to Candidates" and marking guidance with the students (SQA, 2014a; SQA, 2016). In Thistle Wood School, teachers used PowerPoints and paper-based materials ("handbook", "prep sheets", "candidate guide") to talk students through the Assignment in advance.

After the first year of implementation of the Assignment, SQA course reports indicated that it was evident that some schools and colleges had prepared candidates better for the assignment than others (SQA, 2014a, b, c). In physics, markers commented that some candidates had a poor understanding of the requirements of the task, and the content and layout of some reports suggested that candidates may not have been given the "Instructions for Candidates" (SQA, 2014c). The SQA (2014c) stated that many markers commented that candidates did not understand the requirements of the Assignment report. This important preparatory stage was evident from the Thistle Wood School case study but was absent from the instructions given by the SQA in their *General Assessment Information* (SQA, 2016). This may go some way to explain why the SQA reported that many students seemed to be underprepared and unaware of the requirements of the Assignment (SQA, 2014a, b, c; SQA, 2016).

The SQA (2016) describes the research stage as students gathering information/data from a variety of sources including internet, books, newspapers and journals. An experimental activity may be included in this stage but is not required. This stage was the *open inquiry* stage in the Thistle Wood School case study.

Candidates may access any appropriate resources during the research stage of this assignment and it is acceptable practice for teachers to provide students with resource packs. In fact, resource packs were included in early versions of the SQA course documentation (SQA, 2014d). The SQA recommend that several different topics should be included in the resource pack with a range of information and data and that students should have the chance to select information from a range of materials. This is not possible if a limited number of sources and items of raw data are included (SQA, 2014a). There was evidence of the use of resource packs in Thistle Wood School in biology and chemistry but the range of sources was limited.

If an experimental activity is being carried out during the research stage, The SQA (2016) recommend that a structured approach should be adopted, with instructions for the method provided. There was evidence of varied engagement with experimental inquiry in Thistle Wood School but the approach taken (where experimentation was used) was, indeed, structured (Table 1-4).

The SQA (2016) uses the term 'reasonable assistance' to clarify the teachers' role during the research (*open inquiry)* stage. They explain how to balance support with giving too much assistance. Teachers provide reasonable assistance to the students on a generic basis to a class or group of candidates and this may take place prior to the official assessment (SQA, 2016, p. 5). Teachers may direct candidates to the "Instructions for Candidates", clarify instructions and requirements and advise candidates on the choice of the topic or issue. The teachers are asked to provide "some supervision and control" over the candidates' research (SQA, 2016, p. 5). It is acknowledged that research may be carried out outside the classroom but the teacher must also ensure that the work is the student's own. Similarly, the SQA (2016) state that groupwork approaches are acceptable but it is important that individuals are able to show their own evidence for the Assignment. To ensure that this balance between independent research, collaboration with peers and individual record keeping is met, the SQA (2016) recommend that teachers carry out regular checkpoint/ progress meetings with candidates, carry out spot-check individual interviews, keep checklists to record progress, record photographs, film or audio evidence and regularly check candidate work (SQA, 2016, p. 5). In the Thistle Wood School case study, students worked individually. This was likely to have been because it was easier for the teacher to supervise and ensure all students met the requirements when students worked independently.

During the communications stage, students produce a report of their findings under a "high degree of supervision" (SQA, 2016, p. 6). This means that students should be in direct sight of their teacher or invigilator and may not discuss their work (SQA, 2016). This may be done over a number of lessons but no time limits are stated. At this stage, students have access to the notes and other material they collected during the research stage, for example: graphs, numerical or experimental data; data and information from the internet; published articles or extracts; notes taken from a visit or talk; notes taken from a written or audio-visual source (SQA, 2016, p. 4-5). The notes cannot contain a prepared draft report (SQA, 2016). At this stage, the teacher provides less support and the SQA (2016) describe the reasonable assistance allowed as: directing candidates to the "instructions for candidates" and clarifying instructions and requirements for the task (SQA, 2016, p. 5). In Thistle Wood School, this stage was the *supervision* stage.

In practice, observed in Thistle Wood School, the *open inquiry* approach within a structured assessment proved challenging for the teachers to facilitate:

> I don't think the Assignment should be about marking and it shouldn't be about getting the kids the best mark. It should be about them finding [carrying out] research... As soon as the SQA stick a mark on something you are then bound to force them through something...It is a great and noble idea to want to teach research to kids but it is this striving towards marks. (Richard)

Richard wanted to focus on developing skills in students, particularly research, but felt "bound" by the assessment process and this led to a more teacher directed and less open approach.

> I don't think the impact on them was positive. This is the kind of thing that should be good but because it is so prescribed, they need to get this mark, get that mark. They end up getting stressed. I end up getting stressed trying to find that boundary between helping them and not helping them. It has to be their piece of work ultimately. (Tim)

Tim felt that the Assignment had the potential to be "good" but in practice, as an assessment, the students felt "stressed". Tim also found it difficult to implement the SQA's (2016) "reasonable assistance" (p. 5) in practice and find the balance between "helping them and not helping them".

(ii) SSI context (choice of topic)

The National 5 *Course Support Notes* from the SQA (2014d, 2013a, b) contain appendices with resource packs for different topics in biology, chemistry and physics. These give an indication of the types of topics the SQA expect students to explore. The Assignment requires students to "describe an application of biology (or chemistry or physics) and explain the effect on the environment/society" (SQA, 2016, p. 8). "An application must be a deliberate act of humans in which [science] is used to effect change in the world or the environment" (SQA, 2014a, p. 6). As such the Assignment has the potential to be an inquiry into SSI contexts. This is further confirmed by some of the topics given by the SQA (2014d, 2013a, b) in their exemplar materials which are contemporary and controversial topics with multiple points of view to explore.

The biology exemplar topic "the decline of the honey bees" is a contemporary topic which includes "pros" and "cons" which explore both the positive and negative implications of the use of pesticides (SQA, 2014d, pp. 39-44). There are multiple points of view to be explored in terms of environmental concerns and economic considerations. There is also the potential for activism. For example, students may choose to carry out actions to educate others on the use of pesticides or take action within their own community to provide bee habitats.

Another clearly controversial topic that is given as an example by the SQA is "genetically modified crops" (SQA, 2014d, pp. 45-50). There are multiple viewpoints to consider; those who are opposed and those who are for GM crops. There is also the potential to take action by educating others, boycotting GM products, etc.

However, in chemistry the exemplar topic explored "the uses and/or properties of hydrogels". The topic did not contain references to multiple points of view and was not treated as a controversial SSI but simply described the uses of hydrogels in a variety of contexts (SQA, 2013a, pp. 39-4). This meets the criteria set by the SQA where students must describe an application and its effect on society or the environment but does not constitute an inquiry in the context of SSI.

The physics topic given by the SQA (2013b), "car safety", has the potential to be treated as a SSI but is done so incompletely in the exemplar materials. The resource pack contains a range of material relating to various advances in car safety. The topic is contemporary as it explores recent technological advances in car safety but only the benefits are focussed on in the resource pack. A variety of viewpoints are not considered. For example, safety implications or economic barriers (e.g. high cost of implementation of safety features) are not discussed (SQA, 2013b).

In the years following implementation of the Assignment, the SQA (2014a, b, c) provided further guidance relating to topic choice. The SQA (2014a, b, c) described how the choice of topic impacted student achievement and advised teachers and students that topics should be chosen carefully to ensure that they are related to the National 5 courses. The SQA (2014a, b, c) outlined successful topics as those where: the topic was related to content of one or more of the course units; they were at a level of understanding consistent with National 5; and the sources of data and the data itself were understandable at National 5 level and able to be processed by the candidate. The SQA (2014c) described poor choices of topic as those where there was limited or no published data or topics which required an understanding of science at a level greater than National 5 (SQA, 2014c, p. 11). The SQA (2014a, b, c) described how some students chose a topic which they showed an interest in but the science background was beyond their level of understanding leading to difficulties in explaining the background science at the appropriate level or copying information verbatim (SQA, 2014a, b, c).

In practice, there is evidence from Thistle Wood School that this advice caused teachers to steer away from SSI contexts. Teachers in Thistle Wood School saw SSI contexts as too far removed from the National 5 course or the science was not easily translated to National 5 level:

> I did direct brighter kids towards more difficult topics and one of the brightest kids in the year got one of the least marks. He was marked down for taking on something that they thought was beyond his level... the first year I did it there was a range but after I got that mark, the second year, I was like 'no, you are going to do this' (Richard)

Richard moved away from SSI contexts and limited the choice for his students due to his experience of the SQA assessment in practice.

Eve described how the topic was chosen by the biology department:

> At the beginning we thought that the topic of GM crops was quite a nice idea … it was something completely new that they could research. Then we realised that was not the best scenario. It was just a bit too hard for them. We decided to stick with something a bit more familiar with the enzymes that they've heard of and worked with before. (Eve)

> … looking at SQA marks, at pupils who we think should have achieved more highly and why didn't they, pupils who are quite poor ability, why they might achieve highly… in the very first year, even the topic was different. [As a result the Assignment was] changed, altered and amended (Eve)

Eve chose to move away from a truly complex and controversial SSI context with many viewpoints to explore because it was deemed "too hard". She decided to limit the context to something more "familiar". The "best scenario" that Eve is referring to is the best mark. This was reiterated by Danielle who stated:

> They could go on and talk about lots of things but it's very specific what the SQA are looking for... quite a lot of pupils will go away and look at things that are maybe a little bit irrelevant or not in the course and talk about things that they've researched elsewhere. They get penalised for actually doing loads of their own research by the SQA (Danielle)

Danielle described how students lost marks in the assessment if they explored aspects of their topic that were not directly related to the content knowledge prescribed by the National 5 curriculum.

The SQA (2014a, b, c) also recommended choosing topics where data can be retrieved from different sources and that lend themselves to the type of data processing and presenting being assessed. They described how topics which can include elements of their own experimental data for comparison, rather than pure literature-based research tended to achieve higher marks (SQA 2014 a, b, c). This includes topics such as the chemistry "hydrogels" (2013a) that have a range of possible experimental investigations but are descriptive rather than SSI based. Again, in practice this advice steered teachers away from SSI contexts. For example, in Thistle Wood School biology teachers no longer used the topic GM crops, for which there was little scope for experimentation, and instead students explored the topic of “enzymes” for which experimental data was easily obtainable.

In Thistle Wood School, which was in its third year of implementation of the Assignment, very few topic choices were treated as SSI. There appeared to be a high teacher input in topic choice, indicated by the limited range of contexts explored. The contexts used were rarely controversial and contemporary.

(iii) Skills and knowledge

The SQA (2016) describes the National 5 Assignment in terms of skills and knowledge to be assessed. The Assignment aims to assess the following skills, knowledge and understanding: applying knowledge science and interpreting information; selecting and presenting information in a variety of forms; processing information and data; drawing conclusions and giving explanations; and communicating findings and information (SQA, 2016 p. 2). The assessment criteria also give an indication of the skills and knowledge to be assessed and the number of marks allocated to each criterion indicates the emphasis placed on each skill or knowledge (Table 4-6).

Table 4-6 : Assessment criteria for the National 5 Assignment (SQA, 2016, p. 13)

Assessment criteria	**Marks**
Devise an appropriate aim for the investigation	1
Describe an application of biology and its effect on the environment/society	2
Select relevant sources	2
Select relevant information from sources	2
Process and present data/information	6
Draw a valid conclusion	1
Apply knowledge and understanding of biology (*explanation of underlying science*)	3
Structure of the report	3

Of the 20 marks available, 14 are for skills and six are for demonstrating knowledge and understanding. This is in line with the Thistle Wood School case study where a higher emphasis was placed on *skills* than *knowledge*. Although the SQA (2016) does not make it clear which of the above assessment criteria are skills and which are knowledge.

High emphasis is placed on processing and presenting data with six marks allocated to this skill. This skill can be divided into two aspects, presenting and processing. Presenting data is described by the SQA (2016, p. 13) as presenting in appropriate formats such as summaries, graphs, tables, charts or diagrams. Processing data is described by the SQA (2016, p. 13) as performing calculations, plotting graphs from tables, populating tables from other sources, or summarising referenced text. This skill as described by the SQA was observed in Thistle Wood School as *present and analyse data.*

Students are required to apply their scientific knowledge in order to describe an application of biology and its effect on the environment/society, draw a valid conclusion and explain the underlying science of their Assignment (SQA, 2016). This is the equivalent to the skill observed in Thistle Wood School *explain scientifically.* These three assessment criteria together equate to six marks in the Assignment, indicating a large focus on giving scientific explanations justified with scientific knowledge.

As discussed in the previous paragraph, students use scientific knowledge when giving scientific explanations. When explaining the underlying biology there is no expectation that the student will relate their knowledge to the implications for society or the environment. However, students are also asked to describe an application of science and explain its effect on society or the environment (SQA, 2016). Only one mark is awarded for describing the relationship between the application and its effect on the environment/society. The emphasis, in terms of marks awarded, is on recall and application of scientific knowledge without reference to implications for society.

In the National 5 Assignment students carry out *research* (as observed in Thistle Wood School) when selecting relevant sources and selecting relevant information from sources (SQA, 2016). Demonstration of this skill is worth four marks in the Assignment, which makes it of relatively high focus but less so than the skills described so far in this section. The marking instructions describe rigid criteria for the selection of sources. The student should state two sources of data or information and describe them in terms of relevance, reliability and similar/different perspectives (SQA, 2016, p. 9). The skill *research* is also concerned with selection of information for inclusion in the Assignment report, including extracted tables, graphs, diagrams and text from two or more sources. Referencing in terms of a written bibliography in a prescribed format is dealt with under the assessment criteria for the structure of the report, which is discussed in the next paragraph (SQA, 2016, p. 19).

Three marks are awarded for appropriate structure of the report. This includes using heading and sub-headings, referencing in the appropriate format and writing a clear and concise report. Essay style Assignments are not recommended by the SQA and tend to score lower than an appropriately structured scientific report (SQA, 2014a, b, c). The structuring of the report, as described by the SQA, is analogous to the skills theme from the Thistle Wood School case study skill *present information*.

Students are awarded only one mark for devising an appropriate aim (SQA, 2016, p. 8) and this is reflected in practice as there was low emphasis on the theme *propose investigatable questions* in Thistle Wood School. Students are advised “not to be ‘over ambitious’ with the aim of their Assignments and to avoid multiple aims” (SQA, 2014c, p. 14). This is because candidates who stated multiple aims made it more difficult to achieve marks for the later section drawing a valid conclusion (SQA, 2014c).

Self-management was observed in Thistle Wood School but is not assessed in terms of marking criteria for the SQA. It is clearly a skill that underpins performance of the other skills.

Data and evidence from an experimental activity may be included in the report and candidates who included one experiment or practical activity in their assignment tended to achieve a higher mark (SQA, 2014a, b, c). In 2016-17, when the Thistle Wood School case study was being carried out, there was no requirement for inclusion of an experimental investigation and practical work was not assessed (SQA, 2016) therefore the focus on experimentation varied.

When comparing practice in Thistle Wood School to the curricular documentation from the SQA, the alignment is remarkable. The pedagogical approach in practice is clearly dictated by the curricular documentation. The focus given to the different skills and knowledge by the SQA is mirrored in the classroom. The overemphasis on presentation and processing of data without contextualising this in scientific knowledge and the low focus on experimentation stem from the curriculum guidelines (SQA, 2016). The emphasis on recall and application of knowledge without consideration for the implications for society and the environment also stem from the curricular documentation. While exemplar materials focussed on controversial and contemporary SSI contexts, the recommendations of course reports after the first year of implementation discouraged their use (SQA, 2014a, b, c). Teachers in Thistle Wood School also discussed how the use of SSI contexts adversely affected student achievement. This caused the teachers to move away from the use of SSI contexts to topics that were more easily assessed.

It is important to note that the only evidence required to judge student achievement of these skills and knowledge is a final, written report that is marked externally by the SQA (SQA, 2016). The teacher is encouraged to record a variety of evidence such as interviews, written progress records, photographs, film or audio evidence and checking candidate lab books/blogs. These are not assessed and the focus of these is ensuring that the work is being carried out individually. This raises questions about whether a final, written report can truly reflect the practical skills the Assignment aims to assess.

4.2.2 National 5 Assignment: Changes for 2017-18

The National 5 Assignment was carried out for the first time in 2014 so at the time of the Thistle Wood School case study, in 2016-17, the Assignment was in its fourth year. However, Thistle Wood School was in its third year of implementation due to a one-year delay in adoption. The previous section compared the Assignment as intended by the SQA to what was observed in practice. It also discussed SSI contexts and factors that caused a move away from inquiry in the context of SSI. The year following the Thistle Wood School case study, the SQA (2017b) proposed changes to the National 5 Assignment that affect how it is carried out in schools. In the Thistle Wood School case study, the final focus group interviews were carried out at the end of the academic year 2016-17, with these proposed changes coming into place in the academic year 2017-18. It is no surprise therefore that the teachers were keen to talk about their understanding of these changes and how these would affect their teaching of the Assignment. At the time, the teachers understanding of the changes was limited to: "bringing in a time limit for the write up" (Nadia) and "[a requirement] to do an experiment from this session onwards" (Victor).

This section will discuss the changes to the Assignment in terms of the pedagogical approach, the SSI contexts and skills and knowledge assessed.

The curricular documentation informing this section includes the National 5 Course Specification (2017a), National 5 Assignment Assessment task (2017b) and Guidance on conditions of assessment for coursework (SQA, 2017e).

(i) Pedagogical approach

There were few changes in terms of the pedagogical approach to the Assignment. The Assignment is still recommended to take place over two stages: the research stage and the communication stage. An additional preparatory stage is eluded to but, again, not explicitly stated. The overall time limit remains the same at 8 hours but the report writing stage is limited to one hour and a half.

The SQA (2017e) recommends that teachers first advise candidates on coursework assessment before the research stage begins. They clarify this to mean advising on sources of information, relevance of materials, structure of the report, techniques of data collection and presentation, skills of analysis and evaluation, and health and safety considerations (SQA, 2017e, p. 1).

Reasonable assistance is described in a great deal of detail in comparison to earlier curriculum documentation, particularly in relation to facilitation the research stage (*open inquiry* pedagogical approach in Thistle Wood School). For example, the SQA (2017e) describe a teacher "drawing out or teasing out points without leading candidates" by "raising other questions that make the candidates think about the original problem, therefore giving them the opportunity to answer their own questions without supplying the actual answers" (SQA, 2017e, p. 4).

In the final stage of the Assignment, the communication stage (*supervision* in Thistle Wood School), the SQA (2017e) clarify the conditions under which the assessment must be taken. They extend the description of "high degree of supervision" to include covering up classroom display materials, no access to e-mail, the internet or mobile phones, and no interaction with peers. There is further clarification of the role of the teacher and "no assistance of any description" should be given (SQA, 2017e, p. 6).

(ii) SSI context

From 2017-18 students are no longer asked to "describe an application of biology, chemistry or physics and explain the effect on the environment/society" (SQA, 2016, p. 8; SQA, 2017b). In the Thistle Wood School case study this was the only aspect of the Assignment where the students engaged with SSI contexts. Thus, the removal of this requirement is likely to remove any potential to explore SSI contexts. In fact, there is some indication that students may be penalised for discussion of societal implications at the expense of purely scientific evidence: "Credit should only be given for underlying biology [chemistry or physics] not general information, e.g. historical or socio-economic" (SQA, 2017b, p. 11).

The SQA (2017b) give example aims which indicate potential topics. In biology, the aim relates to the topic of enzymes: "to investigate the effect of temperature on the activity of an enzyme" (SQA, 2017b). In chemistry, the aim relates to the topic of de-icers: "to determine the effect of different de-icers on depressing the freezing point of water" (SQA, 2017c). In physics, the topic relates to forces: "to investigate the effects of the length of crumple zones on the force experienced in a collision" (SQA, 2017d). The SQA (2017b) describe appropriate topic choices as those which correspond with National 5, have associated experimental work that can generate numerical data and will allow candidates the opportunity to access all of the available marks.

With the removal of the requirement for the topic to be related to societal implications, and the chance that by allowing students to explore SSI contexts the student may be penalised, it is unlikely that teachers will continue to treat the Assignment as an opportunity to carry out inquiry in the context of SSI at all.

(iii) Skills and knowledge

The National 5 Assignment is an assessment of skills and knowledge and this remains the case the changes implemented in 2017-18. The skills and knowledge assessed and the marks allocated to each one is shown in Table 4-7 (SQA, 2017b, pp. 10-19).

Table 4-7 Skills and knowledge assessed in the National 5 Assignment (2017-18) (SQA, 2017b, pp. 10-19).

Assessment Criteria	**Marks**
Aim	1
Underlying biology	3
Data collection and handling	6
Graphical presentation	4
Analysis	1
Conclusion	1
Evaluation	2
Structure	2
Overall	20

Presentation and analysis of data remains the largest focus of the Assignment with nine marks or 45% of the total assessment, which is an increase compared to previous years (SQA, 2017b). This includes presentation of raw data in a table, calculations, data from secondary research, a comparison with own experimental finding and presentation of data as a graph (SQA, 2017b).

The focus on giving scientific explanations, using scientific knowledge has decreased and three marks are awarded for explaining the underlying biology. Students are no longer required to "describe an application of science and it effect on society or the environment" (SQA, 2016, p. 8). Students will also give scientific explanations when they draw conclusions, which is awarded one mark (SQA, 2017b).

The skills focus has shifted away from secondary research and towards experimental investigation. There are no marks awarded for research directly but one mark is awarded for presentation of data from secondary research (SQA, 2017b). There is no longer a requirement to evaluate sources of evidence.

In terms of presentation of findings, one source of secondary evidence must be presented in an appropriate format such as the full URL and two marks are awarded for report structure. This is the same focus as previous years.

The focus on planning, carrying out and evaluating experiments has greatly increased. Whereas prior to these changes, experimental investigations were recommended but not required, in 2017-18 they are a requirement and awarded three marks. These marks are awarded for a description and evaluation of the method for the experiment. Students are not expected to *plan* the experiment but will carry it out and evaluate it. The teachers are expected to "supply instructions" for the experiment but the student must "summarise the method" (SQA, 2017b, p. 6, p. 12). Students evaluate the method by "identifying a factor which can be expected to have a significant effect on the reliability, accuracy or precision of the experimental work" and giving an "explanation of what could have been or was done to minimise the effect of the identified factor or the evidence supporting the identification of the factor" (SQA, 2017b, p. 18).

The focus on proposing an investigatable question or aim remains the same and is low. As discussed in the previous section (SSI contexts), the aims no longer explore the implications for society.

Large changes to the Assignment were proposed for 2017-18. The pedagogical approach is described in the same way, consisting of a research and communication stage. In practice the Assignment will not be carried out in the way it was previously intended or the way it was observed in Thistle Wood School. This is because the focus has shifted away from an open secondary research-based inquiry to a teacher-led structured experimental inquiry with a minimal amount of secondary research. The skills assessed continue to focus overly on analysis and presentation of data but the focus on experimental skills has increased. There will no longer be a requirement or even an opportunity for students to explore SSI contexts (SQA, 2017b).

4.2.3 Curricular documentation and inquiry in the context of SSI: Looking ahead in Ireland

In Scotland, the science curriculum has moved away from assessment of inquiry in the context of SSI. However, in Ireland the Junior Cycle Science in Society Investigation, an assessment of inquiry in the context of SSI, is proposed to take place for the first time in Autumn/Winter of 2018. As such the NCCA, the body who designed and supports teachers in carrying out this assessment, are in a position to learn from the journey taken by Scottish curriculum designers and teachers over the past four years. The prescribed teaching approach, SSI contexts, and skills and knowledge that the Science in Society Investigation aims to develop and assess are described by the NCCA in the *Guidelines for the Classroom-Based Assessments and Assessment Task* (NCCA, 2016) and the *Curriculum Specification* (NCCA, 2015).

This section will briefly outline the intended approach to the Junior Cycle Science in Society Investigation, as outlined by the NCCA (2015; 2016). It will discuss the pedagogical approach, SSI contexts and skills and knowledge the assessment aims to develop and assess. It will then present recommendations for implementation of inquiry in the context of SSI in Ireland, based on analysis of the Scottish curriculum documentation and practice observed in Thistle Wood School.

(i) Pedagogical approach

The Science in Society Investigation is expected to be carried out over three weeks of class time, in three stages: initiating research, communicating findings and evaluating. The research stage may be carried out collaboratively while the communication and evaluation stages are expected to be carried out individually (NCCA, 2016). Collaboration is described as discussing various aspects of the investigation in small groups (NCCA, 2016).

During the first stage, initiating research, the student chooses the topic for investigation, decides a specific research question, and gathers and records information through secondary research (NCCA, 2016).

In the following stage, communicating findings, the student selects information from their sources of evidence relevant to developing a response to their question for investigation (NCCA, 2016).

In the final stage, evaluating information, the student develops a personal opinion relating to their chosen research question. At this stage, students work individually to compile a report of their investigation (NCCA, 2016).

From the NCCA's description it is unclear where the distinction is drawn between the second and third stage of the assessment. While the second stage is called "communicating findings", it is in the final stage that they compile their report (NCCA, 2016). Unlike the two stages of the National 5 Assignment (SQA, 2016) which have clearly different pedagogical approaches (*open inquiry vs. supervision),* the NCCA doesn't clearly distinguish the role of the teacher in the different stages. The NCCA describes the way in which teachers should facilitate *all* stages of the assessment as "reasonable support" (NCCA, 2016 p. 8). Students should be encouraged to show a "level of initiative" but teachers can support students by clarifying the requirements of the task, providing exemplars, providing instructions at strategic intervals and providing supports for students with special educational needs (NCCA, 2016, p. 9). The teacher acts as a facilitator throughout the stages of the assessment.

Student choice is emphasised as a motivating factor for all stages of the assessment and students choose their own topic (initiating research stage), the format of the report (communicating/ evaluating findings) and the extent to which collaboration is used (initiating research stage only) (NCCA, 2016, p. 23). In this way the assessment can be changed according to the needs, contexts, and circumstances of the students (NCCA, 2016).

The NCCA (2016) emphasises the importance of student and teacher preparation in years one and two of secondary school in preparation for the Science in Society Investigation in third year (NCCA, 2016). The case studies described in Section 4.3 explore practice relating to the development of skills and knowledge in preparation for the Science in Society Investigation in years one and two of secondary school.

Unlike the National 5 Assignment, which was externally marked by the SQA, the Junior Cycle Science in Society Investigation will be marked by the teachers themselves. The teachers use the assessment criteria provided by the NCCA to decide the level of achievement of their students (NCCA, 2016).

(ii) SSI context

The NCCA (2016) recommends that students choose their own topic for investigation and this will increase the personal and local relevance of the topic. The topic is described as a scientific topic and its impact (positive or negative) on society and/or the environment (NCCA, 2016, p. 26). For example, the societal/environmental implications of an application of science. Topics that have a range of points of view are encouraged. The NCCA provides the following set of criteria for choosing the topic for investigation:

1. "Is this topic course-related, an issue of personal interest, or one with local relevance?"
2. "Can the topic be researched?"
3. "Is there a sound base of scientific understanding and ideas?"
4. "Are there two or more sides to the story?"
5. "Can it be turned into a specific research question?"

(NCCA, 2016, p. 37)

Using these criteria, the NCCA (2016) clearly aims to direct students towards choosing SSI contexts. These criteria ensure that the topic has societal or environmental implications but also relevant underlying science. Ensuring the topic has multiple points of view relates to the controversial nature of SSI. Suitable topics can be researched and have research questions associated with them.

The NCCA (2016) provide two exemplar topics that aim to fit the criteria given above. The first topic investigates the technological application of nuclear power plants and their societal and environmental impact, and the second topic explores the technological application of electronic passports and their societal implications.

(iii) Skills and knowledge

The NCCA discusses the skills and knowledge that the Science in Society Investigation aims to assess. The inquiry "should be viewed as part of teaching and learning, and not solely for assessment purposes" (NCCA, 2016, p. 8) and as such should be considered to develop, as well as assess skills and knowledge of science. Unlike the National 5 Assignment, individual skills are not given set marks.

In the initiating research stage, the students are assessed on their performance of the following: Choosing a topic and research question, finding information about the topic from a range of sources and including a reference list, evaluating the reliability (relevance, accuracy and bias) of the sources and considering the quality of the information collected (NCCA, 2016, pp. 31-32).

The skills relating to the communication stage are: Positioning the topic as science in society, explaining the relevant science and the impact of the topic on society and/or the environment, presenting the investigation in a structured, clear and easy to read way, using scientific terminology and representations, using an innovative approach and explaining different sides of the argument (NCCA, 2016, pp. 31-32).

In the final stage, the evaluation stage, students are assessed on their ability to: Evaluate information, consider and discuss their own view on the chosen topic, link the information to the topic, review the information by giving scientific explanations, and giving a personal opinion that is justified by the information in the report (NCCA, 2016, pp. 31-32).

Students will be assessed on their ability to choose a clearly defined research question based on scientific knowledge ("background reading"). This question need not be set in stone at the start of the inquiry but can be changed and refined as the research progresses (NCCA, 2016).

Students will also be assessed on their ability to research. They should gather and record evidence relating to their research question from the internet, newspapers, science journals or magazines etc. Students are asked to record the source of all evidence and evaluate sources in terms of reliability, relevance, accuracy and possible bias (NCCA, 2016).

They are also encouraged to carry out their own primary research such as a "survey to support their research" or "experimental investigation" although this is not a requirement (NCCA, 2016, p. 27).

Students are assessed on their ability to communicate and explain the findings of their primary and secondary research by selecting relevant information from their sources of information and data, e.g. written text, audio/visual, charts, survey responses and diagrams (NCCA, 2016). The student is assessed on their ability to explain the topic in their own words and credit is given for situating explanations within the SSI context; the NCCA describes how students should "position the topic as science in society and discuss the impact of the topic on society and/or the environment" and discuss the "personal or local relevance" and the "different viewpoints and sides of the argument" of the SSI context (NCCA, 2016, p. 31). Scientific knowledge is expected to be used when communicating the findings.

Students are assessed on their ability to evaluate the researched information. They are assessed on their ability to comment on agreement or disagreement between sources of evidence and make judgements about how the information supports or does not support their research question. Students are then expected to state a personal opinion based on their research and justified with scientific knowledge. Assessment of these skills directly relates to exploration of SSI contexts as they relate to the multiple viewpoints and the inability to reach finite conclusions inherent in SSI contexts.

On the surface, the National 5 Assignment (the version that ran for four years prior to 2017-18) was similar to the NCCA's proposed Science in Society Investigation (NCCA, 2016). Both assessments can be described in terms of pedagogical approaches, SSI contexts and skills and knowledge developed and assessed. Both assessments aim to use an open secondary research inquiry approach to assess a range of skills and knowledge. Both ask students to describe an application of science and the implications for society.

However, there are some obvious differences between the SQA's (2016) approach and that of the NCCA (2016). In terms of the pedagogical approach, in practice there were three clear stages to the National 5 Assignment as observed in Thistle Wood School. First the teachers instructed the students about the assessment, then the students carried out their research and experiments, and finally, the students wrote a report of their findings while supervised by their teacher. The stages of the NCCA's (2016) Science in Society Investigation are less clear. The role of the teacher at each stage is not clearly defined. This is because the stages are defined by the skills they aim to develop rather than the teaching approach.

SSI contexts in the National 5 Assignment and in practice in Thistle Wood School were not emphasised and, in fact, students that used SSI contexts were often penalised. However, the NCCA (2016) have placed emphasis on SSI contexts and aim to reward their use. Students are rewarded for choosing an "interesting" or "novel" topic. They are rewarded for positioning the topic as "science in society" and discussing the impact on society. They are rewarded for discussing different sides of the argument and rather than a finite conclusion, the student is expected to give a "personal opinion".

The skills and knowledge assessed in the SQA's National 5 Assignment (SQA, 2016) relate to data analysis and presentation and giving scientific explanations, using scientific knowledge without relating it to impact on society. However, in the NCCA's (2016) Science in Society Investigation (NCCA, 2016) the skills focus is on secondary research, critical evaluation of evidence and giving scientific explanations of the implications of science for society, using scientific knowledge.

The following paragraphs contain recommendations for the NCCA curricular policy relating to the Science in Society Investigation. It is recommended that the pedagogical approach to the stages of the National 5 Assignment are clearly defined. As well as stating the skills that students will develop at each stage, the teacher's role should be discussed. This will help the teachers understand the intended teaching approach to the assessment.

It is promising to see a high emphasis placed on exploration of SSI contexts and the skills relating to this (e.g. secondary research/ critical evaluation of evidence) and this is reflected in the assessment criteria. This should avoid the situation observed in Scotland where students were penalised when discussing the implications for society due to misaligned assessment criteria. However, the NCCA (2016) still recommends that students carry out an experiment, although this is not reflected in the assessment criteria. Observations of practice in Thistle Wood School indicate that inclusion of experiments in inquiry in the context of SSI promote a move away from true SSI contexts in favour of contexts with easily accessible experiments. If the Science in Society Investigation is aimed to be an open inquiry in the context of SSI, which develops skills relating to research and critical evaluation of evidence, then inclusion of experimental investigations may best be avoided.

Section 4.3 explores the Science in Society Investigation in practice. It presents two case studies that follow teachers as they prepare their students to undertake the Science in Society Investigation and discusses the pedagogical approach, SSI contexts, and skills and knowledge developed and assessed in practice.

4.3 Irish case studies: Clover Field School and Daisy Park School case studies

This section presents a study containing two separate case studies that explore the teacher and student experience of carrying out inquiry in the context of SSI. The case studies follow two Irish teachers, from two schools, Clover Field School and Daisy Park School, as they prepare their students to undertake the Irish Junior Cycle Science in Society Investigation. The case studies ask: What are the teachers' and students' experiences of carrying out inquiry in the context of SSI in preparation for the Science in Society Investigation?

This section presents a single methodology relevant to both case studies but presents and discusses findings from each case study separately. Overall conclusions, relevant to both case studies, will then be discussed.

4.3.1 Methodology

This study is comprised of two separate case studies, with the same methodology. The case studies are qualitative, instrumental case studies. They are instrumental in that they provide information for a wider research question rather than the interest being limited to the cases themselves. The role of the researcher in this case study was as a passive and objective observer. The participants are the teachers and the student voice is heard through secondary documentation provided by the teacher. Both case studies are set in Irish secondary ("second level") schools.

Clover Field School case study follows Sam, a biology and science teacher, over seven lessons with a first-year class of 18 students (aged 12-14). Clover Field School is a small (~300 students at the time of the case study), relatively new, mixed-gender school.

Daisy Park School case study follows Joe, a biology and science teacher, through 6 lessons with a second-year class of 19 students (aged 13-15). Daisy Park School is a reasonably large (~700 students), mixed gender school. Both teachers have over ten years of experience each.

The data collection methods include observation of lessons, individual open response interviews and secondary documents (Table 4-8 and Appendix A).

Table 4-8 Data collection instruments (Clover Field and Daisy Park School)

Data collection instrument	Clover Field School	Daisy Park School
Lesson Observations	✓	✓
Teacher interview	✓	✓
Secondary documentation		
Teacher lesson plans	✓	✓
Student work	✓	✓
Student questionnaire		✓

Analysis was carried out qualitatively using thematic analysis as described in Section 2.2.3. Validity was considered and increased by member-checking. This involved checking the initial themes with the participants (the teachers) to determine whether they felt they accurately represented their experience. Reliability of findings was increased through systematic analysis procedures, including the creation of detailed codebooks for thematic analysis (Appendices E and F). This ensured that the researcher's coding was consistent over different time periods.

4.3.2 Findings: Clover Field School case study

Findings will be presented and discussed for each case study separately. Clover Field School case study will first be presented and discussed, followed by Daisy Park School case study.

Table 4-9 shows the themes and sub-themes identified from thematic analysis of the student and teacher data sources from Clover Field School. The sub-themes are displayed in order of emphasis, according to the number of coded references to each sub-theme.

Table 4-9 Clover Field School themes

Theme	Sub-theme
Skills	Plan and carry out experiments
	Evaluate and make changes to experiments
	Propose investigatable questions
	State justified hypotheses
	Explain scientifically
	Present and analyse data
	Self-management
Knowledge	Recall and apply scientific knowledge
	Implications of scientific knowledge for society
Pedagogical approach	Open inquiry
	Guided discussion

Three overall themes were identified in Clover Field School case study: *Skills*, *knowledge* and *pedagogical approach*. The pedagogical approach theme relates to the teacher experience and was identified from the teacher documentation (teacher interview, lesson plans and researcher field notes from lesson observation). The skills and knowledge themes relate to the student experience and were identified from the teacher interview and secondary documentation relating to the teacher, and from student work.

The detailed codebook shown in Appendix E gives an overview of each theme and sub-theme. The following paragraphs present evidence for each theme and sub-theme, which will be discussed further in Section 4.3.3.

(i) Teacher experience: Pedagogical approach

The pedagogical approach used by Sam was a combination of mainly *open inquiry* and, to a lesser extent, *facilitated discussion* (Table 4-9). The sub-themes are presented in order of emphasis, which is also the order in which they occurred.

(a) Open inquiry

Sam took an *open inquiry* approach to facilitating the woodlice experiment. Although the topic or theme for investigation was chosen by the teacher, the question for investigation was chosen by the students. This is a key distinction between open and guided inquiry (see Table 1-4). He described the *pedagogical approach*:

> On the very first day, without telling them anything at all, we rummaged and searched for woodlice…Then I explained to them that what we would be doing was investigating the preferences of woodlice in terms of living conditions. They had more or less free-reign on what kind of living conditions they would look at. (Sam)

The students had “free-reign” to choose their investigation question. He also described his role as facilitator:

> Some of them had more complicated designs which I tried to steer them away from … If it was in any way practical, I would say ‘OK brilliant! Let’s do it.’ … It was a first go and they should give it a go (Sam)

He wanted to say “Brilliant! Go for it.” but at times his role as a teacher was to “steer” and guide students away from one path and towards a more fruitful path. Overall, the aim was to allow the students to plan their own experiment, with imperfections that give rise to opportunities for evaluation and changes. Sam then described how he “would advise them a little bit …rather than giving them advice I would always just ask questions”. With the decreasing emphasis on the teacher as knowledge provider, there was increasing emphasis on the students’ role.

Collaboration between the students was emphasised in this *open inquiry* approach:

> They helped each other a lot. Somebody would figure out a way of doing something that worked well and that would spread around the room...There was disagreements due to conflicting results between groups. So, they would check each other and point out to each other ‘that’s because of such and such’. (Sam)

Sam described the importance of collaboration but this was not reflected in the student work, where the focus was on *self-management*.

(b) Guided discussion

In the final lesson, Sam facilitated student discussion around the ethics of the use of animals in science and animal rights. Evidence for this theme was mainly identified in researcher field notes from observation:

Sam: “Did any of you think about the woodlice before, when you were doing the experiment?”

5 students raise their hands in response.

Sam: “Those who raised their hands, I’d be interested in hearing about your conversations. About what you said about woodlice’s rights?”

Students participated in a mixture of whole class, teacher led questioning and group discussion of a number of questions set by the teacher: *“Why don’t animals have the same rights as humans?”, “Why do we as humans have more rights?”, “Does everyone agree?”.*

Figure 4-11 Extract from researcher field notes showing facilitated discussion in Clover Field School

The teacher posed questions and led whole class discussion. He also facilitated group discussions around the questions posed.

(ii) Student experience: Skills

Seven skills were identified as being developed by students in the Clover Field School case study. The following paragraphs present evidence for each skill as identified from the teacher interview, student work and researcher field notes. The student work included videos, screencasts and written reports. Screencasts are video recordings of the student's work displayed on a screen where they drew images and recorded an audio description of their work.

The skills are presented in order of emphasis in Table 4-9 with the top two sub-themes relating to planning and carrying out experiments. In Thistle Wood School case study (Section 4.1) these two sub-themes were combined into one sub-theme. However, in Clover Field School there was a much larger emphasis on experimentation and two sub-themes were identified: *plan and carry out experiments* and *evaluate and make changes to experiments*. There was little focus on data presentation and analysis, and *self-management*.

(a) Plan and carry out experiments

The skill *plan and carry out experiments* included evidence of equipment and experimental design, and discussion of variables. This sub-theme was mainly evidenced through student work.

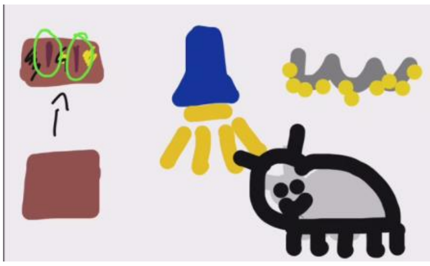


Figure 4-12 Snapshot of student video showing equipment used (student work sample three)

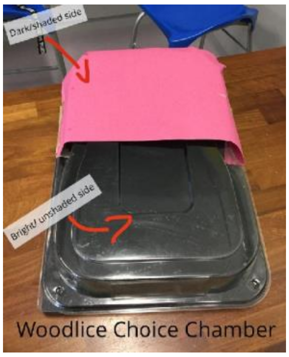


Figure 4-13 Photograph of experimental set up (student work sample ten)

Students also described their experiment as it was planned and implemented, giving details of variables. In this case the independent variable was light intensity:

> Procedure: We cut the sides of the box so we could fold them over the top to create like a shelter and a darker side for the woodlice. Then we let the other side exposed to the light so we could check whether they like the dark or the light. Then we placed the lamp over the open side making sure that it didn't light up the side we wanted dark. We then placed paper on the inside so the surface was even on both sides. (student work sample one)

Student work sample one clearly considered the independent variable ("darker side"/ "exposed to the light") and the control variables ("the surface was even on both sides"). Although some details were lacking, such as a statement of the dependent variable or more control variables.

(b) Evaluate and make changes to experiments

This skill is closely linked to the previous skill (*plan and carry out experiments)*; when planning their experiments students evaluated their plans and made changes. These changes were based on a range of considerations. There were practical considerations, such as "woodlice escaping", "daylight getting through the box" or availability of equipment. Students also considered the feasibility of their designs:

> I drew a very simple design and [my partner] drew a more complicated design. At first we thought we were going to use my design but then we realised we could use Sara's more complicated design (student work sample three)

This sub-theme contains references to the problems and ethics surrounding use of woodlice in experimentation. In evaluating the experiments in terms of the ethics surrounding the use of living things, students discussed the implications of scientific knowledge for society:

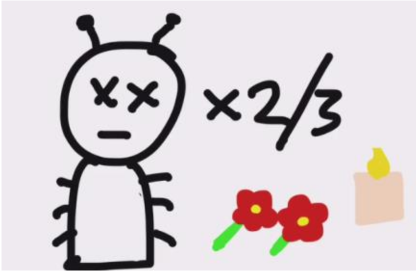


Figure 4-14 Snapshot of screencast describing the issues surrounding use of woodlice in this experiment (student work sample two)

> During our experiment, 2 or 3 of the woodlice died doing it. Maybe because of us dropping them in. So, yeah, R.I.P woodlice. (student work sample two- voiceover)

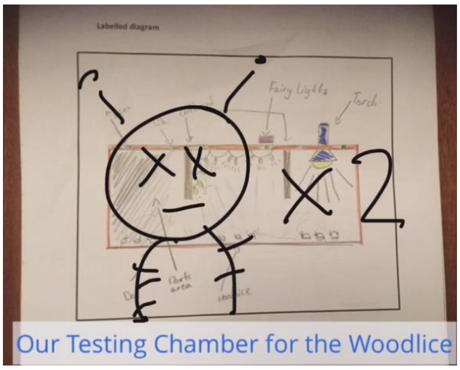


Figure 4-15 Snapshot of screencast describing the issues surrounding use of woodlice in this experiment (student work sample seven)

> Unfortunately, two of the woodlice in our experiment died. (student work sample seven – voiceover)

The tone of the students is not flippant, although the picture and wording might give that impression. There is awkwardness to the statements; they contain nervous laughter.

(c) Propose investigatable questions

This sub-theme was mainly demonstrated through student work. The students did not necessarily state their investigation question as a question, often it was worded as an aim. For example, students said: “We decided to study how much light woodlice prefer to live in” (student work sample two), “We could check whether they liked the light or the dark” (student work sample three) and “To see if they would go to the really bright area or to the fairly bright area or to the dark area” (student work sample four).

(d) State and justify hypotheses

Evidence for this sub-theme was identified in both teacher and student data sources. Sam described the importance of developing justified hypotheses:

> … more than anything else they learnt what it was to form a good hypothesis. I don't think they really got it before doing this. They confused hypotheses with predictions. When they come out of these two weeks they really had a good idea of what a hypothesis was. (Sam)

The teacher did not elaborate on what he believed to be the difference between hypotheses and predictions but talked hypotheses in relation to variables, results and conclusions.

The student work also evidenced the development of this skill:

> My prediction is that they will be more attracted to the dark side as if they are found in their habitat they are usually under objects so I predict they will like the sense of darkness under objects. I think this is their preferable lighting as it is also protection from predators. (student work sample five)

The student used the word prediction but the description clearly described the independent and dependent variables of the experiment. The student also used scientific knowledge to justify the hypothesis, using scientific terms such as "habitat" and explaining their reasoning ("protection from predators").

(e) Explain scientifically

In the case of Clover Field School, students *explain scientifically* when drawing conclusions from their experimental investigations:

> We learnt that the woodlice much preferred the darker area to the light, In the dark they seemed to stick in groups and huddled up close together, while the two woodlice which were in the light area seemed to move around restlessly and tried to find an escape route. (student work sample nine)

The students presented their work in a variety of ways, including written reports, screencasts with voiceovers and time-lapse animation. Although in the Thistle Wood School case study, presenting information was given its own theme, in the Clover Field School case study presentation of scientific evidence was not found without scientific explanation so the sub-theme *present information* was not identified.

For the final lesson examining the ethics surrounding animal experimentation, Sam described how students were expected to *explain scientifically:*

> Being able to articulate their arguments and being able to express themselves and verbalise their ideas and their perspectives on the issues. (Sam)

(f) Present and analyse data

There was evidence of some basic presentation of data in student work:

Results

The results were what we expected. 7/9 made it to the darker chamber. The other two died or couldn't find the way. I think this was in line with what we expected to happen. Here is our table of results.

	Dark	Medium	Bright
No. of woodlice	7	1	1
Condition of woodlice.	Running around enjoying themselves.	Dead (Unmoving, on back)	In a corner looking for the dark

Figure 4-16 Student work evidencing present and analyse data (student work sample seven)

This student presented their raw data in a table and summarised in words. Representations of data were limited to tables of results, no students presented their results as a graph.

(g) Self-management

This skill was evidenced in student work. In the Clover Field School case study this sub-theme focussed on students understanding of their own point of view and opinion, specifically in relation to the use of animals in science:

> Personally, I am not a fan of woodlice. I find them creepy. I've never liked them. While David, he was actually quite happy to pick them up. He didn't mind them walking around. He was looking at them and was like 'OK, they're not too bad'. (student work sample three)

This student recognises his own point of view in relation to using animals in the experiment and how that fits in with others' views.

(iii) Student experience: Knowledge

There were two *knowledge* sub-themes identified from thematic analysis. *Recall and application of scientific knowledge* was the larger of the two sub-themes. Students mainly gave scientific explanations, using scientific knowledge, without discussing the implications for society. The following paragraphs present evidence relating to each knowledge sub-theme.

(a) Recall and apply scientific knowledge

When students carried out the woodlice experiment they recalled and applied their scientific knowledge to justify their hypotheses (*state and justify hypotheses)* and draw conclusions (*explain scientifically*) but implications for society were rarely discussed. The students focussed mainly on the underlying science, e.g. preferences for certain conditions for "protection from predators".

(b) Implications of scientific knowledge for society

This sub-theme was identified mainly from the teacher interview and to a lesser extent the student work. Sam discussed the implications of science for society when describing the final lesson:

> The big skills that I was trying to get them, was to think about the effect that science has on the world around them and on society ... (Sam)

Some students briefly discussed some ethical issues, or at least some of the problems, around using living things in their experiments. They discussed issues with the woodlice dying and recognised that this was an issue and talked about what they did to keep the woodlice "happy" when not in use.

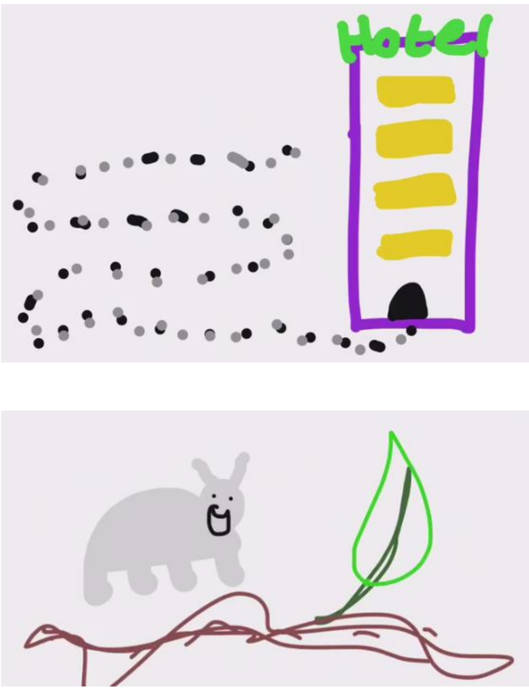


Figure 4-17 Snapshots of student's screencast describing "happy" woodlice in the "hotel" (student work sample two)

> For the moment all the woodlice have gone into a little hotel in [Sam's'] room. So the woodlice are happy now just munching on some leaves (student work sample two- voiceover)

The student personified the woodlice with a smiley face and described it as “happy”. This indicates that the student wanted the woodlice to be well cared for and recognised their own role and responsibility in ensuring the welfare of the animals in their care. This idea of the woodlice being “happy” was also reflected by Sam’s description of the woodlice hotel as somewhere that would “keep them [the woodlice] happy”. He stated that:

> As the two weeks had gone on we skirted round the idea of ‘we must be really careful with the woodlice and we don’t want to harm the woodlice’. That was implied all the time. (Sam)

Sam described the students’ “diversity of views” relating to this sub-theme:

> Some people were like ‘ah they’re only woodlice, it doesn’t matter’. And other kids obviously from the outset had felt really uncomfortable… they didn’t feel comfortable that the woodlice were being ‘put out’ even if they weren’t harmed. (Sam)

4.3.3 Discussion: Clover Field School case study

This section discusses the teacher and student experience of inquiry in the context of SSI in preparation for the Science in Society Investigation, in Clover Field School. First, an overview of the inquiry and *pedagogical approach* (teacher experience) will be discussed, followed by discussion of the student experience in terms of *skills* and *knowledge*.

(i) Overview and pedagogical approach

Sam aimed to combine experimental and discussion-based inquiry in the context of SSI, to form a coherent series of lessons that would develop the skills and knowledge relevant to the Science in Society Investigation. However, the result was a mainly experimental investigation with a short discussion of SSI contexts afterwards:

> It was really an extended experimental investigation …I hybridised it with a mini Science in Society Investigation…It was just an SSI theme tagged onto the end of an experiment. (Sam)

The experimental investigation took place over six 40-minute lessons (2 weeks) and a single final lesson was dedicated to discussion of the SSI context, ethics of the use of animals in science and animal rights. Figure 4-18 gives an overview of these lessons.

During the first six lessons the teacher acted as a facilitator for an *open inquiry*. The students proposed a question and stated a hypothesis for their investigation, planned, carried out and evaluated an experimental investigation, analysed their gathered data and drew conclusions.

In a final lesson, the students took part in whole class and group *guided discussion*, facilitated by the teacher. The teacher posed a variety of questions to the students regarding the ethical issues surrounding the use of animals in science.

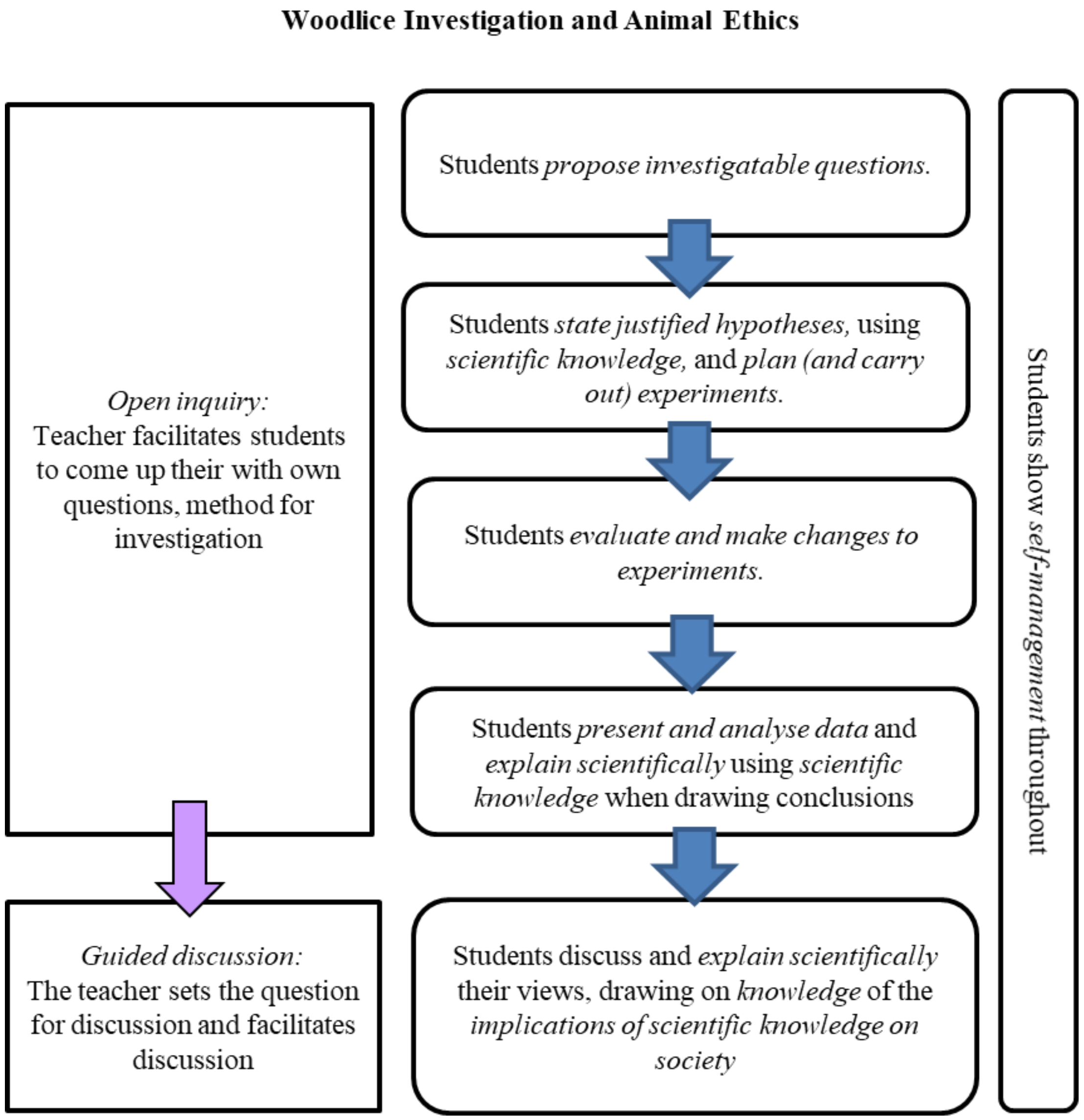


Figure 4-18 Overview of the Clover Field School case study

(ii) SSI Context

The SSI context for the inquiry was the ethics surrounding the use of animals in science and animal rights, as described by Sam:

> ... the role that scientists have in thinking about ethics and making value judgements ...we are doing the science and we have real animals in the room. They have to own and take on that responsibility themselves of making value judgements of getting into the ethics and grappling with the ethical questions. (Sam)

There was no evidence of explicit reflection or discussion of the SSI contexts during the experimental stage of the inquiry. However, at times the students were observed to consider the welfare of the woodlice and described using a "hotel" to keep the woodlice "happy". They also considered their role in ensuring the welfare of the animals they used.

In the final guided inquiry, the students discussed the SSI context:

> We're more developed and until every human have equal rights and we fix our own problems… then we work on their rights. (student one – researcher field notes)

> Animals have so much to offer. (student two – researcher field notes)

While student one presented a human centric view of the use of animals in science and animal rights, student two was more in favour of animal rights. This shows that the chosen SSI context can be considered controversial, with multiple points of view to explore, even between the students in the classroom. The SSI context was authentic but was only a minor focus of the student inquiry and students were not facilitated to take action as a result of their inquiry

(iii) Skills and knowledge

Sam talked about developing and assessing inquiry skills, using the assessment criteria (referred to as "rubrics") produced by the NCCA (2016):

> [I used the] rubrics, started to pull out some little mini-rubrics. So, for a particular investigation would pick out maybe one or two inquiry skills. Such as developing hypotheses or presenting data. (Sam)

This highlights the influence of the curricular documentation on the teacher's approach.

Planning, carrying out and evaluating experiments was the main focus of the inquiry in Clover Field School. The two skills *propose investigatable questions* and *state justified hypotheses* are also closely related to planning experimental investigations and further confirm the student and teacher emphasis on skills relating to experimental inquiry. The skills developed by students relate closely to traditional experimental inquiry, following the "scientific process". The students carried out a series of sequential steps where they first asked questions and proposed hypotheses. They then designed and carried out experimental investigations and evaluated these, before analysing and presenting data gathered through experimentation and drawing final conclusions.

Scientific knowledge was used when stating and justifying hypotheses and *explaining scientifically* but the students rarely discussed implications for society or related their experimental inquiry to the SSI context.

Presentation and analysis of data was carried out when some students put their raw data into a table. This skill was performed procedurally, without reference to underlying scientific knowledge or situated within the SSI context.

Sam indicated his awareness of the curricular documentation relating to the Science in Society Investigation and referred to it during interview. However, in practice the *pedagogical approach*, and *skills* and *knowledge* developed and assessed mainly related to experimental inquiry and did not closely align with the curricular documentation (described in section 4.2.3). The SSI context chosen was authentic but was not a major focus of the inquiry. This indicates that the curricular documentation did not influence Sam's approach greatly.

4.3.4 Findings: Daisy Park School case study

Findings from Daisy Park School case study will now be presented and discussed. Section 4.3.4 presents the themes and sub-themes identified from thematic analysis and includes evidence from teacher interview and secondary documentation. Section 4.3.5 discusses the themes and sub-themes.

Table 4-10 shows the themes from thematic analysis of the teacher interview and secondary documentation (teacher lesson plans, student work, student questionnaire and researcher field notes) gathered in the Daisy Park School case study. The sub-themes are displayed in order of the number of references to the sub-theme, from highest to lowest.

Table 4-10 Daisy Park School themes (Chadwick, McLoughlin & Finlayson, 2018)

Theme	Sub-theme
Skills	Explain scientifically
	Work together
	Research
	Distinguish arguments based on scientific evidence
	Evaluate solutions
	Present information
Knowledge	Implications of scientific knowledge for society
	Recall and apply scientific knowledge
Pedagogical approach	Guided discussion
	Guided inquiry (research)

There were three themes identified from thematic analysis. The theme *pedagogical approach* relates to the teacher experience of inquiry in the context of SSI and was identified from teacher interview and researcher field notes from observation. The *skills* and *knowledge* themes relate to the student experience, as viewed by the student and teacher. These themes were identified from teacher interview and secondary documentation, including teacher lesson plans, student work, student questionnaire and researcher field notes.

Appendix F gives a detailed codebook created and used during analysis, which gives details of each theme and sub-theme.

This section presents evidence relating to each theme, starting with the teacher experience (*pedagogical approach*) and then the student experience (*skills* and *knowledge*).

(i) Pedagogical approach

The *pedagogical approach* theme was identified from the teacher interview, lesson plans and researcher field notes. As such, it represents the teacher experience as viewed by the teacher. Two sub-themes were evident in the teacher experience: *guided discussion* and *guided inquiry (research).*

(a) Guided discussion

During the Transport Problem series of lessons, the students engaged in discussion around a topic and questions set by the teacher. This was evidenced from researcher field notes:

Lesson Opening

Students are separated into 3 groups of 6 randomly by numbering 1,2,3

Teacher introduces the "transport problem" by asking students which forms of transport they use. Whole class discussion where individuals give responses.

…

Lesson body

10.10am

PowerPoint slide shows a list of transport options and teacher elicits a whole

class discussion of what they know about electric cars:

o Student 1: "it is really quiet"

o Teacher: "It is really quiet, that might be a problem"

o Student 2: "How are you meant to hear one coming"

o Teacher: "That's not just restricted to electric cars"

o Student 3: "I just got a new car that's very quiet"

o Student 4: "Don't most cars have sensors for reversing now"

o Teacher : "Has anyone had a lucky escape when it comes to cars?"

[A number of hands go up]

…

10.25am

 Students work in groups to discuss "Do your transport choices have consequences?".

One person per group makes notes. One person per group feeds back to the rest of the class.

Figure 4-19 Researcher field notes (The Transport Problem) evidencing guided discussion

Figure 4-19 shows how Joe introduced The Transport Problem series of lessons to the students through a mix of whole class and group questioning. He set the topic and questions for discussion.

In the lesson following The Transport Problem, Letters to Trump, there was also evidence of *guided discussion*, involving whole class and group discussion.

Lesson Opening

Teacher asks students if they have heard the current news about "Earthquake in New Zealand".

Teacher leads whole class discussion, students comment and ask questions.

o Student 1: "Sir, what about that tsunami?"

o Student 2: "Climate change leads to natural disasters"

Joe probes further how does climate change link to earthquake and into meaning of natural disaster.

o Student 3: "Earthquakes are going to happen because of the Earth."

o Student 2: "Making it more frequent"

Figure 4-20 Researcher field (Letters to Trump) notes evidencing guided discussion

This brief whole class discussion took place immediately prior to the introduction of the Letters to Trump task. Joe introduced climate change using a question relating to a current media interest and allowed students to answer or comment on each other's answers.

(b) Guided inquiry (research)

The pedagogical approach to The Transport Problem was limited to *guided discussion*-based inquiry whereas in the Letters to Trump lessons the teacher also used *guided inquiry* based on secondary research (see Table 1-4 for a reminder of levels of inquiry). This was evidenced from researcher field notes, and teacher lesson plans and interview.

> Students use their i-pads to research information to include in the letter
>
> o Google: "Proof that global warming is real", "Difference between climate and weather", "Global warming"
>
> o Sites: "climate.nasa.gov", "Wikipedia"
>
> No instruction by teacher given on how to research
>
> [How has Joe prepared students for this type of research in the past? How is Joe developing the skills involved?]
>
> Mix of student roles in the groups: Some groups both research and write, others one writes on i-pads and the other researches and swapping roles

Figure 4-21 Researcher field (Letters to Trump) notes evidencing guided discussion

The students were asked to write a letter to President Trump to "inform him of the difference between climate change and global warming" (Joe – researcher field notes). They were asked to research information to include in the letter (Figure 4-21). While the topic was chosen by the teacher, there was little evidence of direct instruction relating to the process of carrying out research, this was mainly devised by the students themselves, making it guided rather than structured inquiry (Table 1-4).

(ii) Skills

There were six *skills* identified in the Daisy Park School case study (Table 4-10). The sub-theme *explain scientifically* was the top focus and *present information* was the lowest.

(a) Explain scientifically

Most of the evidence for this sub-theme came from student work. Students demonstrated this skill when writing about their group's solutions for The Transport problem:

> The bridge would reduce traffic and accidents. The bridge will take 5-7 years and employ 100s of workers. If the limit of cars is cut in half it will reduce fuel gases being released into the atmosphere and traffic and accidents will be reduced too. (student work sample one)

The extract “If the limit of cars is cut in half it will reduce fuel gases being released into the atmosphere and traffic accidents will be reduced” links the solution to the problem and shows the student’s use of *scientific knowledge* as they demonstrate their knowledge of the effect of greenhouse gases. The students also drew diagrams of their ideas.

The students demonstrated the sub-theme *explain scientifically* in the Letters to Trump lessons. Figure 4-22 shows an example of a student’s letter to President Trump. The student used their own words to explain the science at an appropriate level and demonstrated their scientific knowledge while also discussing the implications for society.

> Dear Donald Trump,
>
> I am writing to discuss and prove the point that climate change is a reality.
>
> Climate change is when our weather changes, and it certainly does. Climate changes from summer climates to winter climates. There are also long term changes, for example, we all know that earth was nice and warm, but then climate changed and brought the ice age. Climate change is happening all the time. But what happening now is that climate change is changing again, and we can see that by the melting ice caps and the rising of temperatures.
>
> The average temperate on Earth is increasing by 0.2 degrees per decade. (conserveenergy-future.com) The last ice age the earth has experienced occurred 7,000 years ago.
>
> It was caused by low carbon dioxide levels in the Earth's atmosphere. Now, because of human civilisation the carbon dioxide levels have went very high. From 170 carbon dioxide parts per million, during the last ice age, to 400. The carbon dioxide levels have never been above 300 and in the last 7,000 years is humans have managed to raise it to more than double. (climate.nasa.gov)
>
> If this keeps going, the earth will become way too warm for humans at some point. Or it will melt enough ice to raise the sea levels and decrease land space and cause overpopulation. Although it is another problem for us, climate change could end everything. Scientists suggest that the ice could melt and then spread on top of our warm currents. Causing the sea and ocean to freeze and cause another ice age.
>
> We can help reduce the carbon dioxide levels though. As the new future president, I hope that you can do something, I suggest that you use renewable energy sources more, and stop the fossil fuels. I also suggest that for every tree cut down, 2 must be planted instead. And we increase recycling. (www.met.ie)
>
> Personally, I am concerned about the planet I live in. I hope you do too. And I am hoping you can do something, anything, to help save the human civilisation and the Earth.
>
> Yours sincerely,

Figure 4-22 Student letter to Trump (student work sample two)

(b) Work together

When students described this skill in the student questionnaire they simply stated that they “worked together” or “worked in groups”. Some students elaborated on this by discussing the dynamics of group work, stating that “everyone has a different point of view” and “not everyone will agree with you". Others focussed on overcoming these challenges "you have to respect people's opinions" and "we all thought of different answers" but "we agreed on certain answers".

(c) Research

Evidence for this sub-theme came from the teacher interview, where Joe discussed the Letters to Trump lessons:

> The research for information: analysing information, looking for bias, selecting information that was appropriate for communication and, of course, communicating the information in the appropriate format … the main thing is the interrogation of information and the ability to take a problem and look at it, and conduct systematic research, and to look for bias. (Joe)

Joe also stated that the "factual information" was "lost along the way" indicating his belief that knowledge may simply be forgotten by students whereas the development of the skill is more long lasting. He also highlighted that skills development is something that must be revisited throughout the students' science education in order to be effective.

Students did not talk about the research aspect of Letters to Trump and any evidence from student work was coded into the skill *explain scientifically* as the students explained their findings.

(d) Distinguish scientific arguments

This skill was identified from the student questionnaire relating to the Letters to Trump lesson. There was evidence that the students distinguished between arguments based on science and those based on other considerations, such as politics or economics. This was identified in the student questionnaires:

> I learned that a lot of the things president elect Donald trump says is not fact. There is a lot of evidence of climate change everywhere. Most websites have hard facts about climate change that contradict Donald trump. (student questionnaire – Letters to Trump)

> Donald Trump is very ignorant and has done no scientific research on the matter. (student questionnaire – Letters to Trump)

> I learned that sometimes people in power are there because they have negative views on things that people don't want to make an effort about. I learned that there is a difference between global warming and climate change I learned that the whole class has an educated view on the whole thing. (student questionnaire – Letters to Trump)

The students believe that President Trump's views on climate change are not based on scientific arguments but other considerations. For example, unwillingness to "make an effort" to combat it could be considered a political consideration.

(e) Evaluate solutions

This skill was identified from the student questionnaire relating to The Transport Problem lessons. Students talked about this skill in simple terms without giving much detail on their evaluations. Most students stated that they discussed the "pros and cons" of each "idea" or "solution" to the Transport Problem.

(f) Present information

Evidence of this skill was identified from researcher field notes and from the student questionnaire. Students presented their solutions to their classmates in The Transport Problem lesson, using PowerPoints and oral presentations, and wrote letters to President Trump during the latter lessons. However, presentation of information in student work was coded into the sub-theme *explain scientifically*. The *present information* skill is reserved for presentation of evidence without explanation. For example, Joe stated that student "communicated in the appropriate format", and students referred to "letter writing skills".

(iii) Knowledge

There were two knowledge sub-themes identified from thematic analysis. When students demonstrated or discussed their scientific knowledge they mainly did so by relating it to *the implications for society*. Evidence relating to the two knowledge sub-themes is presented in the following paragraphs.

(a) Implications of scientific knowledge for society (and the environment)

The *implications of scientific knowledge for society* sub-theme was observed in student work and the student questionnaire. Students demonstrated their scientific knowledge and linked it to societal implications:

> I learned the different types of power sources for cars to not necessarily reduce the traffic amount but to reduce the amount of pollution coming from all the cars! (student questionnaire – The Transport Problem)

> I learned that he [President Trump] thinks that global warming is Chinese hoax to Make U.S manufacturing non-competitive. I learned that hurricanes and storms are to become stronger as a result of global warming. I learned that diseases like malaria are spreading as a result of the earth becoming warmer!?? (student questionnaire – Letters to Trump)

Students also demonstrated their scientific knowledge as they gave explanations in their work. In the letter shown in Figure 4-22, the student discusses the underlying science relating to climate change and clearly relates this to implications for society:

> The Earth will become too warm for humans at some point. Or it will melt enough ice to raise the sea levels and decrease land space and cause overpopulation. (Student work sample two)

(b) Recall and application of scientific knowledge

This sub-theme is evidenced by student statements of their scientific knowledge without referring to the implications for society. References to this sub-theme were identified in the student questionnaire:

> There are more renewable energies than I knew about (student questionnaire – The Transport Problem)

> Different types of resources and gases used to power vehicles. (student questionnaire – The Transport Problem)

The quotes above demonstrate the students' knowledge of the science but they do not explicitly discuss impact on society or the environment. This *knowledge* sub-theme was also evidenced from student work:

> Sea Level rise - Global sea levels have risen by 17cm in the last century due to global warming, heating and melting the ice into water which causes the sea levels to rise. (student work sample three – Letters to Trump)

Student work sample three showed knowledge of climate change but did not explicitly discuss the implications for society.

4.3.5 Discussion: Daisy Park School case study

This section discusses the teacher and student experience of inquiry in the context of SSI, in Daisy Park School. First, an overview of the lessons and pedagogical approach will be outlined and then the SSI contexts used will be discussed. Finally, this section will discuss the skills and knowledge developed and assessed.

(i) Overview and pedagogical approach

Figure 4-23 gives an overview of the Daisy Park School case study. First, students completed The Transport Problem and this led into the Letters to Trump. The Transport Problem took place over five lessons while Letters to Trump was carried out over one lesson of class time with additional research carried out by students in their own time.

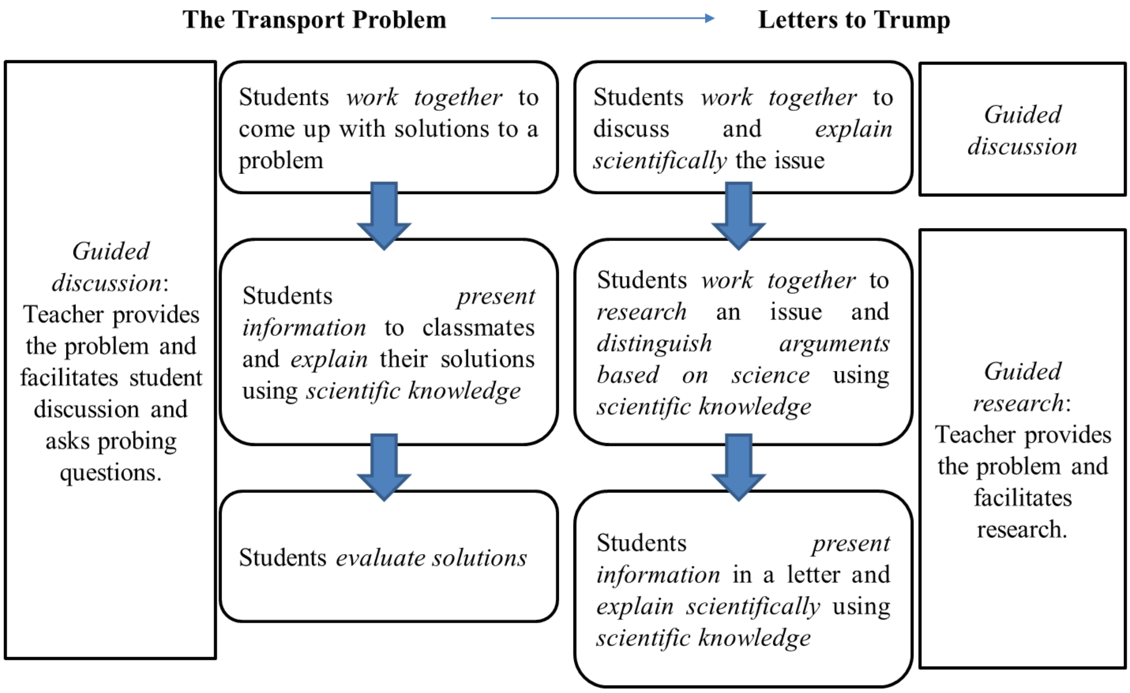


Figure 4-23 Overview of lessons from Daisy Park School

In The Transport Problem, students were asked to discuss the problem of traffic congestion in the local area, in groups of three to five. The students proposed short and long-term solutions and presented these solutions, as a group, to the rest of the class. They received peer and teacher feedback on their proposals before evaluating their own solutions by coming up with the pros and cons of each.

The final lesson was entitled Letters to Trump. Students first engaged in a short, whole class discussion about climate change and the students' understanding of its effect on natural disasters (Earthquakes, Tsunamis etc.). The teacher linked this discussion to current media items.

Joe then introduced the concept of climate change denial and read out controversial, climate change denying "tweets" from the President of the USA, President Trump:

Joe takes out a sheet of paper and reads aloud to students

o Students whispering: "Trump", "Donald Trump"- [very current topic linking global politics and global science]

o Joe reveals that the statements are made by president elect Donald Trump.

o Students are asked to complete a letter to Donald Trump to "inform him of the difference between climate change and global warming". The best ones will be sent to the Whitehouse.

Figure 4-24 Researcher Field notes showing introduction of climate change denial

The approach taken in Daisy Park School followed a *guided discussion* and guided secondary research combination approach to inquiry. Students engaged in initial discussion, followed by personal or group research. They reflected and presented their findings, before further discussion and evaluation of findings. Discussion was used at various points during the inquiry as a method of encouraging students to stop and reflect on the views encountered through their research, and their own views.

The inquiry was neither open nor didactic. While the topic and question were chosen by the teacher, the teacher acted as a facilitator during group discussion and research. The teacher circulated groups and asked probing questions. Joe described his approach as he recommended to other teachers:

> Stand back. Stop talking. One thing that really shocks me is the noise that you hear, more than anything else, is the constant teacher talk … If you are doing something like this [The Transport problem/Letters to Trump] the learning comes from the students' discovery and interaction. They are talking with their peers, engaging in constructive arguments, discussing the pros and cons. This is where true construction takes place. (Joe)

Joe's use of the term "construction" is likely to refer to constructivist theories of learning; the theory that learners construct and internalise knowledge based on their own experiences and knowledge is constructed rather than received (Cohen 2010). The teacher's belief in social constructivism, which emphasises interaction, collaboration and co-operation, is particularly evident through the types of activities chosen for students, i.e. group discussion tasks, presentation and peer review of solutions.

(ii) SSI context

There were two SSI explored in this inquiry. They were chosen by the teacher rather than the students and were skilfully chosen to be relevant and therefore engaging for the students:

> There are three things to remember in education: Motivation, motivation, motivation. They were motivated because they were incensed by the, as they put it, stupidity of the man [President Trump]. When you have students motivated they overcome the challenges and difficulties (Joe)

The Transport Problem was situated within a local context, making it particularly relevant to the students:

> It was looking at an issue that would be relevant to the students, that they could tap into fairly rapidly, and it was the idea of local congestion when getting into school in the morning. Many of them would be familiar with this because they come from the local community and towns. (Joe - interview)

There were clear scientific and societal implications for the SSI context of local congestion, as explored in The Transport Problem. The students explored the science relating to fuels and alternative fuels, and pollution. Student also considered the societal implications, such as economic, political and social factors relating to a local transport issue (e.g. who uses public transport). There were a wide range of viewpoints on the issue and the students in the class expressed a range of conflicting viewpoints: “not everyone will agree with you”, “you have to respect people’s opinions” (student questionnaire – The Transport Problem). This wide range of conflicting viewpoints meant that even after thorough consideration of the available evidence, through research and discussion, the students were not able to reach a definite conclusion. This was particularly evident in The Transport Problem where, even after opportunities to discuss and receive feedback on their solutions, the students still foresaw drawbacks to each solution: “[I learnt to] think about the pros and cons of each idea and that no solution is going to be perfect” (student questionnaire – The Transport Problem)

Letters to Trump was situated within a global context. The context was particularly “current” and contemporary:

> It was fortunate at the time and it just tied in nicely that Trump had just released a series of tweets about global warming and climate change, saying that the whole thing was a very expensive hoax ... The circumstances that set up the lesson were unique in that it happened at a time when Trump had been very vocal on a particular topic. (Joe)

The context considered a range of viewpoints based on a range of economic, political and environmental concerns. There was not the same range of viewpoints within the class as there was with The Transport Problem, all the students supported the existence of climate change:

> Some people think it’s not real and that’s their opinion… but scientists have proven it to be real. (student questionnaire – Letters to Trump)

Inquiry in the context of SSI has the potential to encourage activism and an action-based approach (Hodson, 2010). This was observed in Daisy Park School where the students followed through on their inquiry by writing letters to President Trump, an example of lobbying powerbrokers (Bencze, 2017). This was not directly referenced by the students or their teacher as an activist or action-based approach and as such was not identified in the analysis (unlike the PST case study described later in Chapter 5). Regardless of this, the students, in writing their letters, appear to have reached or at least come close to reaching the highest level of Hodson’s framework for SSI approaches: Preparing for and taking action on socio-scientific and environmental issues (Hodson, 2010, p. 199).

(iii) Skills and knowledge

The skills developed by students in Daisy Park School focussed less on traditional experimental inquiry skills such as questioning, hypothesising, experimenting, analysing data and drawing conclusions, and more on evaluation of scientific evidence, and explanation and presentation of findings. The skills *distinguish arguments based on scientific evidence* and *evaluate solutions* stand out as they relate to critical evaluation of evidence and they have not been observed in other case studies described in this chapter (Thistle Wood School case study and Clover Field School case study).

The main skill emphasised by students and their teacher was the ability to explain the science behind the topic of investigation using scientific knowledge. Students demonstrated their knowledge mainly within the context of the SSI explored by relating it to the implications for society.

During The Transport Problem there was a focus on working collaboratively. The OECD states that "young people need to have the ability to communicate exchange, criticise, and present information and ideas" to allow them to learn effectively in the 21st century (Ananiadou & Claro, 2009). This skill is not specific to science or scientific literacy but has been included because of the high number of references to the sub-theme in the data. Joe referred to the Junior Cycle key skill "working together" (NCCA, 2014b) and described students "ability to work as part of a group, listen to others and present your own opinion" (Joe).

Joe described the students carrying out *research* as part of Letters to Trump:

> analysing information, looking for bias, selecting information that was appropriate for communication… the interrogation of information. (Joe)

This matches with the view of research as discussed earlier in the Thistle Wood School case study (Section 4.1). *Research* involves thinking critically about multiple sources of information and looking for patterns and connections between sources and evidence (McMaster University Libraries, 2016).

Students also evaluated the information taken from sources as they considered whether arguments were based on science or other considerations such as economics or politics. This skill was mainly demonstrated in the Letters to Trump lesson. The students were exposed to controversial views and strived to understand the reasoning behind the viewpoint that conflicted with their own (and in their view conflicted with the science). This led them to consider the basis for the argument:

> I learned that sometimes people in power are there because they have negative views on things that people don't want to make an effort about. I learned that there is a

> difference between global warming and climate change I learned that the whole class has an educated view on the whole thing. (student questionnaire – Letters to Trump)

The student indicated that there was a political argument behind climate change denial (lack of political will to "make an effort"). The student also believed that the class' view (one of acceptance of climate change) is based on science and therefore "educated". Indicating the high regard they place on beliefs based on science, in comparison to other considerations.

Students' evaluation of evidence was not limited to evidence gathered through research. Students also evaluated solutions in The Transport Problem. The SSI context explored could not be easily "solved" by science due to the wide range of societal and economic considerations and so this gave students an opportunity to evaluate their solutions by discussing the "pros and cons" rather than reaching finite conclusions.

4.3.6 Conclusions and implications: Clover Field and Daisy Park School case studies

This section presented two case studies with Irish teachers exploring teachers' and students' experience of carrying out inquiry in the context of SSI in preparation for the Science in Society Investigation. Curricular documentation from the NCCA (2016) describes how teachers should prepare students for the Science in Society Investigation over the course of the first three years of secondary school. They discuss the development of the skills, and knowledge and understanding relating to inquiry in the context of SSI.

In the two case studies presented in this section the teacher experience (*pedagogical approach*), influenced the students' experience, which focussed on the *skills* and *knowledge*. There was little evidence of the influence of curricular documentation on the teachers' approach. The two case studies demonstrated very different *pedagogical approaches*, despite being based on the same curricular documentation (NCCA, 2016). While Sam in Clover Field School took a mainly open experimental inquiry approach with limited focus on *guided discussion* of SSI contexts, Joe in Daisy Park School placed the SSI context at the centre of the inquiry in a *guided discussion* and secondary research based *guided inquiry* approach. Due to these differing approaches, the student experience was very different between the two schools, in terms of the *skills* and *knowledge* developed.

Each of the approaches taken developed different skills but did not develop the full range of skills described by the NCCA (2016). However, the teachers did not aim to carry out the full Science in Society Investigation assessment. The aim of their lessons was to develop skills and knowledge in preparation for the Science in Society Investigation. It is not concerning that the full range of skills and knowledge were not assessed because the focus was on a limited number of skills that would contribute towards the full range for the final assessment. The skills that the Science in Society Investigation aims to assess have been discussed in Section 4.2.3 of this chapter.

The open experimental inquiry approach observed in Clover Field School developed some skills relating to the Science in Society Investigation. The students were given the opportunity to formulate their own questions and practice presenting information in a structured report. The SSI context chosen by the teacher was a scientific topic with clear implications for society and was controversial and contemporary but was given little focus in the overall inquiry.

The approach taken in Daisy Park School developed more of the skills relating to the Science in Society Investigation, particularly those relating to critical evaluation of evidence. The pedagogical approach was also closer to the secondary research approach advocated by the NCCA (2016). In Daisy Park School, emphasis was placed on the SSI context which meant students were more likely to explain the implications for society.

The NCCA (2016) states that allowing students to choose their own topic increases personal and local relevance and therefore motivation. In Daisy Park School, the teacher chose the topics for their personal and local relevance and the chosen SSI contexts had clear scientific, environmental and societal implications and were contemporary and controversial.

4.4 Chapter conclusions and implications

This chapter explored the teacher and student experience of inquiry in the context of SSI in the Scottish and Irish curricula both in practice and in policy.

Section 4.1 presented Thistle Wood School case study, which followed teachers and their students in a Scottish school as they carried out a curriculum prescribed assessment of inquiry in the context of SSI. Section 4.3 presented two case studies which also explored the teacher and student experience of inquiry in the context of SSI. These case studies were set within the Irish curriculum.

Section 4.2 discussed the curricular policy landscape within which the case studies were set. It followed a four-year journey in Scotland which culminated in large scale changes to the assessment of inquiry in the context of SSI (National 5 Assignment) upon which Thistle Wood School case study was based. This section introduced the curricular policy behind an assessment of inquiry in the context of SSI, the Science in Society Investigation, which is planned for implementation in Irish schools in 2018.

In conclusion to this chapter, this section aims to present and discuss an overview of the teacher and student experience of inquiry in the context of SSI in practice in the Scottish and Irish curricula, and implications of these findings for practice. The findings are based on case study research which as discussed in chapter two has limited scope for generalisability compared to purely quantitative research. However, "fuzzy generalisations" and conclusions can be presented in the form "do X and your students *may* learn more" (Bassey, 1999 p51). Based on what has been observed in practice in Thistle Wood School, Clover Field School and Daisy Park School general conclusions and implications can be discussed.

The teacher and student experience of inquiry in the context of SSI focussed on the *pedagogical approach* and *skills* and *knowledge* developed and assessed. Implications for curricular policy in Ireland, looking ahead to the implementation of the assessment of inquiry in the context of SSI will be discussed and related to both the practice and the curricular policy decisions made in Scotland.

There were three varying approaches to inquiry in the context of SSI discussed in this chapter. Each varied according to the level of inquiry and locus of control, between the teacher or student, and the extent to which experimental and secondary research or guided discussion inquiry were used to explore the SSI context. The skills and knowledge developed and assessed also varied according to the pedagogical approach employed to facilitate the inquiry. Although there were 19 teachers in Thistle Wood School case study, the approach was similar for all teachers and so were the skills developed and assessed. As such, Thistle Wood School case study can be considered as a single case for comparison with Clover Field School and Daisy Park School.

In Clover Field School, the inquiry was an open experimental approach. In Thistle Wood School, the inquiry was mainly secondary research based, with varied focus on experimentation. In both case studies, the students carried out a systematic and sequential set of procedures to conduct secondary research and/or experimental investigation: starting with choosing a question for exploration; deciding how to investigate their chosen question through experimentation, research or a combination of both; data presentation and analysis; and drawing a final conclusion.

In Daisy Park School the approach was guided discussion and secondary research inquiry. Students engaged in initial discussion, carried out research and engaged in more discussion. This culminated in students taking action by presenting their findings (presenting to classmates/letter to President Trump).

These contrasting approaches resulted in varied emphasis on the skills of inquiry and content knowledge acquisition.

The "traditional" experimental and secondary research based inquiry approach developed a range of skills that mirrored the systematic steps used in the inquiry: Students proposed investigatable questions; stated justified hypotheses; planned, carried out and evaluated experiments, and research; presented and analysed data; and explained their findings scientifically, usually giving a concrete and final conclusion which neatly tied up their inquiry. The SSI context was considered in the initial question and hypothesis and explored somewhat in the students' explanations. In this type of inquiry, the content knowledge developed tended to focus on recall and application of scientific knowledge without discussion of the implications for society.

The approach observed in Daisy Park School which combined secondary research inquiry with *guided discussion*, and made no attempts to include experimentation, developed a different set of skills and knowledge. Students developed the ability to *distinguish arguments based on scien*tific evidence and evaluate a range of solutions. The focus of this approach was on critical evaluation of a range of evidence and viewpoints. There was not the same expectation that the inquiry would result in a finite and definite "conclusion". They also developed the ability to explain scientifically and their explanations tended to be situated within the SSI context by explaining the implications for society. However, the skills of inquiry such as proposing investigatable questions, hypothesising, planning and evaluating experiments were not developed or assessed.

Both the experimental and the secondary research and discussion approach to inquiry developed students' self-management and ability to work together (when students were given the opportunity to work collaboratively).

The findings from the case studies described in Chapter 4 suggest that the open experimental approach to inquiry can be used to develop the skills relating to experimental inquiry and content knowledge of science. The secondary research and discussion approach appears to be more suited to developing skills related to critical evaluation of evidence and exploration of SSI contexts. This tallies with wider literature relating to inquiry. However, there is little wider research relating to experimental inquiry approaches that develop skills of inquiry while also exploring SSI contexts to their full extent.

Chapter 4 also discussed the curriculum policy relating to assessment of inquiry in the context of SSI and followed developments of the curriculum policy of the National 5 Assignment. This chapter reported on the difficulties faced by Scottish policy makers when they attempted to combine an experimental inquiry approach with SSI contexts. After four years of implementation, policy makers in Scotland chose to focus solely on the "traditional" skills of experimental inquiry, using a structured, mainly experimental approach with some secondary research. Students were no longer required to relate their inquiry to the implications for society. This was in line with the experiences of Scottish teachers in Thistle Wood School who had faced difficulties attempting to embed the SSI contexts within an experimental inquiry format and rigid assessment criteria.

In Ireland, at the time of writing this thesis, the Science in Society Investigation had not yet been implemented. Irish policy-makers are in a position to learn from the implementation of the National 5 Assignment in Scotland. The Irish Junior Cycle Science in Society Investigation aims to assess skills relating to secondary research, communicating findings and evaluating information. It is promising to see emphasis placed on SSI contexts and the skills relating to this (e.g. secondary research/ critical evaluation of evidence). The Junior Cycle Science in Society Investigation aims to reward students for choosing and fully exploring the topic as SSI: students are assessed on their ability to position the topic as science in society; explain the relevant science and the impact of the topic on society and/or the environment; and explain different sides of the argument (NCCA, 2016). Rather than a concrete and final "conclusion" the students are expected to give an opinion and justify this with evidence (NCCA, 2016). The NCCA (2016) encourages a high level of student choice to increase relevance to students. In Scotland, teachers were seen to exercise control over student choices as they became more familiar with the rigid assessment criteria and so in Ireland care should be taken to avoid rigid assessment criteria that would limit the students' ability to choose SSI contexts.

This chapter focussed on the practice and policy of inquiry in the context of SSI in secondary schools. Overall, the teacher's pedagogical approach to inquiry in the context of SSI (which was influenced by curricular documentation to a greater or lesser extent) had a large influence on the students' experience in terms of the skills and knowledge developed.

The findings from the case studies presented in this chapter have implications for training of pre-service teachers (PSTs). If inquiry in the context of SSI is to be assessed as standard as part of the curriculum, then teachers need to be prepared to use appropriate pedagogical approaches to develop the skills and knowledge related to this. This should be included in initial teacher education programmes.

Chapter 5 presents a module designed for PSTs. The module provides an opportunity for PSTs to experience inquiry in the context of SSI as *learners* and reflect on the pedagogical approaches used as *teachers*.

5 Pre-Service Teacher experience of inquiry in the context of SSI as learners and as teachers

This chapter explores the overall research question: *How can the teacher and student experience of the development and assessment of scientific literacy in secondary schools inform initial science teacher education?* Unlike the previous chapter, this study was not carried out with secondary school students and in-service teachers directly, instead the focus of this chapter is on the development of scientific literacy in PSTs.

Section 5.1 of this chapter discusses the design of an intervention, an inquiry-based module for undergraduate PSTs studying science education. The module aimed to develop the skills and knowledge that contribute to scientific literacy in the PSTs as *learners* using a pedagogical approach of inquiry in the context of SSI. The module also aimed to develop skills and knowledge relating to pedagogical approaches to inquiry in the context of SSI, to prepare them as *teachers* to develop scientific literacy in their own students.

Section 5.2 presents a case study of the module. It explores the PSTs' experiences of carrying out inquiry in the context of SSI as *learners* and as *teachers*. This section will also provide examples of work produced by the PSTs and their commentary around the module.

5.1 PST module design

This section will present the design of a module for PSTs that uses a pedagogical approach of open experimental and secondary research inquiry in the context of SSI. First, the rationale for the design of the module will be outlined, including how the studies described in chapters 3 and 4 of this thesis informed the design. This section then provides an overview of the module. Finally, it discusses the assessment of students in relation to the two aims of the module: development of skills and knowledge as *learners*, and development of pedagogical approaches as *teachers*.

Appendix G presents a profile of one PST, including a sample of relevant work. This has not been included in the main body of this section because it focusses on the design of the module only. Appendix G provides examples of completed assessments and other student work relating to the development and assessment of inquiry in the context of SSI in the PSTs as *learners* and as *teachers.*

5.1.1 Rationale and influence of other studies

Inquiry in the context of SSI is increasingly being embedded in the national curricula of countries around the globe as a way of increasing scientific literacy in students (NCCA, 2016, SQA, 2016). As such, PSTs need to be prepared to teach using these approaches. However, there are barriers to implementation of inquiry teaching in practice (see Section 1.5.2). Research suggests that PSTs should be involved in activities as *learners*, that allow them to experience inquiry first-hand and develop the skills and knowledge of scientific literacy (Section 1.5.1). They should also be given the opportunities for deliberate and explicit reflection on the *teaching* approaches to inquiry (Section 1.5.2). An initial teacher education module was designed to allow students to experience inquiry in the context of SSI as *learners* and as *teachers*.

A clear vision of inquiry was devised prior to the design of the module, that could be used as the basis of the design. This was based on the description of inquiry from the literature, described in Section 1.4. In the PST module, inquiry is described in two distinct lights:

1. A set of skills and knowledge to be developed
2. A pedagogical approach

The skills and knowledge of scientific inquiry contribute to the overall scientific literacy of the individual (Figure 1-2). In this module seven inquiry skills were aimed to be developed and assessed:

1. Develop a question that is possible to investigate scientifically
2. Make and justify a scientific hypothesis

3. Propose a way of exploring a question scientifically
4. Evaluate ways of exploring a question scientifically
5. Interpret data and evidence scientifically
6. Draw appropriate conclusions
7. Explain the potential implications of scientific knowledge for society

Content knowledge of science is also developed through inquiry in the context of SSI and is specific to the context within which the inquiry is set. Knowledge of scientific processes and knowledge of NOS are also required to carry out inquiry.

As a pedagogical approach, that aims to develop the skills and knowledge described in the previous paragraphs, inquiry in the context of SSI is deemed to be: Student centred and collaborative, comprised of different levels that vary according to the level of teacher and student control, assessed both formatively and summatively and uses SSI contexts (Colburn, 2000; Wenning, 2005; Sadler, 2009; Hodson, 2010).

This module aimed to address some of the concerns relating to inquiry teaching using the vision of inquiry as described. The aims of the module were to*:*

1. Develop inquiry skills and knowledge in PSTs as *learners*
2. Develop pedagogical skills relating to inquiry in PSTs as *teachers*

It is proposed that through experience of inquiry methods as *learners*, the PSTs will develop the skills and knowledge of inquiry in the context of SSI that contribute to their own scientific literacy (Figure 1-2). It also expected that the PSTs will begin to reconceptualise some of the perceived barriers such as inquiry being too challenging for students.

Through explicit instruction and reflection regarding the pedagogical approaches used, it is proposed that the PSTs will gain confidence and knowledge of a repertoire of pedagogical approaches to inquiry learning. This will allow them to develop their skills and knowledge relating to *teaching* through inquiry in the context of SSI.

While there was a clear, literature-based rationale for the design of the module, other studies carried out by the researcher also influenced the design (Figure 5-1).

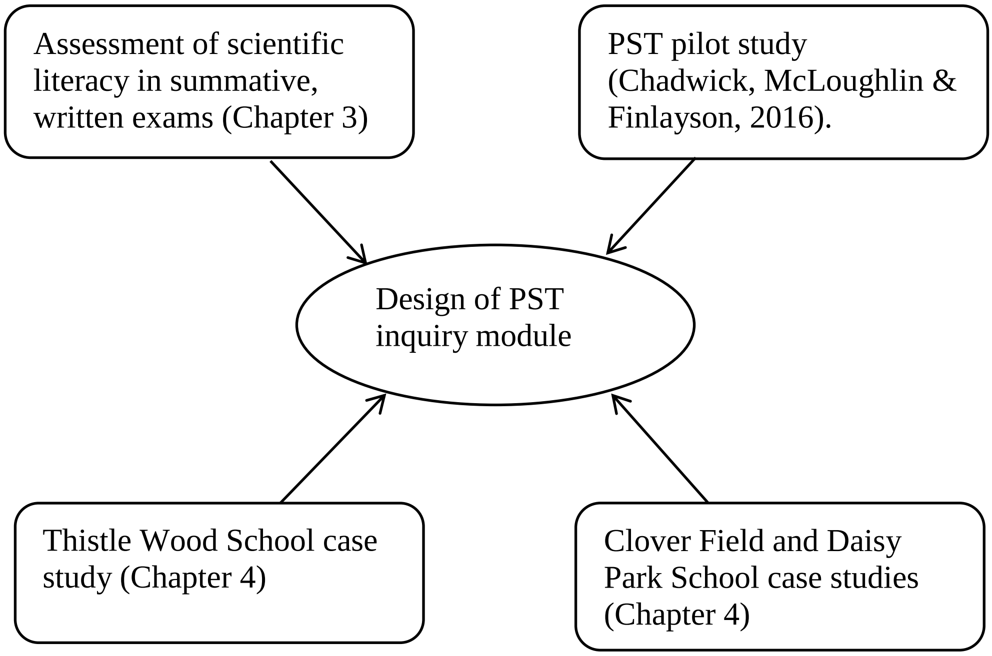


Figure 5-1 Previous studies that informed the design of the pre-service teacher module

Chapter 3 focussed on the assessment of PISA's scientific literacy competencies and knowledge in summative, written exams. One of the major findings from this study was that summative, written exams do not assess all the skills and knowledge of scientific literacy; some aspects of scientific literacy were over-represented, and others were not assessed at all.

The PST module was planned and implemented in April-May of 2017. In the academic year 2016/17 Thistle Wood School, Clover Field School and Daisy Park School case studies were all in their main data collection stages. A timeline of research carried out over the year 2016/17 is helpful to situate the PST case study within the overall research (Figure 2-4).

As Figure 2-4 shows, at the time that the PST module was being planned and implemented, data collection and analysis had begun for the secondary school case studies, described in Chapter 4. However, interviews were not carried out with the secondary school teachers until June of 2017. This was an ideal time to carry out interviews because it was close to the end of the academic year and teachers were keen to reflect on their teaching both looking back at the year gone by and ahead to the next year. However, it meant that final data collection and analysis for these case studies was not completed until after the PST module had been designed and implemented. This meant that while initial findings informed the module design, some key findings were not yet identified. At the time of planning the PST module, the curricular documentation of Scotland had not yet been fully explored and this meant that the researcher was not yet aware of the important decision of Scottish policy makers to move away from an experimental and SSI combination approach to a purely experimental approach.

There were also two pilot versions of this module that contributed to the design of the final module (Chadwick, McLoughlin & Finlayson, 2016). These pilot studies explored the experience of the PSTs as *learners* carrying out inquiry in the context of SSI but did not discuss the pedagogical approach taken. In these pilot studies, the PST experience as learners consisted of two themes: *Skills* and *knowledge*.

5.1.2 Overview and tasks

The module aimed to use the pedagogical approach to inquiry in the context of SSI as described in Section 5.1.1 and develop the seven skills stated. The level of inquiry aimed for was "open" as students were provided with materials but they were asked to devise their own question and procedures to solve their problem (Table 1-4). The PSTs were invited to explore a question of their choosing through experimental and secondary research inquiry.

Two facilitators were involved in the module: the researcher (main facilitator) and the academic in charge of the lab (second facilitator). Both facilitators had a key role in ensuring learner progression. The facilitators were responsible for:

- Supporting transitions between tasks (discussion into lab-work and vice versa)
- Supporting paired and whole group discussion by providing discussion topics and asking relevant questions
- Introducing the particular inquiry skills and facilitating a group discussion about the skills at the start of each lab and facilitating a final reflective discussion at the end of each lab
- Providing pre-determined assessment criteria for each inquiry skill (with the exception of evaluate scientific inquiry)
- Providing a range of equipment to lead students towards topics of investigation
- Supporting the progression of the inquiry task by asking relevant questions during lab-work and answering questions and providing guidance where required
- Supporting PST progression after absence by providing individual guidance and support.
- Facilitating discussions of homework activities and providing individual written and verbal feedback on post-lab activities.

The facilitators avoided positioning themselves as the providers of knowledge or experts.

Assessment approaches included formative and summative approaches. Formative assessment is concerned with providing students with feedback on the quality of their work in order to improve the work (Sadler, 1989). This contrasts with summative assessment which attempts to summarise the student's achievement and provide information for reporting, particularly for certificated courses. The key difference between the two forms of assessment is the presence of informative feedback (Sadler, 1989). A range of formative and summative assessment approaches were used in the module which will be discussed later in this section.

The context for the inquiry was SSI based. The broad topic “implications of UV radiation for society and the environment” was given and the PSTs were asked to choose an investigatable question relating to this topic. The aim was that by allowing the learner to choose their own question would increase the personal relevance of the inquiry.

The module took place over four weeks, each weekly session lasting approximately 3 hours. Table 5-1 gives an overview of the activities carried out in the module and relates these to the skills that were focussed on each week.

Table 5-1 Module overview and outline

Week 1: Introduction to inquiry and SSI; investigatable questions
Inquiry Skills Focus
Distinguish questions that are possible to investigate scientifically Make and justify scientific hypotheses/ predictions
PST Activities
Create a mind-map showing vision of learning through inquiry and discuss "vision of learning through inquiry" as a whole class. PSTs are given a range of equipment and generate *any* questions. PSTs are facilitated to distinguish between *investigatable* and *non-investigatable* questions and generate criteria for what makes an *investigatable* question. PSTs choose initial *investigatable* questions for research and self-assess their *investigatable* questions using pre-determined assessment criteria. PSTs choose *background questions* for secondary research PSTs reflect on their experience as *learners* and pedagogical approaches used

Week 2: Early planning and implementing
Inquiry Skills Focus
Propose ways of exploring a question scientifically Evaluate ways of exploring a question scientifically
PST Activities
PSTs are facilitated to reflect on open questions from last week and make initial plans. Students are facilitated to: share ideas with their partner/group- reach a consensus, test and trial methods and equipment or initial secondary research articulate their plans in their research log – including variables, fair testing, repeatability, materials, how data and information will be recorded and presented, discuss initial plans reflect within (and between) partnerships Students self-assess their early plans against the pre-determined assessment criteria Students are facilitated to devise with their own assessment criteria for "Evaluate scientific inquiry" PSTs reflect on their experience as *learners* and pedagogical approaches used

Week 3: Late planning and implementing
Inquiry Skills Focus
Analyse and interpret data and evidence scientifically Draw appropriate conclusions
PST Activities
PSTs are facilitated to use their initial plans to carry out primary research to collect data PSTs are facilitated to present and analyse their gathered data and draw conclusions PSTs self-assess their data presentation, analysis and conclusions against pre-determined assessment criteria PSTs reflect on their experience as *learners* and pedagogical approaches used

Week 4: Taking action! Module reflection
Inquiry Skills Focus
Explain the potential implications of scientific knowledge on society
PST Activities
PSTs discuss how their topic impacts on society and plan to take action. PSTs self-assess their log-books against pre-determined assessment criteria. PSTs work in groups of 3 to critique initial lesson plans and make recommendations for increasing the inquiry content of the lesson. PSTs create a mind-map showing vision of learning through inquiry. PSTs reflect on their experience as *learners* and pedagogical approaches used.

Ten PSTs participated in the module but due to non-attendance only eight PSTs completed a sufficient number of assignments to complete the module. The PSTs were in their second year of a BSc in science education in mathematics, chemistry or physics teaching at secondary level. The module took place in April/May, with the PSTs having completed their first in-school placement in January. This meant that the students had four weeks of field experience prior to starting the module.

Assessment (both formative and summative approaches) related to the two aims of the module: develop inquiry skills in students as *learners* and provide instruction to increase pedagogical skills as *teachers*. Table 5-2 below lists the tasks and assignments completed by the PSTs and whether these provided evidence of the development of skills and knowledge of the PSTs as *learners* or the development of pedagogical approaches as *teachers.*

Table 5-2 Tasks and assignments of the PST inquiry module

Task/ Assignment	**Develop as *learner***	**Develop as *teacher***
Logbook (inc. self and facilitator assessment)	✓	
Initial lesson plan		✓
Final lesson plan and explanation		✓
Video analysis		✓
Initial and final mind-map of inquiry	✓	✓
Reflections	✓	✓

The summative assessment approaches contributed towards the PSTs' final module accreditation. These were four weekly reflections worth 5% each (total 20%) and one lesson plan with an accompanying explanation worth 80%. Examples of formative assessment used in this module include questioning and peer and self-assessment (Black *et al.*, 2004). Formative assessment elements were not graded and instead written or verbal feedback was given relating to how to improve performance of the skills.

5.1.3 Assessment of skills and knowledge as learners

The PSTs were encouraged to store all their work in an online "logbook", a Google Drive folder, that could contain multiple documents, which was shared with the facilitators. These logbooks were the main source of evidence for the development of the skills and knowledge of inquiry in the context of SSI. Two other tasks allowed the PSTs to demonstrate their skills and knowledge as *learners*: weekly reflections and inquiry mind-maps (Table 5-2). These tasks asked the PSTs to reflect on their development as *learners* and as *teachers* and so can be discussed in relation to both aims of the module.

(i) Logbooks

The Figure 5-2 shows the instructions provided to the PSTs regarding organising and writing their logbooks.

Organising Your Folder and Writing Your Logbook

Your folder and the contents are a detailed record of what you have done during the module. The Google Drive folder and logbook should be a detailed record of EVERYTHING you have done but try to keep it organised (clear titles and dates).

Your logbook (the Google Doc you made using the instructions above) is an electronic document that contains drafts, ideas, questions for investigation, questions for secondary research, initial and late planning and methods, results and gathered data, conclusions, sources of information, findings from research and action plans.

Each time you write in your logbook (usually during and after each week's lab) you should write the date and give each section a clear title (e.g. 29 March 17 Initial Questions). This will help keep your logbook organised and make it easy when you look back later. You will also upload other work (e.g. photographs, documents) produced through the course. Any individual uploads should be given a clear title and dated (e.g. Mind map of Inquiry 29 March 17, photo of early questions 29 March 17).

Figure 5-2 Student instructions for completion of logbook

The logbook was completed both in-lab and at home. The PSTs were encouraged to create one document with detailed information about the progress of their inquiry, including all drafts and discarded work (e.g. questions that were not going to be investigated). The logbook document was stored in the logbook folder and any additional files (e.g. photographs, assignments) could also be stored in the folder.

The logbook provided students with an organised space to document their progress but the logbook itself did not contribute towards the summative assessment. Instead, the logbook was assessed formatively. Each week the logbook was self-assessed by the student and assessed by the facilitator (researcher) using assessment criteria relating to the skills focus of the week (see Table 5-3 for assessment criteria). The facilitator provided brief, written formative feedback relating to performance against the assessment criteria and suggestions for improvement. Appendix G contains examples of written feedback given by the facilitator.

The assessment criteria for the seven skills is shown in Table 5-3 were adapted and amalgamated from a range of sources, including the PISA framework for Scientific Literacy (OECD, 2013), Inquiry and the National Science Education Standards: A guide for teaching and learning (Olson & Loucks-Horsley, 2000), the Science in Society Investigation features of quality from the Irish Junior Cycle science specification (NCCA, 2016), Exploratorium (2006) and SAILS (Csikos *et al.,* 2016). They were refined through discussion between the researcher (lead facilitator) and academic supervisor (second facilitator). The assessment criteria present a continuum for each skill and it is possible to place a students' performance between levels.

Table 5-3 Assessment criteria for skills in the PST module

1. Distinguish questions that are possible to investigate scientifically			
High self-direction <--- > Low self-direction			
Learner poses a question that is possible to investigate scientifically	Learner selects among questions (those that can and cannot be investigated scientifically)	Learner sharpens or clarifies questions posed by other	Learner engages in question provided by others

2. Make and justify scientific hypotheses/ predictions			
High performance <--- > Low performance			
Learner makes a prediction that is testable, states the variables and a clear expected outcome that is justified with sound scientific reasoning and prior knowledge	Learner makes a prediction that is testable, linked to the question and states a clear expected outcome	Learner makes a prediction that is testable and linked to the question	Learner makes a prediction that is not testable by scientific investigation or linked to the question

3a. Identify variables giving consideration to fair testing (dependent, independent and controlled variables)			
High performance <--- > Low performance			
Learner explicitly states variables changed, measured and controlled	Learner explicitly states *all relevant* variables	Learner mentions concepts from the investigation (temperature etc)	No answer

3b. Identify appropriate materials required			
High performance <-- > Low performance			
Learner selects all resources that are adequate to answer the question.	Learner selects some *essential* resources that are adequate to answer the question.	Learner mentions resources but not adequate to answer the question, *essential* resources are missing	Learner does not mention resources required

3c. **Describe a method of collecting accurate and precise data**			
High self-direction <--- > Low self-direction			
Learner independently determines a method of collecting data and information and collects it	Learner is directed towards a method of collecting data and information and collects it	Learner is given the method to collect their own data and information	Learner is given the data and information and told how to analyse

5. **Present and analyse data and evidence scientifically**			
High performance <--- > Low performance			
The learner presents information and data in multiple formats. Analysis is appropriate to the data and is presented completely (e.g. graphs have titles, axes, scale etc)	The learner presents information and data in multiple formats but analysis is not complete (e.g. graph lacks appropriate scale, labels etc.)	The learner presents information and data in an organised format with limited analysis (e.g. a table of raw data)	The learner presents information and data but poorly organised (e.g. copied and pasted from websites or disorganised raw data)

6. Interpret data and draw appropriate conclusions			
High performance <-- > Low performance			
The learner presents valid arguments that relate to their research question. The learner uses their own words, makes reference to data/ information and backs up their arguments with scientific knowledge.	The learner presents valid arguments in their own words and relates these to the research question but does not justify with data or scientific knowledge.	The learner does not provide arguments in their own words/ arguments are not developed or related to the research question.	The learner does not interpret data or draw conclusions (e.g. simple restatement of data/information)

7. Explain the potential implications for society			
High performance <--- > Low performance			
The learner explains the relevance of their primary and secondary research to society and describes the impact of the topic on society. The learner relates their conclusions/ findings to implications for society.	The learner explains the relevance of their chosen topic to society. The learner relates their conclusions/ findings to implications for society.	The topic has implications to society and the learner mentions these in passing but does not make these explicit or relate to their findings	The learner does not make links between their topic of investigation and implications for society (e.g. a purely scientific research topic)

Assessment of skill one *distinguish questions that are possible to investigate scientifically* gives the student feedback on the level of self-direction or independence. At the lower level the student participates in investigating a question but does not supply or contribute to its formulation. At the highest level of self-direction, the student poses their own question and the question is an investigatable question. The criteria for an investigatable question were pre-determined by the researcher. Investigatable questions, in this inquiry, should consider: availability of materials, availability of time, age and developmental appropriateness, opportunities for taking action and implications for society.

For skill two *make and justify scientific hypotheses/ predictions*, a prediction is considered as a simplified hypothesis. At the lowest level the student makes a prediction only. At the highest level of performance, the student states a clear hypothesis. The prediction is testable, explicitly states variables and is justified with scientific knowledge.

The skill *propose ways of exploring a question scientifically* is broken down into three separate assessment criteria: Identify variables giving consideration to fair testing (dependent, independent and controlled variables); identify appropriate materials required; and describe a method of collecting accurate and precise data. The first criteria relates to the identification of variables, the second to a statement of materials and equipment required and the final assessment criteria assesses the students' performance in describing their method of investigation. The assessment criteria (3c) focuses on planning the method of investigation in terms of the student's self-direction or independence. At the lowest level, the level of support is high. At the highest level, the level of support is much lower, although appropriate support is still given by the facilitator.

Students were not given pre-determined assessment criteria for skill four *evaluate ways of exploring a question scientifically*. By this point students had self-assessed against pre-determined criteria five times so they were asked to determine their own success criteria. The facilitator's lesson plan had suggested criteria, which included: Discussion and comparison with other groups (reproducibility), comments on the PSTs' own experiment in terms of fair testing and reliability (repeats of own experiment), comments on the reliability (trustworthiness) and validity (relevance) of the sources of data and information and suggestions of improvements to the investigation.

Performance of skill five *present and analyse data scientifically*, has two aspects: presentation of data and analysis of data. At the lowest level of performance, the student presents data but this consists of presentation of raw data only with no analysis. At the highest level the analysis aids the presentation of data in multiple formats. Data is analysed from raw data into tables, graphs or summaries. Analysis is of a high-quality meaning tables have appropriate headings and units and graphs have appropriate labels, units and scales.

Performance of skill six *interpret data and draw appropriate conclusions* involves two aspects; interpretations and conclusions are interlinked and cannot be assessed separately. At the lowest level there is an attempt to interpret data or draw conclusions, such as a restatement of the data or information with no use of content knowledge of science and an unsuccessful attempt to interpret data or draw conclusions. At the highest level of performance, scientific knowledge is used to justify the conclusion.

Skill seven *explain the potential implications of scientific knowledge on society* relates to the students' ability to situate their inquiry within the SSI context. At the lowest level of performance, there is an attempt to discuss the context but the implications for society are not explicit; the context is dealt with purely scientifically. At the highest level of performance, the learner explains their gathered data and evidence in relation to the implications for society. Performance of this skill requires demonstration of content knowledge of science. This skill also relates to raising student awareness and developing activism in relation to the SSI explored. The first step in this is for students to gain an increased appreciation of the societal impact of scientific knowledge (Hodson, 2010).

(ii) Weekly reflections

Students were asked to submit a reflection shortly after each weekly lab which contributed to the summative assessment for the module (20% of final grade). Aspects of these evidenced the skills and knowledge developed as *learners*.

> Reflect on today's lab by answering the following:
>
> a. What have I learnt from this week? Reflect on the skills and knowledge you personally have gained.
>
> b. How will this affect my approach to teaching science? Reflect on the skills and knowledge you have gained that you may use in your teaching.
>
> c. Describe any specific actions you plan to carry out as a result of this session.
>
> d. Anything else you would like to add. (Weekly reflection assessment descriptor)

The aim of this activity was to encourage the PSTs to reflect on their learning and teaching, in terms of the skills and knowledge developed as *learners*, and to demonstrate reflective practice relating to the pedagogical approaches used. The PSTs were encouraged to develop their own view and establish their own underlying position on many aspects of the module including their position in relation to the SSI context (as *learners*). The final question of the reflection asked students to outline actions they would take as a result of the lab. This reflective, action based approach aimed to mirror and model the activist approach advocated in relation to the SSI context (Hodson, 2010).

(iii) Mind-map of inquiry

In week one of the module, the PSTs were asked to draw a mind-map showing what "learning through inquiry" was and in the final week, PSTs were asked to draw a second mind-map. The mind-map drawn after four weeks of instruction was be compared to that drawn in week one, prior to any instruction, to look for any changes in the PST's understanding of inquiry in terms of skills and knowledge development.

5.1.4 Assessment of pedagogical approach as teachers

The module also aimed to develop and assess the PSTs' skills and knowledge relating to their approach to inquiry in the context of SSI as *teachers*. Evidence of this was gathered from the PSTs' lesson plans, video analyses tasks, weekly reflections and mind-maps (Table 5-2).

(i) Initial and final lesson plan

Prior to attending the first week of the module, the PSTs were asked to submit a lesson plan from their recent school placement (approximately 3 months prior) that they felt showed "learning through inquiry":

> Upload a lesson plan from your recent placement that you think demonstrates learning through inquiry. Note that this will not be assessed. It will be used as a comparison, to show your knowledge of inquiry before the module begins. (Initial lesson plan assessment descriptor)

The initial lesson plan provided evidence of the PSTs' understanding of the pedagogical approach to learning through inquiry. The lesson plan was not assessed summatively but peer-assessed through a group activity which employed comment-only marking:

> 1. Make notes on the lesson plan to show how/when/where the lesson demonstrates learning through inquiry.
>
> 2. What level of inquiry do you think these activities show? Don't worry too much about using the correct terminology (e.g. Structured, guided, open, something in between, your own description)
>
> How can the teacher improve this lesson and make it more focussed on developing the inquiry skills focussed on in this module? (task descriptor taken from PowerPoint)

Peer-assessment of the lesson plans occurred in the final week of the module. This allowed the PSTs to use what they had learnt during the module when marking their peer's lesson plans. The activity aimed to provide the PSTs with the opportunity to give and receive feedback on teaching activities. The benefits to the learner of carrying out peer-assessment, both for the student receiving and the student giving the feedback (Section 1.4.1). However, the PSTs' comments were generally short, disparate and unrelated comments on various aspects of the lesson plan and did little to suggest how the overall plan could be reworked to clearly demonstrate a defined vision of learning through inquiry. This is because the students focussed mainly on "how/when/where the lesson demonstrates learning through inquiry" and "the level of inquiry". This activity tended to benefit the peer marker's understanding of learning through inquiry more than the person being assessed.

After completion of the four-week module, the PSTs were asked to submit a lesson plan and accompanying explanation showing learning through inquiry. It was expected that the PSTs would draw on the comments given by their peers when writing their final lesson plans and make changes to increase the inquiry focus. PSTs were asked to:

> Make changes to the lesson plan submitted at the start of the module or submit a brand-new lesson plan. The year group and length of time available for the lesson is up to you.
>
> You should also submit a short (half page or so) explanation of your lesson plan that describes:
>
> 1. How/when/where the lesson demonstrates learning through inquiry.
>
> 2. What level of inquiry you think these activities show? Don't worry too much about using the correct terminology (e.g. Structured, guided, open, something in between, your own description)
>
> 3. Which of the key skills you have chosen to focus on.
>
> Your lesson plan and accompanying explanation will be broadly marked on how well you have demonstrated your understanding of inquiry and the particular key skills. (Assessment descriptor)

The final lesson plan and explanation were assessed summatively and formed the main assessment for the module (80% of the final grade). The lesson plans were assessed by the main facilitator (researcher) and individual written feedback was given. The activity aimed to develop the PSTs' pedagogical skills in relation inquiry in the context of SSI by encouraging them to explicitly relate their learning in the module to their practice as teachers. Assessment criteria relating to the lesson plan is shown in Table 5-4.

Table 5-4 Assessment criteria for final lesson plan and accompanying explanation

Lesson Plan:			
80-100	65-80	50-65	40-50
Learner demonstrates evidence of reflection based on many of the peer comments, major changes have been made to the lesson plan to increase inquiry content. The LP clearly relates to the vision of inquiry and key skills of the module through learning intentions, success criteria and activities. The activities are clearly described and expected outcomes (where students lead the learning) are explicitly considered.	Learner demonstrates evidence of reflection based on peer comments and has made changes/ additions to increase the inquiry content of the lesson. The activities in the LP are clearly described and there is evidence of inquiry relating the vision of inquiry and key skills of the module.	Learner demonstrates evidence of reflection and has made some changes/ additions to increase the inquiry content of the lesson. The activities in the LP may not be clearly described but there is evidence of inquiry relating to some aspects of the vision of inquiry of the module.	Learner demonstrates minimal evidence of reflection based on peer comments with only basic changes made (e.g. timing). The LP contains some elements of basic guided inquiry activities.
Accompanying Explanation			
80-100	65-80	50-65	40-50
The accompanying explanation clearly/ explicitly states the learner's vision of inquiry, with reference to specific examples within the LP. The accompanying explanation explicitly states the level of inquiry and the key skills intended to be developed and gives clear and relevant justification linked to the key skills with reference to specific examples from the LP.	The accompanying explanation demonstrates the learner's vision of inquiry although this may not be made explicit. The accompanying explanation explicitly states the level of inquiry and the key skills intended to be developed and gives some justification with reference to specific examples from the LP.	The accompanying explanation gives evidence of the learner's vision of inquiry but is not clear or elaborated upon. Some justification with reference to the lesson plan is given.	The learner makes some reference to inquiry concepts, but the accompanying explanation does not demonstrate the learner's vision of inquiry and no specific examples are given in the explanation.

At the lowest level of performance, the final lesson plan shows little change compared to the initial lesson plan, in terms of focus on inquiry. The student has not acted upon the peer feedback (where appropriate feedback has been given) to increase the inquiry focus.

At the highest level of performance, the PST made clear changes relating to increasing or improving the focus on inquiry learning between the initial and final lesson plan. The activities proposed in the lesson plan relate to the development of the key skills of the module and the PST has considered student outcomes. The activities are clearly described and understandable.

At the lowest level of performance, the accompanying explanation does not give enough detail to show the learner's "vision of inquiry" and does not refer to examples from the lesson plan. At the highest level of performance, the lesson plan gives enough detail relating to inquiry concepts to demonstrate the PST's vision or understanding of learning through inquiry. The aim of the activity was not to memorise a specific definition of inquiry but to develop their own understanding of inquiry.

The final lesson plan was assessed summatively by the facilitator and written feedback was provided. The feedback related directly to the assessment criteria and aimed to identify what was done well and what still needed improvement (Black *et al.*, 2004). However, students were not given further opportunities to make changes after this written feedback was provided and so the assessment was purely summative.

(ii) Video analyses

To assess the PSTs understanding of pedagogical approaches to learning through inquiry, they were asked to comment on two videos showing real-life classroom scenarios with varying inquiry-based approaches. The task descriptor is shown below:

> 1. Make detailed notes showing how/when/where the lesson shows learning through inquiry.
>
> You may wish to make notes on everything you see in the video and then go back and highlight/draw attention to the bits that you think show inquiry taking place. It may help you to think about the skills you have covered so far in the module.
>
> 2. What level of inquiry do you think these activities show? Don't worry too much about using the correct terminology (e.g. Structured, guided, open, something in between, your own description)
>
> 3. Do these activities develop the inquiry skills you have focused on in this module? Give specific examples (Assessment descriptor)

The first video analysis task showed two separate guided inquiry activities where students designed an investigation. The teacher proposed the question for this investigation. The second video showed a structured, mainly teacher-led inquiry. This video was included to show a different view of inquiry from the open/semi-structured approach taken in the module. This view of inquiry aligned with many of the initial lesson plans from the PSTs so this video analysis also gave the PSTs an opportunity to critique the teaching without offending their own peers or judging themselves harshly. Other videos were considered but discounted for use because the focus and vision of inquiry were too closely linked to that of the module. It was decided that this may have reinforced the idea that inquiry is only done "one way", thus making integrating it into the classroom more difficult. However, while the videos used real-life scenarios (e.g. bath bombs, rockets) the videos did not focus on SSI contexts.

(iii) Weekly reflections and mind-maps of inquiry

Weekly reflections were used to explore the PSTs' development as *teachers*. Each week they were asked how their participation in the module would affect their "approach to teaching science?" and asked to "reflect on the skills and knowledge you have gained that you may use in your teaching." (weekly reflection task descriptor).

The mind-maps, were not assessed by the facilitator, but could also be examined to show evidence of the development of the PSTs understanding of pedagogical approaches to inquiry.

Overall, the design of this module was based on a desire to develop the PSTs' skills and knowledge as *learners* and give opportunities for reflection and exploration of pedagogical approaches to inquiry in the context of SSI as *teachers*. The module aimed to address the barriers that teachers, particularly PSTs and newly qualified teachers, face when attempting to implement inquiry into their practice. The module was underpinned by a view of inquiry in the context of SSI that was based on literature and studies carried out by the researcher, and this informed the development of the tasks and assessments.

The module aimed to develop seven skills relating to experimental and secondary research-based inquiry and SSI contexts. Detailed assessment criteria relating to the seven skills were devised that aimed to reward students for increasing levels of self-direction and performance. They also aimed to reward students for using secondary research and experimental inquiry approaches and for situating their inquiry within SSI contexts.

The pedagogical approach used in this module aimed to be student centred and collaborative, show varying levels of inquiry, assessed formatively and summatively and situated in SSI contexts. However, the aim was not to dictate a limited view of the pedagogical approach to inquiry and the PSTs were given freedom to explore their own views relating to how they would teach inquiry.

5.2 PST case study

This section presents a case study exploring the PSTs' experience of carrying out inquiry in the context of SSI as learners and as teachers. Section 5.1 presented the design of the module in terms of the pedagogical approach and skills and knowledge it aimed to develop. Section 5.2 explores the module as it was carried out in practice.

This module was designed to develop PSTs' inquiry skills and knowledge as *learners*, and pedagogical skills in relation to inquiry in the context of SSI as *teachers*. This section presents a case study following eight PSTs over four weeks as they completed the 12-hour long module described in Section 5.1. The research questions explored in this study are:

1. What are the PSTs' experiences of carrying out inquiry in the context of SSI as *learners*?
2. Which PISA competencies are developed and assessed through inquiry in the context of SSI in this module (PSTs as *learners*)?
3. What are the PSTs' experiences of carrying out inquiry in the context of SSI as *teachers*?

5.2.1 Methodology

This research presents an embedded, mainly qualitative, instrumental case study. The case study is instrumental in that it provides information towards an overall research question. It is embedded in that it is mainly qualitative in approach but there are some quantitative data collection and analysis methods used. The role of the researcher in this module was researcher and facilitator. There were two facilitators and the researcher took a lead role in facilitating all labs.

Data was collected through a mixed methods style questionnaire (Appendix A), open ended interviews (Appendix A) and secondary documentation.

The questionnaire focussed on the PST experience as a *learner*, in terms of the skills and knowledge developed and assessed. Questions 1-5 of the questionnaire were open response questions and asked the PSTs about their experience as learners. Questions 6-8 and part two of the questionnaire asked the PSTs to report on their use of the PISA competencies of scientific literacy. These questions, relating to PISA competencies and sub-competencies, gathered quantitative data about the student experience as *learners*, in terms of the skills developed and assessed. Table 5-2 shows how the secondary documentation related to the PSTs' experience as *learners* or as *teachers* (or both). Researcher field notes were also included as secondary documentation. The researcher/facilitator's own lesson plans and schemes were not included. Section 5.1 gave an overview of the pedagogical approach the facilitator took to the module and the case study described in Section 5.2 is concerned with how the PSTs viewed the pedagogical approach.

The interviews gathered information about the PSTs' experience as *teachers*. The PSTs participated in the module for four weeks spanning April and May, and in June the PSTs completed their second in-school placement. Following their in-school placement, a sample of three PSTs were interviewed by the researcher and these interviews related to their teaching on placement.

Ten PSTs were enrolled on the module at the beginning of the four-week course, eight of which completed the course and submitted the majority of assessed work. Only these eight participants were included in this case study (Table 5-5). The PSTs were in their second year of a four-year BSc in science education which would qualify them to teach two subjects from chemistry, maths and physics in secondary school.

Table 5-5 PST participants and data sources

	Secondary documentation / student work						
Name	Questionnaire	Reflection				Final LP	Logbook
		Week 1	Week 2	Week 3	Week 4		
Jane	✓	✓	✓	✓	✓	✓	✓
Amy	✓	✓	✓	✓	✓	✓	✓
Sophie	✓	✓		✓		✓	✓
Catelyn	✓	✓		✓		✓	✓
James	✓	✓		✓		✓	✓
Rebecca	✓	✓	✓	✓		✓	✓
Louise	✓	✓	✓	✓		✓	✓
Morgan	✓	✓	✓	✓		✓	✓

Thematic analysis was carried out on all data using NVIVO software as a database for storage and display of themes. Thematic analysis was carried out according to the procedures described in Section 2.2.3. Firstly, the researcher read and transcribed the qualitative data and noted initial ideas and thoughts (*initial ideas* stage). Next, the researcher formed themes from the initial ideas and began a process of systematic coding of data extracts (quotes, pictures, snapshots, video and audio extracts) into each theme (*initial themes* stage). This coding process continued until all data from the data source (e.g. questionnaire) had been coded. At the end of this stage member-checking occurred, where the initial themes and sub-themes were discussed with a sample of the PSTs and they were asked whether the themes represented their experience of the module. Thirdly, the researcher reviewed the themes and sub-themes by checking all coded extracts fitted within the theme they were allocated. The themes were given clear descriptions and names, which were written up in a "codebook" (Appendix H). The final stage of analysis was when all data sources were analysed together. The themes and sub-themes were combined for all data types. All references/extracts were re-checked against the allocated theme/sub-theme and the codebook to ensure consistent coding across all the data types. Examples of extracts and quotes from the various data sources can be seen in Section 5.2.2 and 5.2.4, where they are given as examples highlighting each sub-theme.

Validity was considered through member-checking initial themes with the PSTs themselves to see whether these themes were deemed to be an accurate representation of their experience. Member-checking took place during the interviews. Validity was also considered as the method of thematic analysis used allows the combination of themes from different data sources (comparison of student work vs. self-reported questionnaires), which is a form of triangulation.

Reliability was increased through consistent coding procedures including the creation of a detailed codebook (see Appendix H). Intercoder agreement was not used but themes were subject to consultation with academic supervisors at various points throughout the analysis.

The PISA competencies and sub-competencies used by the PSTs were analysed quantitatively. The percentage of PSTs who reported using the PISA competencies (Q6-8 of questionnaire – Appendix A) and sub-competencies (part two of the questionnaire – Appendix A) was calculated and displayed graphically. This can be compared to the findings from thematic analysis that report the skills used.

5.2.2 Findings: PSTs' experience as *learners*

Thematic analysis of all data sources revealed three themes: *skills*, *knowledge* and *pedagogical approach*. The *skills* and *knowledge* themes related to the PSTs' experience as *learners* while the *pedagogical approach* theme related to their experience as *teachers*. In this section the findings relating to the PSTs experience as *learners* will be presented, including relevant examples from student work and other data. These skills and knowledge will then be discussed in terms of the PST experience of inquiry in the context of SSI and compared to the aims of the module.

Findings relating to the PSTs' experience as *teachers* will be presented and discussed separately.

Table 5-6 shows the results of thematic analysis of the PST questionnaires, interviews and secondary documentation relating to their experience as *learners*. The sub-themes are displayed in order of the number of references to the sub-theme, from highest to lowest but will be presented and discussed in the order they were carried out by the PSTs for ease of reading.

Table 5-6 Themes and sub-themes relating to the PSTs' experience as learners

Theme	Sub-theme
Skills	Plan and carry out experiments
	Propose investigatable questions
	Present and analyse data
	Evaluate and make changes to investigations
	Explain scientifically
	State justified hypotheses
	Research
	Take action
	Self-management
Knowledge	Implications of scientific knowledge for society
	Recall and apply scientific knowledge

(i) Skills

Of the three overall themes, skills is the largest, meaning that the PSTs mainly talked about themselves as *learners*, and focussed on the development of *skills* over *knowledge*. A detailed codebook describing each theme and sub-theme can be found in Appendix H. Evidence from student work, questionnaires and other relevant secondary documentation is presented here for each sub-theme.

(a) Propose investigatable questions

This sub-theme relates to planning and stating questions for their investigation and includes evidence of a range of questions from initial and background questions to final investigatable questions. The PSTs also discussed the criteria for defining investigatable questions. The PSTs' final investigatable questions are shown below:

> Are physical or chemical methods of protection more effective in blocking UV light and hence preventing the beads from changing colour? (Louise and Morgan)
>
> Compare the colour change of the UV Beads (i.e. the UV strength) under tanning bed lights and the sun. (Catelyn and Sophie)
>
> How does the distance from the beads to the light source affect the colour change? (Amy and James)

> What colour changes are observed in UV beads placed behind and in front of a window and *what does this tell us about the window's usefulness as protection from sunburn*? (Jane and Rebecca)

The PSTs' final questions are shown above. These were devised by the PSTs after stating initial and background information questions that were then refined into questions for investigation:

> We were then handed out beads and a UV torch and asked to write down any questions we might have about the beads and how the UV torch affects them.
>
> Initial questions we had about the beads: Why do some beads change colours and others don't? What causes the beads to be different colours?
>
> Refined questions about beads (to investigate): How can the beads be protected from UV light? How UV light affects beads of different absorbance?
>
> Final question which we would like to investigate: Are physical sunscreens more effective than chemical sunscreens at blocking UV light? Physical meaning that it contains zinc oxide or titanium dioxide and chemical meaning that it doesn't contain zinc oxide or titanium dioxide. (Morgan's logbook)

The example above shows how Morgan initially asked broad but not investigatable "why" questions and changed these to "refined questions" that met some of the criteria for investigation but did not have implications for society. Morgan's final question for investigation considered her initial questions and related to implications for society.

The PSTs also discussed criteria for choosing an investigatable question:

> I learned more about asking scientific questions that I am interested in and also how to form investigatable questions out of them. I was also introduced to the criteria which makes questions investigatable such as measurement, variables, time, resources and apparatus. I found this practice very beneficial as I had not had much experience with forming investigatable questions previous to the lab. (Morgan's week one reflection)

Morgan focused on the criteria used to define a question for investigation, such as stating dependent and independent variables and required resources.

> Not all questions can be investigated by scientists. It is therefore necessary to examine the initial questions I posed and decide which, if any, can be investigated scientifically. In order to do this, I have to first set out criteria for what I think allows a question to be investigated. These criteria are displayed in the image below. (Jane's logbook)

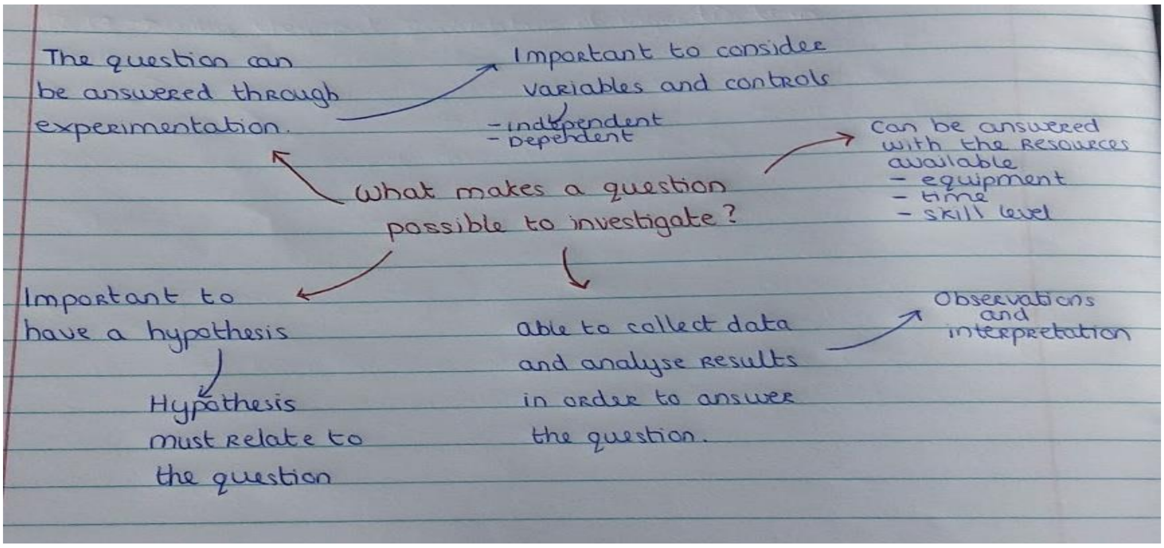


Figure 5-3 Development of Jane's ability to distinguish investigatable questions

Jane showed her understanding of the skill by including hypotheses, variables, the ability to gather analysable data and she clearly relates the question to implications for society. However, she only focuses on questions that can be answered through experimentation, not secondary research.

Catelyn discussed the criteria which she used to decide her final question for investigation and considered implications for society as an important aspect of choosing a question:

> After we finished the initial experimentation, we began to narrow down the questions into questions we could find the answers to and the ones we couldn't. After much deliberation, my partner and I settled on trying to discover the strength of the UV lights in tanning beds vs the sun as many people in society use tanning beds and this could strike interest with students. (Catelyn's logbook)

(b) State justified hypotheses

This sub-theme is evidenced by PSTs making predictions and hypotheses. Six PSTs stated a hypothesis in their logbook, Catelyn and Sophie did not:

> Chemical protection is a more effective method of protection than physical protection, as there is no colour change of UV beads. (Louise and Morgan)

> The beads will turn to a darker shade with less distance to the UV light source. (Amy and James)

> The beads will show the same extent of colour change on both sides of the window and it can be deduced from this that windows offer no protection against sunburn. (Jane and Rebecca)

PSTs talked about to what makes a good hypotheses as part of their investigation:

> I also learned that a proposed hypothesis should be clearly related to the investigable question and that refuting a hypothesis is just as important as gathering evidence to support it. (Jane's reflection week one)

> A hypothesis is a statement that has arose directly from the question and contains very similar aspects: knowing the variable, what you are looking for, how you will approach it. The link between the hypothesis and the investigable question is very strong and should act as a good guide to how you will approach the investigation. (Rebecca's reflection week one)

According to Rebecca the hypothesis is the link between the question for investigation and the method for investigation. It begins to introduce the method ("how you will approach it"), including variables.

(c) Research

The PSTs referred to carrying out *research* as part of their investigation:

> After this lab and for my experimentation next week, I am researching some of the background questions that myself and my partner discussed while working with the UV beads and the UV torch. We wrote down questions that we wanted to research in order to help us complete the experiment. (Catelyn's reflection week one)

> I will also need to continue researching UV light and its connection with sunburn so that the results we get in our investigation can be related back to the question we are trying to answer. (Catelyn's week three reflection)

Catelyn indicated that secondary research was used to inform her question and method, and to provide a scientific justification for her conclusions.

Findings of secondary research was evident in the PSTs' logbooks but this was coded into the *explain scientifically* sub-theme and *knowledge* theme because it included the PSTs' explanations and interpretations of their research using scientific knowledge.

(d) Plan and carry out experiments

This sub-theme includes references to planning and carrying out experimental work and evidence from student work. Evaluating and making changes to experiments is considered under a separate sub-theme (*evaluate and make changes to investigations).*

> In this week's lab I learned how to properly plan to carry out my own investigation. I discovered how important it is to think of all the details. For example: materials, resources, methods, repetition, dependent and independent variables, measuring and taking measurements, gathering data instantaneously, forming results etc. (Morgan's week two reflection)

Morgan emphasised the importance of planning the method of the experiment including describing variables and stating the required resources. This was prior to commencing carrying out the experiment. The mind-map (Figure 5-4) taken from Jane's logbook, shows how Jane organised her plan:

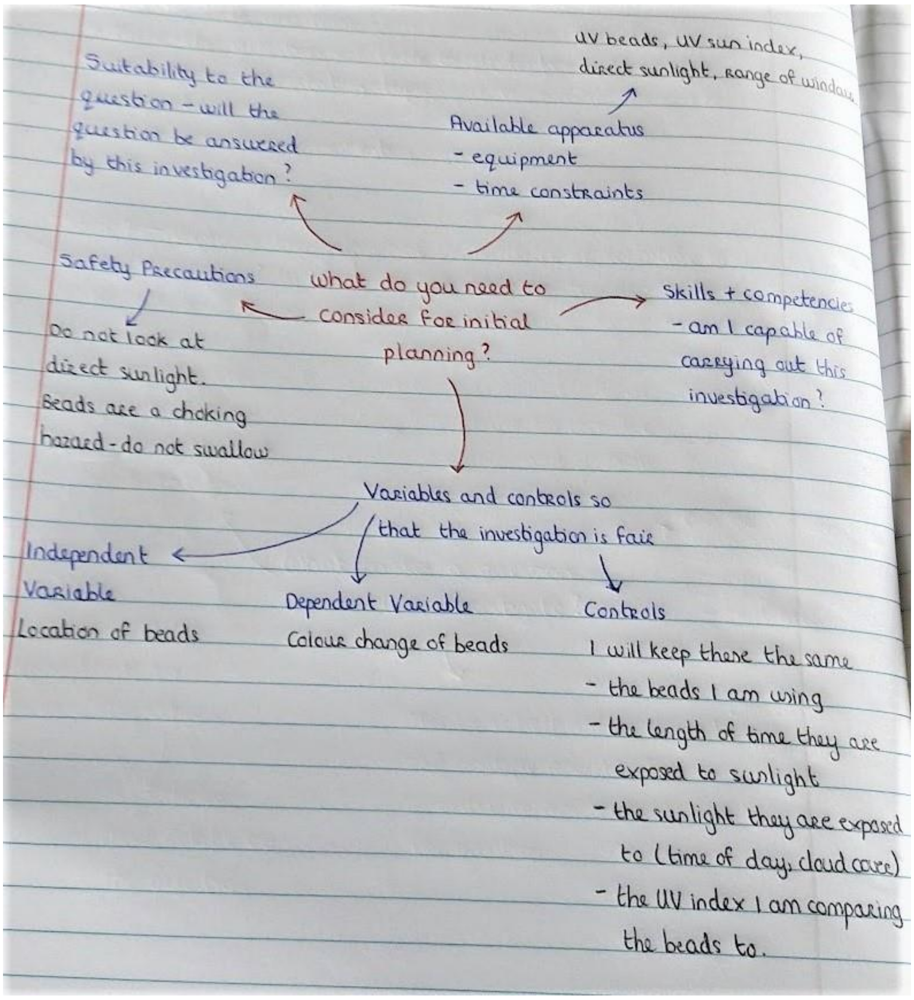


Figure 5-4 Evidence for sub-theme plan and carry out experiments (Jane's logbook)

She stated explicitly all relevant variables (independent, dependent and controlled) and equipment required, and questions whether the chosen method is suited to the question. The focus on planning prior to commencement of experimentation was reiterated by Amy:

> Before we started planning the procedure, we had to figure out what our variables, controlled variables, our resources and what exactly we were measuring. (Amy's logbook)

She then outlined the method for the experiment in her planning:

1. Place the UV beads in a petri dish
2. Place the petri dishes under the UV light source
3. Turn on the time and leave the beads there for 2 minutes.
4. Once the 2 minutes are up, take a picture of the UV beads.

5. Compare the colour change to the UV index guide and write down the results.
6. Repeat the procedure in a dark room and in sunlight.
7. Graph and Analyse the results. (Amy's logbook)

Amy stated her variables as "Beads in Tanning Bed, beads under sun and beads in a dark room" and "controlled variables" as "time, same beads, same petri dishes". She also included a list of resources including "tanning bed lights, sun, UV beads, UV scale, timer, petri dishes".

(e) Evaluate and make changes to investigations

This sub-theme is evidenced by PSTs' references to evaluation of their investigation and changes made as a result, including evaluation of their investigatable question, experimental methods and some evidence of evaluation of sources of evidence for secondary research, and evidence of this in student work.

> The light was held at different distances to the beads and the intensity of the colour change was observed. This was too difficult to observe as the intensity of colour change in the beads could not be measured. We then decided we would observe the length of time it took the beads to return to colourless after exposure. (Amy's logbook)

Amy gathered initial data through experimentation and after evaluation she made changes to both her experimental method and question for investigation based on this evaluation. This was backed up in Amy's week two reflection:

> I learned more about how the beads can work and what needs to be thought about in order to run experiments on them; such as length of time of exposure or intensity of UV light they're exposed to. (Amy's week two reflection)

Evidence from Jane and Rebecca's logbooks showed extensive evaluation and changes based on reflection, initial planning and information from secondary research:

> We are not happy making a decision as to whether we will support or refute our hypothesis based on one set of measurements. We decided we would like to repeat the experiment at a later stage to verify the results we already have. We also decided we would like to open our experiment to more windows to see if there are any similarities or differences between them. (Jane's logbook)

Jane and Rebecca extended their experiment to include a range of different types of glass, which showed clear evidence of evaluation, identification of changes and action required.

There was little evidence of explicit evaluation of sources of evidence for secondary research. Morgan's evaluation focused on the relevance of the information for the question for investigation:

> [the website] provides background information into not just UV light but the full electromagnetic spectrum. In order to carry out a proper experiment, the theory behind it must be understood. This will allow for us to understand and know exactly what it is we are investigating. (Morgan's logbook)

(f) Present and analyse data

This sub-theme contains references to the PSTs presenting and analysing data that they gathered through experimentation (there was no data from secondary research) and evidence of this from student work.

> We had to analyse this information and represent in the form of tables or graphs, this is a skill that I have had but from my own investigations I genuinely have worked on and improved this skill. (Catelyn's reflection)

The PSTs referred to presenting their data as tables and graphs, no other representations were discussed. Raw data was presented as photographs or statements which were then analysed and presented as tables and graphs. Jane's logbook provided the comprehensive data presentation and analysis. Initially, data was presented in a detailed but overly complex table and graph:

Table 5-7 Evidence of sub-theme present and analyse data (Jane's logbook initial table)

	Inside Window		Outside Window	
	UV Sun Index	Quantity of Beads	UV Sun Index	Quantity of Beads
Group 1	4	3	5	4
	5	4	6	3
Group 2	4	5	7	5
	5	3	8	3
Group 3	No observable change		4	3
			5	4
			6	3
Group 4	2	3	6	4
	3	4	7	3
Group 5	2	4	8	6
	3	3	9	1

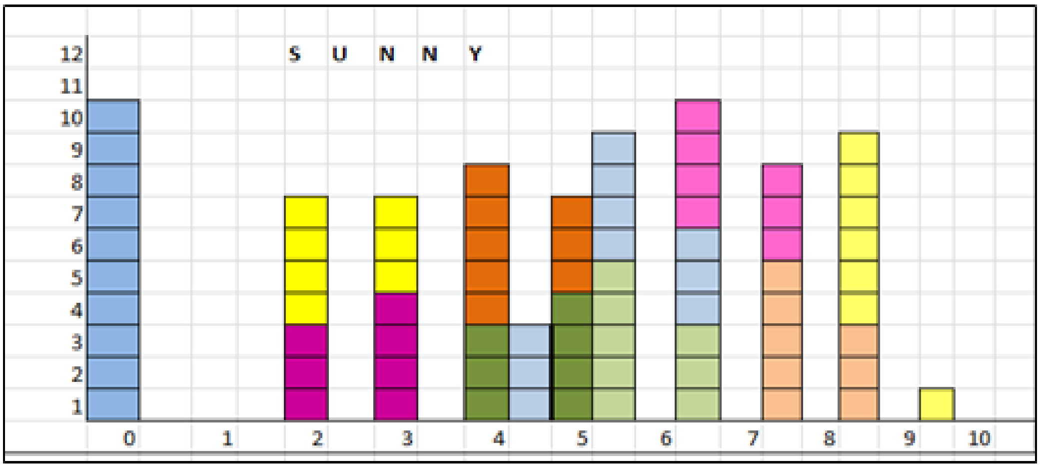


Figure 5-5 Evidence of sub-theme present and analyse data (Jane's logbook initial graph)

She reflected and made changes to the method of presentation and analysis as she progressed through her inquiry:

> However, after designing Graph 1, it became apparent that it is so detailed it is difficult to read. Our question and hypothesis do not require this level of detail. We are not interested in the colour of every single bead but merely in the UV index value with respect to the location of each bead. Therefore, we decided to present the data in a manner that is easier to read and hence interpret. (Jane's logbook)

Based on these evaluations her original table and graph were simplified by combining the results from different coloured beads:

	Quantity of Beads		**Quantity of Beads**		
UV Index	Inside	Outside	UV Index	Inside	Outside
0	10	0	6	0	10
1	0	0	7	0	8
2	4	0	8	0	9
3	7	0	9	0	1
4	8	3	10	0	0
5	7	8			

Figure 5-6 Jane's simplified table of data (logbook)

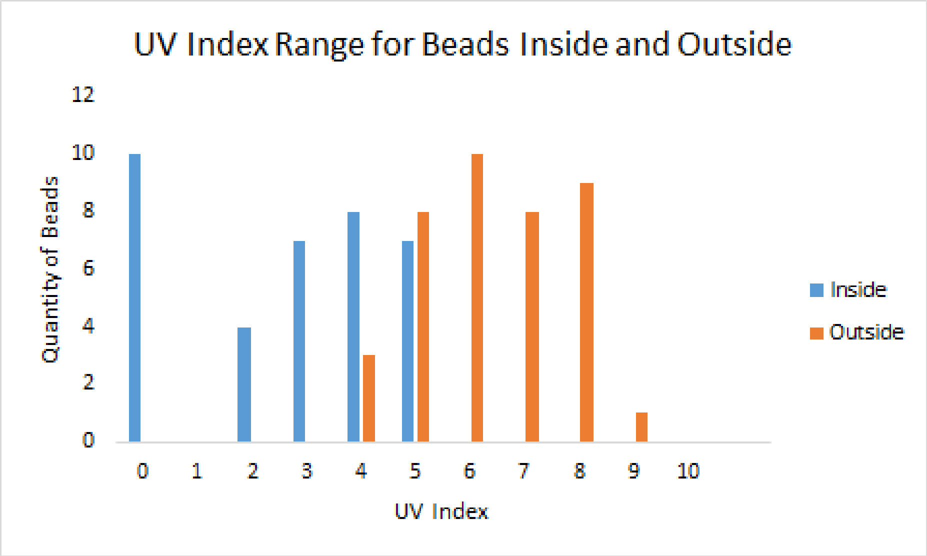


Figure 5-7 Jane's simplified graph of data (logbook)

(g) Explain scientifically

Evidence for this sub-theme was identified in student work when the PSTs drew conclusions from their experimental investigation and when describing the findings of their secondary research. The sub-theme overlapped with the *knowledge* theme, both with implications for society and without; PSTs used scientific knowledge to give scientific explanations. The extract below shows Jane *explaining scientifically* when drawing conclusions from her investigation.

> As we tested three different types of window, we can make conclusions about each of them. While we are satisfied that they each offer a certain extent of protection against UV radiation, none of these windows offer complete protection. It is therefore *recommended that sun protection be worn if travelling in a car, especially if the day is particularly sunny, in order to protect the body against sunburn and other forms of UV skin damage*. (Jane's logbook)

Jane based this conclusion on experimental findings and secondary research and considered the implications for society. However, other PSTs gave a conclusion for their experimental investigation that did not explicitly consider the implications for society:

> The results we obtained showed us that the strength of UV [from a tanning bed] is overall stronger than that of sunlight or in the dark room. (Catelyn's logbook)

Catelyn gave a final conclusion relating to her experimental investigation and then gave a conclusion relating to her secondary research (see below) but did not tie these together to answer her original investigation question:

> We discovered through research that UVC rays do not penetrate the ozone layer while UVA and UVB do. (Catelyn's logbook)

(h) Take action

This sub-theme is characterised by the PSTs statements of planned actions they could take as a result of their inquiry:

> Boycott Tanning beds due to their damaging effects. Provide information to educate others about their harmful effects. Try and develop a protective screen for tanning beds to prevent some harmful rays from getting through. Spread awareness through social media, creating hashtags and making a twitter page. (Catelyn's logbook)

Jane described actions she could take to address the SSI context:

> Make a poster - display in classroom. Present findings to other students. Wear sun cream when in close proximity to windows as well as outside. Advise others to wear sun cream. Provide services - have sun cream in classroom. Visual demonstration to make people aware of the findings of the investigation. Write letters home - school letter with students involved. Have it as a focus on the school website or newsletter (Jane's logbook)

She described personal actions she could take (wear sun cream) and actions that aimed to educate others (advise others, write letters home).

(i) Managing myself

This sub-theme is evidenced by references to timekeeping and working towards goals, including self-assessment: "Knowing the goal/aim of what you're learning and having something to work towards" (Amy's week four reflection). This sub-theme also included PSTs talking about choosing topics that were personally relevant: "[investigating] topics that interest you" (Catelyn's logbook).

Due to the nature of the sub-theme there was no evidence from student work.

(ii) Knowledge

The *knowledge* theme includes two sub-themes: *implications of scientific knowledge for society* and *recall and application of scientific knowledge*. In the PST case study, implications of scientific knowledge is the larger of the two sub-themes. Each of the knowledge sub-themes will be described below and evidence presented.

(a) Implications of scientific knowledge for society

This sub-theme was evidenced from PSTs' statements of scientific facts or demonstration of knowledge that clearly stated impact on society. This included PSTs' hypotheses, explanations of findings from secondary research and conclusions, and proposed actions.

> The beads will show the same extent of colour change on both sides of the window and *it can be deduced from this that windows offer no protection against sunburn*. (Rebecca's logbook)

Rebecca's hypothesis clearly links the investigation to implications for society, using scientific knowledge of how UV radiation travels through different materials. However, the explanation lacks detail.

Findings from research were presented and interpreted by the PSTs using scientific knowledge and explaining the implications for society:

> What causes sunburn? Sunburn is caused by exposure to UV light. The energy in UV radiation damages molecules in the skin. UV radiation is composed of UVA, UVB and UVC. UVC is completely blocked by the atmosphere. UVB is responsible for the majority of sunburns. UVA also contributes towards sunburn but not as much as UVB. *Getting sunburnt a lot means you are at a higher risk of skin cancer*. (Jane's logbook)

> What is the UV index? The UV index is a measure of how much UV radiation is expected to reach the Earth's surface. It ranges from 0 to 12. *In Ireland, it is extremely rare for the UV index to have a value of 8. The higher the index, the greater the rate of skin damage due to UV radiation*. (Jane's logbook)

Jane's background research clearly related to the implications for society in terms of the dangers of UV radiation to human health.

The PSTs used their scientific knowledge of the implications of UV radiation on society, mainly focussing on the effect on human health, to propose actions to address these implications:

> Use what was learned from the experiment to link to other uses of UV light and make a poster to make more people aware of tanning beds and how they affect your skin. (Sophie's logbook)

Sophie demonstrates her knowledge of the implications of the use of tanning beds ("how they affect your skin") but does not go into detail about what these are.

Few conclusions included implications for society:

> Therefore, members of society should take caution to wear sun protection if they are seated beside a window in their workplace or if they spend a lot of time at windows at home. As was seen in the findings of our background research, prolonged exposure to UV light causes sunburn. (Rebecca's logbook)

Rebecca's statement "prolonged exposure to UV light causes sunburn" clearly outlines implications for society, although as with Sophie's explanation, detail was lacking.

(b) Recall and application of scientific knowledge

This sub-theme is evidenced through student work containing scientific explanations that did not relate to implications for society:

> Physical sunscreens are sunscreens which contain zinc oxide and titanium dioxide and chemical sunscreens are sunscreens which don't contain these ingredients. (Morgan's logbook)

While Morgan's description of physical and chemical sunscreens relates to an application of science she does not explicitly discuss the implications for society.

Findings from background research were presented using scientific knowledge:

> The EM spectrum is the range of all types of EM radiation including: visible light, UV light, microwaves, x rays, gamma rays etc. Electromagnetic radiation is a stream of wavelike mass-less particles called photons. These travel at the speed of light. (Louise's logbook)

Louise's description of the electromagnetic spectrum demonstrated *recall and application of scientific knowledge* and did not attempt to discuss impact on society.

(iii) PISA competencies and sub-competencies used in the Assignment

Table 5-8 shows the percentage of PSTs who reported using each *overall* competency as part of their inquiry in the context of SSI (Appendix A - Questions 7-9 of questionnaire).

Table 5-8 Percentage of PSTs who reported using the competencies of PISA

PISA competencies	**Percentage of PSTs (number, n=8)**
Explain phenomena scientifically	63% (5)
Evaluate and design scientific enquiry	100% (8)
Interpret data and evidence scientifically	88% (7)

All three competencies were stated as having been used by most of the PSTs. All PSTs reported using competency 2 and fewer, five out of eight, PSTs reported using competency 1.

Figure 5-8 shows the percentage of PSTs who reported using each sub-competency in the Assignment (part two of the questionnaire).

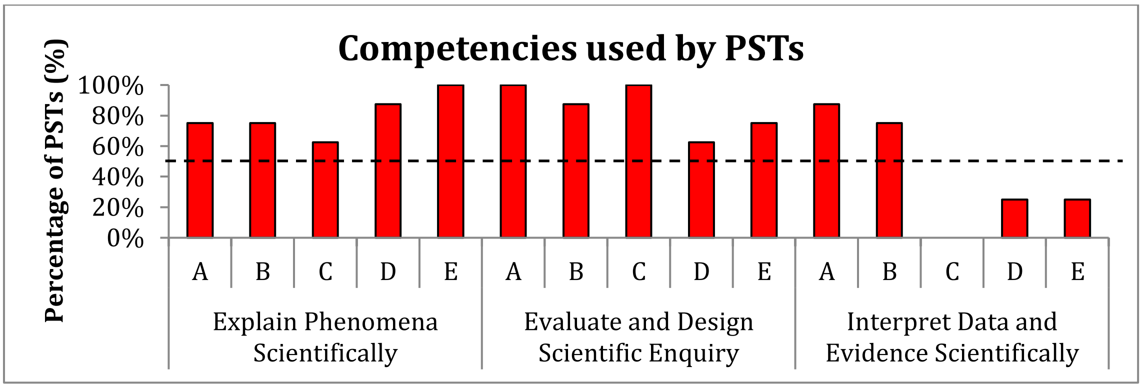


Figure 5-8 Percentage of PSTs using the PISA sub-competencies

All PSTs reported using the sub-competencies 1E, 2A and 2C. Only two out of the eight PSTs reported using sub-competencies 3D and 3E. No PSTs reported using sub-competency 3C.

5.2.3 Discussion: PSTs' experience as *learners*

Figure 5-9 shows an overview of the PSTs' experience of inquiry in the context of SSI as *learners*.

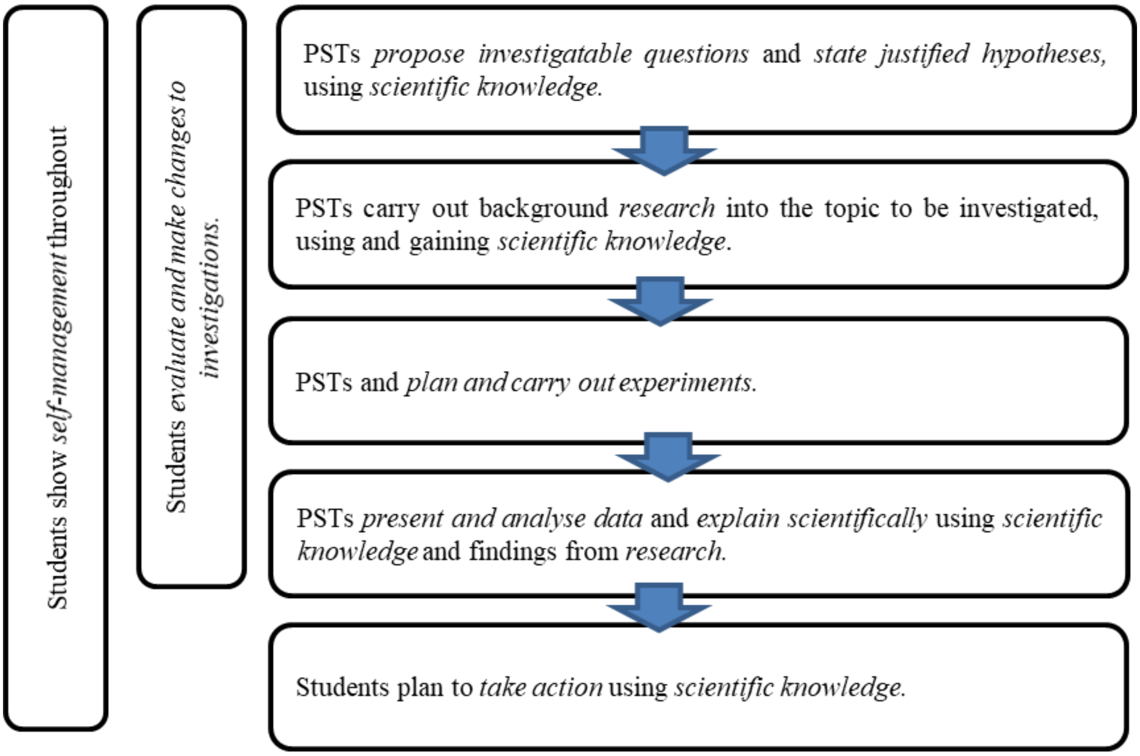


Figure 5-9 Overview of the PST experience as learners

The PSTs' experience as *learners* focussed on the *skills* and *knowledge* developed and assessed. Firstly, the PSTs proposed questions for investigation and made predictions justified with *scientific knowledge*, with and without stating *implications for society*. The PSTs carried out background *research* into their topic at home and presented their findings using *scientific* *knowledge*. The PSTs then planned their experimental investigations and began to carry them out. These initial methods and findings were evaluated by the students and changes were made where required. The PSTs carried out experiments and gathered data over two weeks and in the second week the students *presented and analysed data* in their logbooks and *explained scientifically* when they stated conclusions, which were based on *scientific knowledge*, and backed up by findings from *research*. The final phase of the investigation involved the PSTs making plans to *take action* using their *knowledge of the implications for society*.

(i) SSI Context

The context of the inquiry was based on the societal implications of UV radiation, which was the topic chosen by the facilitator. The questions chosen for investigation by each pair of PSTs indicated their chosen SSI context.

Louise and Morgan chose to explore different methods of protecting skin from the sun. Their initial question did not explicitly discuss implications for society. Their background research also did not focus on implications for society, instead they discussed the electromagnetic spectrum, e.g. "The EM spectrum is the range of all types of EM radiation including: visible light, UV light, microwaves, x rays, gamma rays etc." (Morgan's logbook). Neither Louise nor Morgan stated a conclusion for their investigation, data was analysed and presented as a table but not explained. Louise and Morgan stated actions they would like to take as a result of their investigation but the implications for society were not explicit:

> Make people aware of the different ingredients in sunscreens. Get students to test the sunscreens they have at home. (Louise's logbook)

Louise and Morgan's investigation had the potential to be considered as SSI. They could have discussed considerations around the use of sunscreens, from different points of view (e.g. why people choose not to wear sun-screens) and health implications of exposure to UV radiation. The topic could have been discussed in local contexts (e.g. Irish statistics). However, their inquiry did not explicitly consider implications for society and was simply an experimental investigation related to an application that is used by humans (sunscreen).

Catelyn and Sophie focussed on a potentially controversial SSI topic, use and dangers of tanning beds. Their question for investigation did not explicitly consider implications for society but the pair considered this in other aspects of their inquiry. They asked questions that related to the implications for society from the early stages of their investigation:

> How does UV damage skin? What number on the UV index is damaging to human skin? What is the wavelength of the sun in Ireland? (Catelyn's logbook)

Catelyn explained how their investigation related to a topic relevant to society:

> After much deliberation, my partner and I settled on trying to discover the strength of the UV lights in tanning beds vs the sun as many people in society use tanning beds. (Catelyn's logbook)

Their secondary research also focussed on the implications for society:

> Medium-wavelength UVB is very biologically active but cannot penetrate beyond the superficial skin layers. It is responsible for delayed tanning and burning; in addition to these short-term effects it enhances skin ageing and significantly promotes the development of skin cancer. (Catelyn's logbook)

In culmination of their inquiry Catelyn and Sophie stated an experimental conclusion and then discussed actions which they could take and these had clear implications for society.

> The results we obtained showed us that the strength of UV [in a tanning bed] is overall stronger than that of sunlight or in the dark room. (Sophie's logbook)

The experimental conclusion did not consider implications for society but it is clear from the actions stated that the PSTs developed a personal opinion about the SSI context, they would not personally use tanning beds ("boycott tanning beds"). They had decided that overall they were more harmful than beneficial and that they would "educate others about their harmful effects". Catelyn and Sophie's topic provides an excellent SSI context for exploration. The experimental inquiry aspects did not feel forced or shoehorned in. They were able to state a final experimental conclusion and their proposed actions provided an indication of their views on the SSI. However, Catelyn and Sophie did not discuss the benefits of tanning beds or why people chose to use them despite the dangers and so did not fully explore the SSI context.

Amy and James chose to explore the application of UV radiation in forensics. Their question for investigation was stated in week one and implications for society were not considered until later in week two:

> What impact does the investigation have on society? In forensics UV light is used to look for bodily fluids by first reacting them with a fluorescent chemical such as luminol and then shining the UV light. Luminol is only reactive for a short period of time, so the UV light test needs to be done quickly. (Amy's logbook)

This meant that the experimental question drove the choice of context. The overall conclusions linked the experimental conclusions to the implications for society:

> This shows that the distance of the UV light source to the beads has an impact on the time it takes them to react. This is important to note since once substances are treated with a fluorescent chemical there is only a short period of time that the reaction takes place, and from this experiment it is important to be within a distance of 2 meters,

> as this is the distance when the light intensity was high enough to cause a visible result. (Amy's logbook)

When stating proposed actions, Amy described actions based on investigations her peers had carried out:

> Make a poster to make more people aware of a new issue: effectiveness of sun creams, how UV light goes through windows, tanning beds and how they affect your skin. (Amy's logbook)

Amy was not able to state any proposed actions for her topic of investigation because the implications for society were descriptive. The topic explored was limited to an application of UV radiation that has implications for society rather than an authentic SSI context. The topic was not discussed in terms of moral or ethical implications or a range of viewpoints.

Jane and Rebecca chose to explore how glass protects against damage caused by UV radiation. They considered implications for society from early on:

> Investigation Question - Attempt 1: What protection, if any, do windows provide to minimise sunburn? (Rebecca's logbook)

Rebecca included two conclusions, one was an experimental conclusion and one focussed on the implications for society:

> Each of the three windows offers some protection from UV radiation, none of them offer complete protection. As our background research highlighted, prolonged exposure to UV radiation can have serious health implications. It would therefore be recommended that sun protection is worn at all times by those in society who are often positioned next to a window. (Rebecca's logbook)

Rebecca considered the health implications of the topic and formed a personal opinion based on the results of her inquiry ("sun protection is worn at all times"). Jane and Rebecca also stated actions based on their investigations and these aligned with their opinion stated in the conclusion.

Jane and Rebecca's topic is not an obvious SSI context. However, it can be considered a relevant topic and their interest in it was demonstrated by their thorough investigation. It was explored incompletely and it is likely that if they had done additional secondary research they would have unearthed a wealth of conflicting views on the issue. The SSI context also allowed them to propose actions and their main proposition was to advise others to "wear sun cream when in close proximity to windows". This is a view backed up by Cancer Research UK (Cancer Research UK, 2017).

Overall, the PSTs related their inquiry to implications for society but the extent to which these were explored as SSI was variable. Two of the topics for inquiry stood out as being SSI based and investigatable through experimental and secondary research-based inquiry: the "tanning beds" topic and the "how glass protects against UV radiation" topic.

The pedagogical approach used by the facilitator did not explicitly discuss SSI contexts as scientific topics with moral/ethical/societal implications, their inherent controversial nature and inability to be easily concluded even after thorough examination of available evidence. If these criteria had been shared with the PSTs in advance this may have helped them to choose more appropriate SSI contexts.

(ii) Skills and knowledge of inquiry

The module aimed to develop and assess seven skills using the pedagogical approach of inquiry in the context of SSI. These skills were outlined in section 5.1.1. Findings from analysis of student work and questionnaires indicated that nine skills were developed and assessed. Table 5-9 compares the skills that the module intended to assess with those identified from thematic analysis.

Table 5-9 Skills aimed to be developed vs. skills identified from thematic analysis

Aims of the module	**Skill evidenced from thematic analysis**
Develop a question that is possible to investigate scientifically	Propose investigatable questions
Make and justify hypotheses	State justified hypotheses
Propose a way of exploring a question scientifically	Plan and carry out experiments/ Research
Evaluate ways of exploring a question scientifically	Evaluate and make changes to experiments
Interpret data and evidence scientifically	Present and analyse data
Draw appropriate conclusions	Explain scientifically / knowledge (with and without implications)
Explain the potential implications of scientific knowledge for society	Take action /Knowledge of implications for society
N/A	Managing myself

There is high level of alignment between the aims of the module and the findings from the case study of the module. All the skills that the module aimed to develop and assess were evidenced. The module also aimed to develop content knowledge of science, which was evidenced as the two knowledge sub-themes: *recall and application of scientific knowledge* and *implications for* *society*. The module aimed to develop the PSTs' ability to explain the potential implications of scientific knowledge for society. The knowledge sub-theme *implications of scientific knowledge for society* was the larger of the two, indicating that when PSTs gave scientific explanations they did so by discussing the implications for society and situating their knowledge within the SSI context. The following paragraphs will discuss each skill and knowledge as it was observed in the case study.

All PSTs were able to state a range of questions and modify these into a question for investigation. However, despite one of the criteria being that questions (in this inquiry) should relate to implications of UV radiation for society, this was not always the case, meaning that the SSI context did not permeate through all aspects of the inquiry. Most of the questions were limited to experimental investigation with only Jane and Rebecca's question explicitly considering implications for society.

The PSTs then stated hypotheses relating to these questions. These related closely to their experimental inquiry, including dependent and independent variables and stated a clear expected outcome. Scientific knowledge was demonstrated in these hypotheses:

> Chemical methods of protection are more effective than physical methods of protection from UV light as the beads did not change colour. (Louise's logbook)

Louise's correct use of scientific terminology ("chemical" vs "physical" methods, "UV light") demonstrates her scientific knowledge. However, most PSTs (six out of eight), including Louise, did not situate their hypothesis within the SSI context.

The largest focus of the inquiry was on planning, carrying out and evaluating experiments. The focus was so large that it consisted of two sub-themes, one focussed on planning and carrying out experiments, and the second focussed on evaluating. The latter encompassed evaluation of secondary research-based inquiry but this was a lesser focus. Planning, carrying out and evaluating experiments occurred throughout the four-week module. When planning experiments, the PSTs focussed on variables, those changed, measured and controlled, and required equipment. Evaluation occurred in cycles of questioning, experimentation and formulation of new questions based on evaluations (Exploratorium, 2006). Figure 5-10 below shows the overlapping cycles of evaluations and changes made.

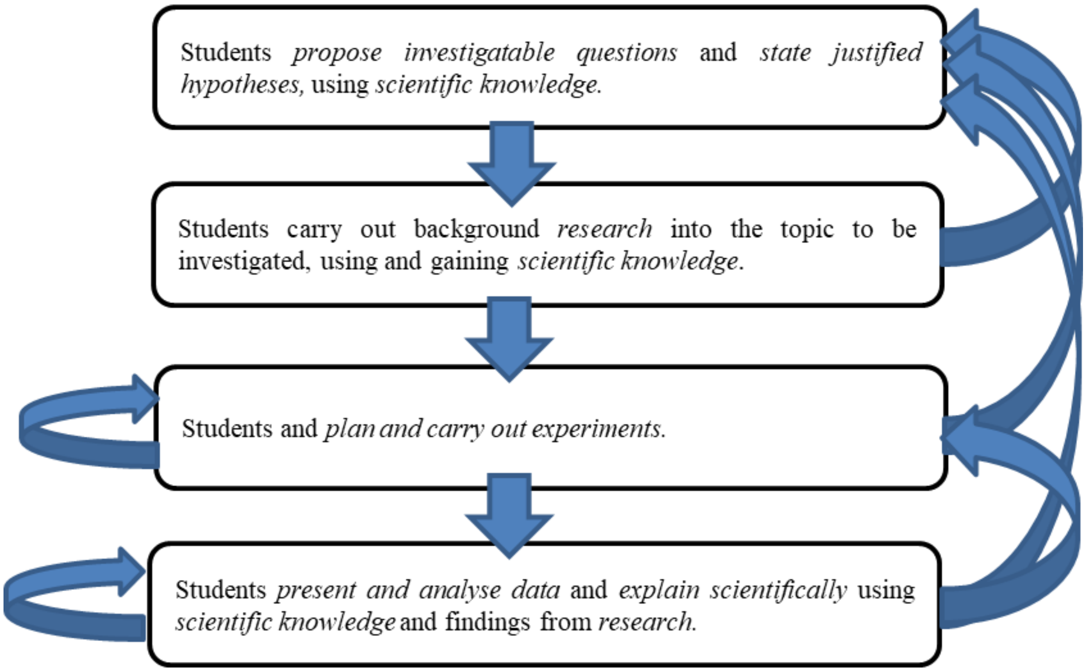


Figure 5-10 Evaluation cycles carried out by PSTs

Evaluation took place both within and between stages (as shown by the curved arrows). Firstly, based on their secondary research students evaluated and made changes to their investigation questions. Based on evaluation of their initial method (third box), PSTs evaluate their question and make changes to both their question and method (between and within stage evaluation). Based on evaluation of their presented and analysed data (fourth box) PSTs made changes to their question, method and data presentation and analysis. Ideally, the evaluation cycles stopped when the PST was happy with the question and method and confident in the data gathered, presented and analysed (see Jane's quote below). Final conclusions were drawn at this point.

Recall and application of scientific knowledge and *implications of scientific knowledge for society* was demonstrated to some extent by the PSTs when planning, carrying out and evaluating experiments, mainly when the PSTs evaluated their question or method based on findings from research. However, this skill was largely performed procedurally, outwith the context of the SSI.

Secondary research was used by the students to inform their investigatable question and provide justification for their final conclusions by explaining the science behind their investigation and exploring implications for society. However, the PSTs mainly viewed research as a justification for their experiment or to back up their experimental findings:

> We wrote down questions that we wanted to research in order to *help us complete the experiment.* (Catelyn's reflection week one)

> I will also need to continue researching UV light and its connection with sunburn so that the *results we get in our investigation can be related back to the question we are trying to answer*. (Catelyn's week three reflection)

The vision of inquiry advocated in the module included experimental and secondary research as methods of gathering data and evidence. The lesser emphasis on research compared to experimental investigation, was not intended in the module design. However, it is clear from the assessment criteria and focus of the labs that a mainly experimental inquiry was inadvertently advocated. There was a focus on skills relating to traditional scientific processes. The hypothesis for example was expected to include "variables" and have a "clear expected outcome". This is not something that would be expected of an inquiry in the context of SSI, which are not easily concluded even after examination of the evidence. The PSTs were asked to state in their method "variables changed, measured and controlled" which is associated with experimentation and not secondary research. The PSTs were asked to state resources needed and determine a method of collecting data and evidence, which could constitute secondary research. However, this came after the initial focus which emphasised experimental methods. Secondary research and experimental methods were considered by the facilitator but this was of little focus for the PSTs:

> Evidence of reflection: Comments on own experiment in terms of fair testing and reliability (repeats of own experiment). Comments on the reliability (trustworthiness) and validity (relevance) of the sources of data and information. (Facilitator suggested assessment criteria for skill four)

The PSTs recognised that their lack of focus on secondary research was at odds with the vision of inquiry advocated in the module:

> [If I did the investigation again I] would have done more secondary research. It would have benefitted my logbook and experiment. (Caitlyn's questionnaire part one).

The PSTs presented and analysed data from their experiment and drew conclusions. The presentation and analysis of data was limited to photographs, tables and graphs. Some PSTs were diligent in their analysis and presented their data in multiple formats and ensured the inclusion of labels, appropriate scale etc. Other PSTs presented their data in tables and did not complete the analysis to present their findings as graphs (if appropriate).

The PSTs demonstrated their ability to explain their data gathered through experimentation and evidence researched when they stated conclusions. These were justified with scientific knowledge. When demonstrating their scientific knowledge in their scientific explanations they did so largely within the context of the SSI by explaining the implications for society. The PSTs discussed the use and technological applications of UV radiation and the implications for society mainly in terms of the health implications of exposure to UV light and how these can be minimised.

In culmination of their inquiry, PSTs were asked to plan actions they could take to address the SSI. However, due to limited time, these were not carried out. The PSTs' planned actions relate to the six actions described by Bencze (2017). The PSTs' actions aimed to:

- Educate others: "Provide information to educate others about their harmful effects" (Catelyn's logbook)
- Develop better inventions: "Try and develop a protective screen for tanning beds to prevent some harmful rays from getting through" (Catelyn's logbook)
- Boycott offenders: "Boycott Tanning bens due to their damaging effects" (Catelyn's logbook)
- Improve personal actions: "Wear sun cream when in close proximity to windows as well as outside" (Jane's logbook)
- Provide services: "Have sun cream in classroom" (Jane's logbook)

Some PSTs did not personally relate to the actions and instead chose to plan actions for their students to carry out: "Make a poster - display in classroom" (Jane's logbook), "have sun cream in classroom" (Rebecca's logbook). It is likely that if the PSTs had been given an opportunity to carry out their planned actions these would have been more detailed and personally relevant.

PSTs were also asked to report on their use of the competencies and sub-competencies of PISA. When asked about the three competencies of scientific literacy, the PSTs indicated that all three were used in their inquiry. There was a high emphasis on Competency 2 *evaluate and design scientific inquiry* and Competency 3 *interpret data and evidence scientifically,* and a lesser focus on Competency 1 *explain phenomena scientifically*. This aligns with the findings from the qualitative aspects of the study which indicated a high focus on experimentation and presentation and analysis of data with a lesser focus on explaining scientifically.

When asked to indicate which of the PISA sub-competencies were used during the inquiry, 14 of the 15 sub-competencies were stated as having been used. 12 out of 15 sub-competencies were stated by most of the PSTs as being used in the module. Three sub-competencies stood out as most PSTs stated these were *not* used: Identify the assumptions evidence and reasoning in science related texts (3C), distinguish between arguments based on scientific evidence and theory and those based on other considerations (3D) and evaluate scientific arguments and evidence from different sources (3E). These sub-competencies relate to critical evaluation of evidence gathered through secondary research and further confirm the lack of focus on secondary research and the skills associated with this.

5.2.4 Findings: PSTs' experience as teachers

The module was designed to allow PSTs to experience inquiry in the context of SSI as a pedagogical approach for the development of the skills and knowledge of scientific literacy. The PSTs' discussion of pedagogical approaches in this module were wider than the approach they experienced. This section presents evidence for and then discusses the findings from analysis of interviews and secondary documents relating to the PSTs' experience as trainee teachers in terms of their pedagogical approaches.

Table 5-10 shows the results of thematic analysis of secondary documentation (PSTs' weekly reflections, lesson plans and video analyses, and researcher field notes) which include discussion and evidence relating to the PSTs' teaching, either hypothetical or from their prior in-school placement. Interviews, which were carried out after the module and after a subsequent in-school placement, also focussed on pedagogical approaches in practice (what they did on placement). The sub-themes are shown in Table 5-10 in order of emphasis but are discussed in sense-order rather in the following paragraphs.

Table 5-10 themes and sub-themes relating to PST experience as teachers

Theme	Sub-theme
Pedagogical approach	Guided inquiry
	Structured inquiry
	No inquiry
	Open inquiry

This section presents evidence from secondary documentation and interviews relating to the three sub-themes identified as contributing to the PSTs' experience as *teachers.*

(i) No inquiry

The following descriptions of teaching episodes depict the *no inquiry* sub-theme in that the activities described do not fit the vision of inquiry proposed in this module (see Section 5.1):

> Show the class a video to do with levels of organisation. The class will the complete the video analysis sheet and answer questions about the video (James' initial lesson plan)

> Show a diagram of the microscope that with all the labels. Students will be asked to take note of these labels so they can complete the activity later in the class. The functions of the different parts of the microscope will also be noted by students. (James' initial lesson plan)

James' lesson plan shows a teacher-led approach that is not student centred. The teacher "shows" a video and later a diagram. Students answer written questions and take notes. There is no evidence of students collaborating.

> The teacher will go through the PowerPoint with the students teaching about enzymes. A video on enzymes will also be watched. (Morgan's final lesson plan)

Morgan's planned approach is didactic; the activities are not student centred or collaborative. The students do not take part in any form of experimental or secondary research inquiry.

(ii) Structured inquiry

This sub-theme is evidenced by proposed teaching episodes that are student centred and collaborative. They include some form of experimental or secondary research-based investigation but with a high level of teacher control:

> I would propose questions to students and lead them into the direction of making measurements. I would show them measurements that in fact could be useful to support their work. (James' reflection week three)

James suggests that a high level of support should be given to students carrying out inquiry. He would choose the question and "lead" students towards a set method of investigation.

(iii) Guided inquiry

This sub-theme was a "catch-all", encompassing sub-theme, incorporating a range of inquiry based approaches. This is because data was coded into this theme if there was more student control than described above in the structured approach but it was not a clear open inquiry from start to finish. This sub-theme contained a wealth of information about how the PSTs viewed inquiry in general:

> [inquiry] is a student-based method of learning where it is essential that students are actively involved rather than having a passive involvement in a class where the teacher does all the work. (James' reflection week one)

> I think it would be important for me to act as a facilitator in the class room. I would act as a guide and a mentor rather than a lecturer. (Morgan's reflection week one)

James' and Morgan's statements discuss inquiry as a pedagogical approach as student-centred, with less teacher control than the previous sub-theme but do not evidence an open inquiry approach. However, there is little detail in these statements to indicate what would actually take place in the classroom.

Other references were more clearly related to the "guided" inquiry definition (Table 1-4) where students investigate a given problem using their own method: "Students were just given a task (i.e. question) and allowed to design and carry out their own plan of action." (Louise's video analysis)

(iv) Open inquiry

This sub-theme is evidenced by the PSTs' descriptions of inquiry tasks where the student chooses the question for investigation and designs their own experimental or secondary research-based method of investigation:

> An approach that I would also like to take would be a complete open approach. I would simply provide all necessary equipment to a class and just allow them to make their own investigations and come up with experiments. (James' week one reflection)

> If a more open approach was to be used, all apparatus could be just handed out to students and an open question could be asked such as: 'Why does the gelatine not set? (Morgan's final lesson plan)

James and Morgan's descriptions of their open approach gave little detail of the role of the teacher as facilitator but met the criteria for the open approach as students choose their own question for investigation. Amy's description of open inquiry gave a more comprehensive overview of open inquiry as a pedagogical approach:

> Inviting the students to come up with their own investigations; either completely by themselves or with a prompt such as the Beads.

- Have them come up with their own questions and what they might want to investigate - do a mind map of what constitutes a investigatable question
- From their questions ask the students to come up with hypotheses that relate to their questions- Come up with what the actually think might happen
- Discuss what kind of things could be measured in their experiments; how can they investigate
- Students could come up with possible investigations; let them play with the beads with different resources (variety of equipment) and see what kind of plans are possible (Amy's week two reflection)

Amy's detailed description touches upon many of the inquiry skills discussed in the module and clearly shows the locus of control with the students.

5.2.5 Discussion: PSTs' experience as teachers

The module aimed to present a pedagogical approach to inquiry that was situated within SSI contexts and was student centred and collaborative. The module presented inquiry as an approach that could take varying levels that differ according to the locus of control (teacher vs. student) and the level of intellectual sophistication. The module presented assessment of inquiry as both formative and summative. This section discusses the PSTs' experience as teachers focussing on their development in terms of pedagogical approaches to inquiry in the context of SSI. First, an overview of the PSTs' experience as teachers is presented and then each of the sub-themes from the *pedagogical approach* theme are discussed. The sub-themes present different levels of inquiry, and PSTs expressed the view that some levels were better suited to more experienced or higher ability students. This view is also explored in this section.

The PSTs showed development of their understanding of pedagogical approaches to inquiry in the context of SSI. Their view of inquiry as a pedagogical approach evidenced three levels which varied according to the locus of control (Figure 5-11).

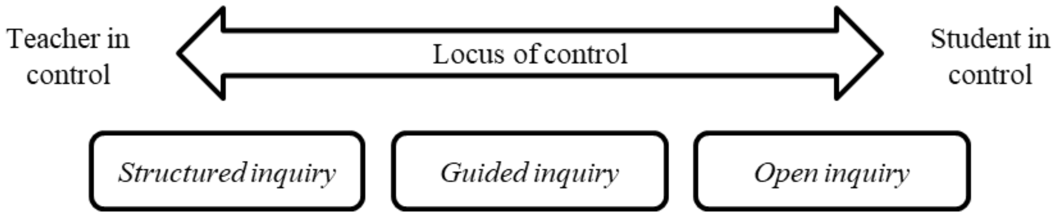


Figure 5-11 Overview of PSTs' experience as teachers

When they discussed or presented pedagogical approaches in their work they mainly focussed on inquiry approaches and mainly discussed *guided inquiry*. *Open inquiry* was given little focus (Table 5-10). The PSTs discussed pedagogical approaches in terms of whether the teacher or student was in control of the progression of the learning and decisions made. The more decisions the teacher made, the less control the student had. The sub-theme *no inquiry* was evidenced when the references to pedagogical approach did not fit with the vision of inquiry proposed by the module.

In the PSTs' descriptions of *structured inquiry*, the locus of control is with the teacher. The PSTs described choosing the question and the method for investigation:

> I would propose questions to the students…I would show them measurements that in fact could be useful. (James' logbook)

In a structured inquiry the question and method are provided by the teacher and the students work to discover the relationship between variables and draw conclusions from data collected (Colburn, 2000). This level of inquiry is given a relatively large focus in the PSTs' descriptions of their planned *pedagogical approach* to inquiry in the context of SSI.

Guided inquiry represents a middle ground in terms of locus of control. Whereas in *structured inquiry* the teacher chooses both the question and the method of inquiry, in *guided inquiry* the method of investigation is chosen by the student. *Guided inquiry* was given a large emphasis by the PSTs when describing their planned pedagogical approach.

Open inquiry was of little focus for the PSTs despite this being the level of inquiry experienced in the module. In an open approach to inquiry, the locus of control is with the student and the teacher provides a supporting role. When discussing how they would carry out *open inquiry* some of the PSTs' descriptions lacked the necessary detail to show their understanding of the approach:

> …all apparatus could be *just* handed out to students and an open question could be asked… (Morgan's final lesson plan)

> I would *simply* provide all necessary equipment to a class and *just* allow them to make their own investigations and come up with experiments. (James' week one reflection)

The descriptions of open inquiry here indicate that the PST may see this as the soft option in terms of planning equipment is "just"/ "simply" handed out and students get on with it. There is no discussion of the role of the teacher in facilitating the inquiry. This lack of focus may indicate two things: firstly, that the PSTs were not confident in the teachers' role in facilitating open inquiry as shown by the lack of detail in their description; secondly, that while the PSTs themselves experienced open inquiry, they did not feel it was appropriate for secondary school students and therefore did not feature heavily in their plans. This second aspect is discussed further in the following paragraphs.

Examination of the initial and final lesson plans for each PST gave evidence of development of their understanding of pedagogical approaches to inquiry. Six of the eight PSTs showed a shift away from teacher-led learning, towards student control. Two PSTs who had initially submitted lesson plans containing *no inquiry*, submitted final lesson plans demonstrating *guided inquiry* and two lesson plans changed from *structured* to *guided*. Two final lesson plans demonstrated *open inquiry*, one lesson plan changed from *guided* and another from *structured*. Of the two lesson plans that did not demonstrate changes towards higher levels of student control one showed no changes from *structured* inquiry and another showed an increase in teacher-led inquiry from *guided* to *structured*. The lesson plan that showed no change belonged to Jane and she explained why he had chosen to present a lesson based on structured inquiry:

> The level of inquiry shown in the activities of this lesson is quite structured and guided… This group of students had *not previously been exposed to inquiry so I feel it is necessary to guide them*. (Jane's accompanying explanation of final lesson plan)

Jane's comments indicate a view that was expressed by PSTs throughout their discussions of pedagogical approaches to inquiry. This view describes how the level of inquiry should be based on the class's experience and ability. The PSTs highlighted the importance of students experiencing a structured approach in their early experiences of inquiry:

> These activities show a very structured approach. They are focused towards a first-year class being introduced into a completely new topic… They are being introduced to inquiry learning in a manner that allows them to have each step clear and easily understandable. This lesson would allow students to become more confident in their scientific skills before getting complete control of their investigations. (Amy's final lesson plan)

Amy makes it clear that both the content knowledge to be learnt and inquiry skills focus are unfamiliar to the student and so a "step by step" approach is taken to scaffold the learning. The last sentence indicates that the ultimate goal would be to progress to an open inquiry approach. This is a view that is reiterated by the PSTs throughout the module:

> Depending on what age group you may have, some students may find it very difficult to collect data for their investigations … it can also be very difficult to analyse it after. That is why as a teacher I think it is essential that when teaching students these skills that the inquiry-based approach is not left too "open". (James' reflection week three)

James believes that an open approach is not appropriate for less experienced (younger) students because some aspects (data gathering and analysis) are too difficult and therefore the teacher should exercise greater control over the inquiry. Open approaches, according to the PSTs, are only suitable for older, more experienced (in inquiry) learners:

> This would be more suited to a class group which is experienced in learning by inquiry and a group which will feel comfortable with carrying out the investigation with little guidance. (Morgan's final lesson plan)

Colburn (2000) states that there is confusion around the idea that inquiry-based instruction is only for "advanced" students and that this is a misconception. However, he also asserts that familiarity with the activity (level of inquiry), materials and context (content knowledge) will make it easier for students to develop the skills and knowledge associated with the inquiry being conducted. If the inquiry is either too challenging or too easy the students will not develop the intended skills and knowledge effectively (Colburn, 2000). Colburn (2000) recommends an approach where different students are doing different versions of the activity, which is more likely to be the case in an open inquiry approach. Differentiation in terms of levels of inquiry or inquiry activities was not discussed by the PSTs. They talk about the ability and experience of the whole class, not individuals, and as such the idea they put forward of open inquiry being too "difficult" for the *whole class* is naive and underdeveloped as some students would find this to be an ideal level of cognitive challenge. The PSTs' seemed to rail against the open inquiry as they experienced it, repeatedly stating that this would only be suitable for those more experienced students. This may indicate that the level of challenge was too high for the PSTs in this module. Alternatively, they may see themselves as "experienced" and are incredulous about their own students' ability to conduct such an inquiry. Colburn (2000) states that many students initially resist open-ended instruction and that it may take some time for students to appreciate its value, which may be the case here.

5.2.6 Conclusions and implications: PST case study

The PSTs' experience of inquiry in the context of SSI reflected their dual role as *learners* and as *teachers*.

Their experience as *learners* centred around the skills and knowledge developed and assessed and largely matched those that the module aimed to assess. There were a wide range of skills evidenced. Worryingly, there was a lack of focus on secondary research and the skills relating to this including analysis and evaluation of scientific texts from a range of sources and the ability to evaluate information from these sources. This lack of focus on secondary research approaches was due to the overemphasis on experimental approaches not just planning, carrying out and evaluating the experiments but also hypothesising and drawing conclusions.

It is promising that the PSTs discussed their inquiry mainly in terms of implications for society and there were some genuine SSI contexts used ("tanning beds", "UV light travelling through glass"). SSI contexts in this vision of inquiry were considered to be scientific topics with societal implications that included a range of points of view to be explored and were not easily "solved". They should also be contemporary, increasing their relevance. Finally, SSI contexts should encourage activism. However, the module did not share these criteria with the PSTs from the outset. The PSTs were told that their topic should relate to "implications for society" and should give rise to "action". It is possible that highlighting the controversial aspects of SSI may have affected the PSTs' topic choice to increase alignment to the criteria for authentic SSI (Section 1.4.2).

The PSTs discussed situating the student inquiry within real-life contexts and discussing with their students the implications for society. However, there was no evidence of engagement with the controversial aspects SSI contexts:

> They will be asked to come up with a "real-life" scenario where forces have a role and decide how they will investigate this role. (Amy's final lesson plan)

The class will be asked to investigate the question 'Would the food you've chosen be more beneficial to a marathon runner or a sprinter?' (Louise's final lesson plan)

The PSTs' experience as teachers also matched the pedagogical approach to inquiry they experienced in the module. They viewed inquiry in the context of SSI as student-centred and collaborative and carried out in different levels. However, they focussed little on assessment approaches. The PSTs discussed the full range of levels of inquiry but focussed mainly on guided inquiry and little on open inquiry, despite this being the level of inquiry they experienced. This indicates that the PSTs were not comfortable using open inquiry as a pedagogical approach, even by the end of the module. This is backed up by the lesson plans, submitted after the module, which showed development of more student-centred approaches but only two of the eight PSTs chose to present an open inquiry. The PSTs appeared to rail against open inquiry approaches, believing it too challenging for their own students. When open inquiry approaches were discussed, the descriptions were naïve and did not consider the role of the teacher.

5.3 Chapter conclusions and implications

This chapter presented the design of a module for PSTs that aimed to allow them to experience inquiry in the context of SSI as *learner* and as *teachers*. It then presented a case study exploring the eight PSTs experience of the module as both *learners* and *teachers*.

This module aimed to develop skills and knowledge that contribute to scientific literacy using inquiry in the context of SSI as the pedagogical approach. It also aimed to provide opportunities for explicit reflection on the pedagogical approaches relating to inquiry in the context of SSI.

There was evidence of strong alignment between the skills and knowledge that the module aimed to develop and those evidenced from the case study. However, there was an overemphasis on the skills relating to experimentation and not enough focus on secondary research and critical evaluation of sources and information. While it was promising that the PSTs mainly related their inquiry to implications for society, the extent to which SSI contexts were used and explored varied.

In terms of the PSTs' development as teachers, the PSTs were exposed to open, mainly experimental inquiry and they planned and discussed mainly guided approaches for their own students. However, they also indicated that they would feel comfortable progressing to more open approaches as the students (and likely the PSTs themselves) gained more experience in inquiry approaches.

This has implications for the module design. There are a range of choices for changes to the module based on what has been learnt from the PST case study but also based on the findings from the studies described in Chapter 4.

Option one, the route taken by Scottish curriculum developers, would be to remove the requirement for SSI contexts. This would mean that the PSTs would carry out a mainly experimental inquiry, with a lesser focus on secondary research but with no requirement to link their inquiry to implications for society. However, this would not be in keeping with the aims of the module which were to expose the PSTs to inquiry in the context of SSI pedagogical approaches.

Option two would more closely match the Irish Science in Society Investigation and would involve removal of the requirement to carry out an experiment. This would essentially take the module back to the form it took during the pilot study where PSTs followed the guidelines for carrying out the Irish Science in Society Investigation (Chadwick, McLoughlin & Finlayson, 2016). However, there would be increased opportunities for reflection and demonstration of pedagogical approaches to inquiry compared to the pilot.

The final option, the option that the researcher recommends, would be to continue to strive towards an inquiry that develops both the skills and knowledge of experimental and secondary research and uses authentic SSI contexts. The module would essentially remain the same but with a number of changes designed to increase the focus on secondary research and SSI contexts.

Firstly, the assessment criteria would be revised to give equal credit for secondary research and experimental approaches. Some specific changes may be to remove the requirement to state a hypothesis altogether (or simply subsume it into experimental assessment criteria). The assessment criteria currently reward a statement of a "clear expected outcome" and this is not compatible with SSI contexts which are not easily "solved". Assessment criteria relating to planning and carrying out investigations should also be changed to clearly reward secondary research and critical evaluation of sources of evidence. The requirement to draw appropriate conclusions, may be reworded to take account of the tentative nature of SSI. The Irish Science in Society Investigation, for example, rewards students for explaining "different sides of the argument" and giving a "personal opinion" (NCCA, 2016, p. 32). Additionally, it should be made clear to the PSTs from the outset what makes a good SSI and this would aid their own topic choice (as learners) and their understanding of teaching using SSI.

The reason that this approach is preferred by the researcher is because there is evidence that this module showed progress in integrating SSI contexts and experimental inquiry approaches that proved unsuccessful in the Scottish curriculum. Two of the topics explored by the PSTs, "tanning beds" and "UV radiation travelling through glass", were authentic SSI contexts. These two inquiries successfully integrated SSI contexts and relevant experimental investigations although they were then limited by the assessment criteria that did not reward exploration of these contexts in full.

6 Conclusions and implications

The research presented in this thesis is situated within the existing literature and policy relating to scientific literacy, inquiry and SSI contexts. This literature was described in detail in Chapter 1. The findings and conclusions from the studies contribute to and extend the existing literature, and narrow the observed gaps between literature, policy and practice. This explores the overarching question: *How can the teacher and student experience of the development and assessment of scientific literacy in secondary schools inform initial science teacher education?,* through thorough examination of the literature and policy, and studies of practice in secondary and tertiary level education.

There is a wealth of research that focuses on the development of skills and knowledge of scientific literacy in secondary schools, using inquiry in SSI contexts. However, the pedagogical approach tends to be guided discussion inquiry and the aim is to develop skills relating to argumentation and critical evaluation of evidence (Sadler, 2009; Zeidler & Nichols, 2009). In the studies presented in this thesis, the description of inquiry is wider, including experimental, secondary research and discussion, and described according to levels of inquiry. The skills developed as a result of these inquiry approaches were also wider and not limited to argumentation and critical evaluation of evidence. Importantly, the research presented in this thesis is focussed on specific curricular contexts (i.e. policy) and current practice. The two curricular contexts (Scottish and Irish), and the assessments in particular, have been given little focus in published literature. This means the findings have usefulness for informing specific policy and practice relating to assessment in the Scottish and Irish curricula.

The research presented in this thesis also aims to extend the published literature relating to initial teacher education. There is little published research into the use of inquiry in the context of SSI at tertiary level, and less so with pre-service teachers, compared to the literature and policy focussed on secondary schools. Research suggests that initial teacher education should take account of the dual role of PSTs as *learners* and *teachers* (Topcu, Sadler & Yilmaz-Tuzun, 2010). However, much of the research into initial teacher education programmes that aim to develop PSTs' ability to teach using inquiry approaches focus on the PST as a *learner* only (Topcu, Sadler & Yilmaz-Tuzun, 2010; Bencze & Sperling, 2012). There are also few specific recommendations in the literature regarding how to design and implement these initial teacher education programmes. The module designed, implemented and evaluated in this thesis was based on literature and research into practice in secondary school contexts. This aimed to contribute to the literature relating to use of inquiry in the context of SSI with PSTs to develop their scientific literacy as *learners* and their pedagogical approaches as *teachers.* This case study also aimed to make specific recommendations for others when planning and implementing initial teacher education programmes.

6.1 Development and assessment of scientific literacy in secondary schools

The assessment of scientific literacy in summative, written assessments was examined in two studies (Chapter 3). These studies defined scientific literacy, narrowly, as the three competencies and 15 sub-competencies of PISA, and the three knowledge types (Table 1-1 and Table 1-2). The study *assessment of scientific literacy in a PISA assessment item* (Section 3.1) found that the range of skills and knowledge assessed was limited and only the PISA competency, *interpret data and evidence scientifically*, and PISA knowledge type, *content knowledge*, was assessed. Additionally, this study showed that if students are given the opportunity to explain their reasoning then it is also possible to determine the level of scientific literacy of the individual. A second study, *assessment of scientific literacy in the curricular exams of Scotland and Ireland* (Section 3.2), showed evidence of assessment of a range of sub-competencies and knowledge types of PISA. However, some sub-competencies and knowledge types were assessed frequently while others were assessed infrequently or absent altogether. The skills assessed in these summative, written assessment items focussed on easily assessed skills such as interpretation of data and drawing conclusions or providing scientific explanations, using scientific content knowledge. There was little evidence of the assessment of inquiry skills such as proposing investigatable questions and ways of exploring a scientific question, or skills associated with secondary research such as critical evaluation of information or sources of evidence.

The overall conclusions from the studies of summative, written assessments (Chapter 3) agree with the existing literature relating to assessment of the skills and knowledge of scientific literacy. Ratcliffe & Grace (2003) describe written, summative assessments as “artificial” and “contrived”, with a focus on high reliability that lowers the overall validity of the test (p. 44). They describe how the skills that are assessed are “atomistic”, meaning that they are assessed discretely and out of context (Ratcliffe & Grace, 2003, p. 44). The lack of assessment of inquiry skills was indicative of these issues (Chapter 3). Students were not given the opportunity to carry out the skills relating to the inquiry aspects of scientific literacy in an authentic situation and the focus was on the performance of skills as discrete instances in individual assessment items. Literature and policy suggest that a more authentic approach to the assessment of scientific literacy is to carry out classroom-based assessments of inquiry skills using socioscientific issues as contexts (Ratcliffe & Grace, 2003; NCCA, 2015; SQA, 2016). Focus on a range of inquiry skills in a range of SSI contexts allow the performance of these skills in a less “atomistic” and more “interconnected” way. This increases the validity of the assessment although it is also likely to lead to decreased reliability (Ratcliffe & Grace, 2003, p. 44).

With the literature and policy urging more authentic approaches to assessment and the conclusions from studies of summative, written exams (Chapter 3) supporting this, the development and assessment of the skills and knowledge of scientific literacy through inquiry in the context of SSI was explored (Chapter 4). Three case studies explored the teacher and student experience of inquiry in the context of SSI in the Scottish and Irish secondary school science curricula. The curricula that shaped the teachers approach and therefore the student experience was considered, including a major shift in Scottish curriculum policy relating to assessment of inquiry in the context of SSI that occurred after the study had taken place.

The findings from all three case studies are compiled together in Table 6-1. Each case study is summarised according to the pedagogical approach used by the teacher which relates to the type and level of inquiry, and also the SSI context used (green box), the skills developed and assessed (blue box) and the knowledge developed and assessed (yellow box). The skills and knowledge are presented in order of the emphasis placed on them by teachers and students in each case study. It is acknowledged that these case studies are not directly comparable or generalisable due to the relatively small number of participants in each case study but more importantly that only one or two cases were observed in each context (Scottish and Irish). It is nonetheless informative to look at the case studies in terms of patterns emerging between the cases. The influence of the pedagogical approach (level of inquiry and SSI context) on the skills and knowledge developed and assessed is discussed in more detail in Section 6.1.1.

Table 6-1 Skills and Knowledge, pedagogical approach to inquiry and SSI context in secondary school case studies

Thistle Wood School		**Clover Field School**		**Daisy Park School**	
Some authentic SSI but not emphasised & incompletely explored		SSI authentic but not emphasised		SSI authentic & central to inquiry	
Open/ guided secondary research & Structured experimental	Present and analyse data	Open experimental	Plan and carry out experiments	Guided secondary research and discussion	Explain scientifically
	Explain scientifically		Evaluate and make changes to experiments		Work together
	Research		Propose investigatable questions		Research
	Present information		State and justify hypotheses		Distinguish arguments based on scientific evidence
	Self-management		Explain scientifically		Evaluate solutions
	Plan, carry out and evaluate experiments		Present and analyse data		Present information
	Propose investigatable questions		Self-management		Implications of scientific knowledge for society
	Recall and apply scientific knowledge		Recall and apply scientific knowledge		Recall and apply scientific knowledge
	Implications of scientific knowledge for society		Implications of scientific knowledge for society		

Thistle Wood School case study followed teachers and their students in a Scottish school as they carried out an assessment of inquiry in the context of SSI. The teachers' experience focussed on their pedagogical approach to inquiry while the student experience, as described by the students and their teachers, focussed on the skills and knowledge developed and assessed. In Thistle Wood School case study, the focus was on secondary research inquiry with little emphasis on experimentation. The skills developed and assessed were mainly procedural skills that students carried out without reference to the SSI context. These included presentation and analysis of data, research with little evidence of critical evaluation of information and the presentation of information in scientific formats (Table 6-1). There was also a high emphasis on giving scientific explanations but these were not situated within the SSI context and students used recall and application of scientific knowledge without consideration for the implications for society (Table

6-1). The contexts used were not authentic SSI as they weren't controversial or particularly contemporary. Instead, the contexts used were scientific topics that were more easily researched and described as part of the assessment.

The experience of the teachers in Thistle Wood School was heavily directed by the curricular policy and this dictated the student experience in terms of the skills and knowledge developed and assessed. The rigid assessment criteria was a barrier for implementation of inquiry in the context of SSI and promoted a shift away from authentic SSI contexts (e.g. GM crops) towards more easily assessed topics (e.g. enzymes). The teacher and student experience of inquiry in the context of SSI in Thistle Wood School mirrored changes in the Scottish curriculum policy. After four years of implementation, the SQA removed the requirement to explore SSI contexts and increased the emphasis on experimental investigation (SQA, 2017b, c, d).

Two related case studies exploring inquiry in the context of SSI in the Irish curriculum, Clover Field School and Daisy Park School case studies (Section 4.3), showed two very different pedagogical approaches and resulted in the development of different skills and knowledge. In Clover Field School, the students carried out an open experimental inquiry and a short, guided discussion of SSI contexts took place afterwards. This resulted in the development of skills relating mainly to experimentation and little focus on the SSI context (Table 6-1). In Daisy Park School the students participated in guided discussion and secondary research that placed SSI contexts at the centre of the inquiry. The skills developed related to critical evaluation of evidence and scientific explanations that demonstrated the students' knowledge of the implications of science for society (Table 6-1). These two varying approaches to inquiry were based on the same curricular documentation and this indicates that there was little influence of the curriculum on the teacher and students' experience in the Irish case studies.

The approach taken in the Daisy Park School case study and the resulting skills and knowledge developed and assessed align with and match conclusions from existing literature. However, the approaches to inquiry taken in Thistle Wood School and Clover Field School use a wider description of inquiry. The case studies (Chapter 4) combine research into the different levels and types of inquiry (Colburn, 2000; Linn, Davis & Eylon, 2004; Wenning, 2005) with the use of SSI as the context for the inquiry. While the integration of a range of inquiry approaches, including experimental and secondary research, with SSI contexts did not prove wholly successful in practice in secondary schools, this is a crucial insight into an under-researched field. The conclusions from these studies can be used to inform policy decisions and teachers' practice with the aim of narrowing the gap between the literature, policy and practice in the area of the development and assessment of scientific literacy.

6.1.1 Development of an extended Framework for Scientific Literacy

A Framework of Scientific Literacy was presented (Figure 1-2) which aimed to describe scientific literacy and summarise existing literature. It described scientific literacy as consisting of individual and societal aspects. The individual aspects, which are the main focus of science curricula, are the competencies and skills of science, knowledge of the content of science, knowledge of Nature of Science (NOS) and knowledge of scientific processes. In this framework it was asserted that these individual aspects impact on the individual's interactions with society and so impact society as a whole. Three societal aspects of scientific literacy were proposed: participation in a scientific society, personal enrichment through science and sympathetic and critical attitude towards science. The skills and knowledge of scientific literacy allow the individual to participate in society, gain personal enrichment from science and develop a sympathetic and critical attitude towards science (Figure 1-2). Scientifically literate individuals have developed the range of skills and knowledge that allow them to participate in society, for example by voting responsibly and influencing public policy about science (Miller, 1983). They gain personal enrichment from science through increased employment prospects (although not necessarily in scientific jobs), lifelong learning and personal enjoyment of science (DeBoer, 2000). The scientifically literate individual also has a sympathetic and critical view of science that benefits them in their daily lives (AAAS, 1994; DeBoer, 2000). For example, they can carry out basic critical evaluation and participate in discussion about reports of science in the media (DeBoer, 2000).

Having carried out the studies into the teacher and student experience of inquiry in the context of SSI in secondary schools, the Framework of Scientific Literacy (Figure 1-2) can be extended to form a new framework. This extended Framework for Scientific Literacy aims to provide a framework for the development and assessment of scientific literacy, linking the pedagogical approaches used to the skills and knowledge developed and assessed. The focus is on secondary school contexts and pedagogical approaches using inquiry in the context of SSI (Figure 6-1).

The framework shown in Figure 6-1 breaks down the competencies and skills (blue boxes) and knowledge of the content of science (yellow boxes) of scientific literacy into those observed in the studies carried out in this thesis (also see Table 6-1). It also shows the pedagogical approaches used by the teachers in the studies (green boxes), including the type and level of inquiry, and the SSI context used, which led to the development of these competencies and skills, and knowledge of scientific literacy. The following paragraphs discuss these skills in relation to the framework for the development and assessment of scientific literacy and highlight the influence of the pedagogical approach taken by the teacher. The grey boxes highlight areas which were discussed in the literature but not observed in the studies (dark grey boxes) or were not the focus of the studies (light grey boxes) and so may be areas of further research.

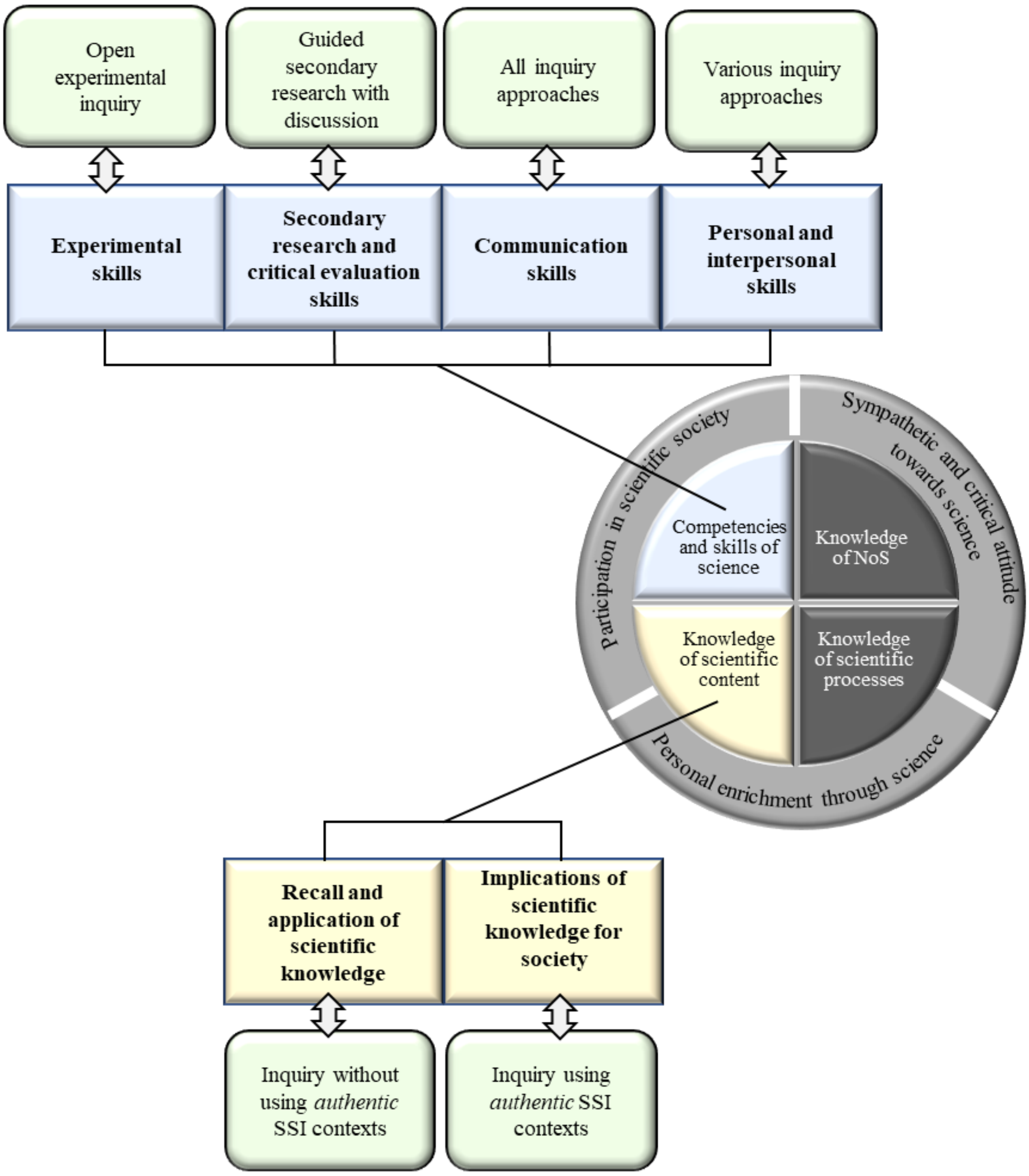


Figure 6-1 An extended Framework for Scientific Literacy

(i) Development and assessment of the competencies and skills of scientific literacy

There were a range of competencies and skills of scientific literacy identified from the secondary school case studies (Table 6-1). These skills were: experimental skills, secondary research and critical evaluation skills, communication skills and personal and interpersonal skills (Figure 6-1 blue boxes). These skills are outlined in the following paragraphs and discussed in terms of how they influence the individual's interactions with society (Figure 6-1 light grey boxes).

The pedagogical approach to the development and assessment of scientific literacy explored in the secondary school case studies (Chapter 4) was limited to inquiry in the context of SSI. All pedagogical approaches were inquiry based but varied according to the level and type of inquiry, and the extent to which an authentic SSI context was explored. As discussed in Chapter 1, "authentic" SSI contexts should be scientific topics with moral, ethical and societal implications (Sadler, 2009). They should be controversial, meaning that they include a range of viewpoints and cannot be easily concluded even after thorough examination of the evidence (Oulton, Dillon & Grace, 2004; Levinson, 2006). SSI contexts should be contemporary, to increase their relevance to the students (Zeidler *et al.*, 2009). Finally, they should encourage the student to take action to address the issue (Hodson, 2010; Bencze & Sperling, 2012). The types of inquiry observed in the secondary school case studies included combinations of experimental, secondary research and guided discussion inquiry. While it has been acknowledged at various points in this thesis that the small number of participants and case studies within each context do not allow for concrete generalisations, there is scope for the identification of patterns between the case studies. One such pattern is the influence of the pedagogical approach on the skills developed.

The experimental skills identified as contributing to scientific literacy are (Table 6-1):

- Propose investigatable questions
- State justified hypotheses
- Plan and carry out experiments
- Evaluate and make changes to experiments
- Present and analyse data

The experimental skills were only observed in the Thistle Wood School and Clover Field School case studies (Table 6-1). In Thistle Wood School the pedagogical approach was combined secondary research and experimental inquiry and in Clover Field School the approach was mainly experimental inquiry (Table 6-1). In Thistle Wood School, while the overall approach was open inquiry, the experimental part of the inquiry was structured. The teacher in Clover Field School took an open approach to the experimental inquiry (Table 6-1). In both schools the emphasis on SSI contexts was low. While in Clover Field School the teacher proposed an authentic SSI context, most contexts explored by students in Thistle Wood School were not authentic. The experimental skills were only observed to be developed through experimental, or combined experimental and secondary research, inquiry approaches. Students may work together while carrying out the inquiry but the focus is on independent learning (self-management). When comparing the approach taken in Clover Field School to Thistle Wood School, there was evidence that the open level of the experimental inquiry increased student engagement and ownership of the inquiry. This is in line with literature suggesting that open approaches increase engagement (Jiang & McComas, 2015). However, Jiang & McComas (2015) also caution that open inquiry approaches decrease achievement in assessment. This was also supported by the findings in Thistle Wood School case study where the teachers commented that students who were given more freedom around the inquiry achieved poorly in the assessment.

There has been little published research relating to the use of experimental inquiry approaches in combination with SSI contexts. From the limited research carried out in this thesis there appears to be a conflict between experimental approaches and the use of SSI contexts. Experimental approaches acted as a barrier to the exploration of authentic SSI contexts because the focus was on the development of skills relating to scientific processes including hypothesising expected outcomes and drawing final conclusions. These skills conflict with SSI contexts which, by their nature, should be unpredictable (e.g. surprising, conflicting views) and not easily concluded (Oulton, Dillon & Grace, 2004).

These experimental inquiry skills contribute to an individual's scientific literacy and allow them to understand the general processes that scientists use when carrying out inquiry, from proposing initial questions to presenting and analysing data (Miller, 1983; DeBoer, 2000; OECD, 2013). The development of these experimental skills will positively impact the individual's interactions with society (Figure 6-1). These skills will allow the individual to gain personal enrichment, including the possibility of employment in industries that require an understanding of scientific processes (not limited to scientific careers) . They will be able to participate in society through decision making relating to scientific policy (Miller, 1983). The individual can understand, and evaluate, scientific inquiry that may be reported in the media and decide whether the claims are trustworthy based on the scientific processes followed by those carrying out the inquiry (DeBoer, 2000). This allows them to feel confident when faced with decisions regarding scientific policy. Through an increased understanding of the procedures and processes of science the individual will gain confidence and trust in science as a rigorous and ethical process but will also be able to identify when scientific inquiry is not rigorous and ethical. The scientifically literate individual should also understand that these procedures are not rigid (Bybee, 2002) and that questioning, hypothesising, planning, evaluating and data analysis happen in cycles and feedback loops (Figure 5-10).

The secondary research and critical evaluation skills contributing to scientific literacy are (Table 6-1):

- Research
- Distinguish arguments based on scientific evidence

- Evaluate solutions

Skills relating to secondary research and critical evaluation of evidence were developed when teachers used a secondary research and/or discussion approach to inquiry. In Thistle Wood School, students carried out a mainly secondary research-based inquiry and this resulted in the development of procedural skills relating to "research" but did not result in the development of critical evaluation skills. In Daisy Park School, the approach used was discussion and secondary research inquiry. This was the only secondary school case study where skills relating to critical evaluation of evidence (*distinguish arguments based on science* and *evaluate solutions*) were developed. The students developed their ability to distinguish the reasoning behind arguments they were presented with, in terms of scientific, political or economic considerations. They also evaluated solutions, rather than stating final conclusions, encouraging them to recognise that complex socio-scientific problems often do not have easily accessible solutions (Oulton, Dillon & Grace, 2004). The level of inquiry was either open or guided (Table 1-4). In Daisy Park School, the question for investigation was chosen by the teacher, making the inquiry guided. There is some question around the level of teacher control over the inquiry in Thistle Wood School. Regardless, the level of inquiry appears to be less important in the development of research and critical evaluation skills than the type of inquiry and the authenticity of the SSI context chosen. Discussion around authentic SSI contexts, rather than procedurally carrying out secondary research, shifts the focus from procedural "research" towards "critical evaluation".

The teacher in Daisy Park School chose authentic SSI contexts and placed them at the centre of the inquiry. In Thistle Wood School, the SSI contexts were not authentic (they did not meet the criteria described above) or they were explored incompletely by discussing one side of the argument only. In Clover Field School the students engaged in a short, guided discussion into an authentic SSI context. This approach should lead to the development of critical evaluation skills (Zeidler *et al.,* 2009). However, the focus of the inquiry in Clover Field School was overwhelmingly on experimentation and the development of experimental skills and so critical evaluation was not discussed by either the teacher or students. The findings from the studies support current literature around the use of discussion-based inquiry to develop skills relating to argumentation and critical evaluation of evidence (Zeidler *et al.*, 2009). Considering the literature, Daisy Park School case study demonstrated a typical inquiry into SSI contexts and the skills developed were as expected.

Secondary research and critical evaluation skills contribute to scientific literacy and relate to the individual's ability to source valid and reliable scientific evidence, upon which to base their decisions, and recognise when sources of information and evidence are not sound (DeBoer, 2000; OECD, 2013). This involves finding the information (research), then deciding whether that information is trustworthy (evaluating the source itself and the basis for the argument made), and evaluating the claims or solutions proposed. These individual skills allow a person to positively interact with society (Miller, 1983; OECD, 2013). The secondary research and critical evaluation skills allow the individual to gain personal enrichment. In modern times, individuals can quickly access a wealth of information in a matter of seconds and the ability to quickly distinguish trustworthy information allows them to find the "correct" information and discard unsound evidence. When faced with controversial scientific issues, where the "correct" information may not be the same for everyone (Oulton, Dillon & Grace, 2003), the individual can make informed, personal decisions based on a full understanding of the source of the information and the reasoning behind the claims. These skills allow the individual to participate in society through involvement in scientific policy decision making (Miller, 1983). For example, the Irish public were asked to vote in a referendum regarding "the regulation of termination of pregnancy" on the 25th May 2018. The ability to distinguish the reasoning behind the arguments made and the source of the information, help individuals to make an informed decision based on sound understanding of the issue. These skills are the basis of a sympathetic yet critical view of science. Individuals are willing to trust the information if they decide it is valid and reliable, following their own critical evaluation (DeBoer, 2000).

The communication skills contributing to scientific literacy are (Table 6-1):

- Explain scientifically using scientific knowledge
- Present information scientifically

The communication skills were developed regardless of the inquiry approach taken and so can be considered fundamental skills of scientific inquiry, and more broadly scientific literacy.

These skills relate to how the scientifically literate individual communicates scientific ideas. They explain and present their understanding using scientific knowledge (OECD, 2013). These individual skills of scientific literacy impact on their interactions with society (Miller, 1983). The individual gains personal enrichment through expressing themselves in a clear and systematic way, using scientific language, in day to day life and their employment (not limited to scientific disciplines). They also recognise scientific reporting styles from other styles of writing and this allows the individual to participate in scientific policy decision making (DeBoer, 2000). For example, while some individuals would want "proof" and definitive results, reports of a high likelihood or correlation may be enough to satisfy the scientifically literate individual. Through an understanding of scientific reporting styles and an ability to express themselves scientifically, the individual will be more sympathetic and critical towards science (DeBoer, 2000). In the example given, the scientifically literate individual is sympathetic towards the inability of science to provide a definitive answer and recognises that this does not make it untrustworthy. They also recognise when outlandish claims are made or reports are not in standard scientific formats and so may be wary of these.

The personal and interpersonal skills contributing to scientific literacy are (Table 6-1):

- Self-management
- Work together
- Take-action

The personal and interpersonal skills developed depended on the pedagogical approach. Students in Thistle Wood School and Clover Field School developed the skill self-management. Students in Daisy Park School developed the skill work together. The skill take action was identified through thematic analysis in the PST case study rather than the secondary school case studies. However, the students in Daisy Park School took action when presenting their solutions to the Transport Problem to their classmates and writing letters to President Trump.

The findings indicate that students develop the ability to collaborate (work together) when engaged in discussion into authentic SSI approaches. This is supported by existing literature that proposes discussion-based inquiry approaches using SSI contexts (Ratcliffe & Grace, 2003; Linn, Davis & Eylon, 2004).

Literature suggests that working with others while carrying out an experimental investigation develops students' collaborative skills (Century *et al.*, 2002; Linn, Davis & Eylon, 2004). Students in Clover Field School worked in pairs to carry out an experiment but this did not result in teacher or student focus on collaboration. In fact, experimental approaches and secondary research approaches, particularly when open in level, appear to be more likely to develop the ability to work independently (self-management), even when carried out in pairs. This is likely to be because in the open inquiry approach, with a focus on experimental procedures, students were not given opportunities for explicit, teacher guided discussion about their experiment.

Research indicates that inquiry in SSI contexts is an ideal vehicle to develop student activism and ability to take action on an issue (Bencze & Sperling, 2012). The findings from the secondary school case studies, presented in Chapter 4, support this. Only those approaches that placed the SSI context at the centre of the inquiry (Daisy Park School/ some PST approaches) developed students' ability to take action. However, Bencze & Sperling (2012) advocate combining experimental and secondary research approaches with SSI contexts to develop students' ability to take action. This was not observed to be a successful approach in the secondary school case studies carried out as part of this thesis. Only the discussion-based inquiry approach allowed students to fully engage with the SSI context and take action as a result of their inquiry. In pre-service science teachers, the experimental and secondary research approach was partially successful at developing the skill take action and this will be discussed further in Section 6.2.

These personal and interpersonal skills relate to how the scientifically literate individual manages themselves, works with others in groups and with wider society, in scientific contexts (Miller, 1983; Holbrook & Rannikmae, 2007). These individual skills of scientific literacy impact on their interactions with society (Miller, 1983). Personal enrichment is derived from the ability to practice personal discipline including timekeeping and organisation, and so be more productive. Personal enrichment also comes from the ability to interact productively with others in employment and social situations. These skills also relate to benefits to society more widely; productive individuals contribute more to society (e.g. organisation in terms of voting and decision making). The ability to take action relates to personal activism that will make a difference to society (Bencze & Sperling, 2012). For example, writing letters to the local Member of Parliament (Teachtaí Dála) on a scientific issue or making changes within the local community. These skills also relate to the development of a sympathetic and critical attitude towards science (AAAS, 1994; DeBoer, 2000). Individuals may reflect on their own viewpoints (e.g. regarding their feelings towards animal rights/ethics of use of animals in science), or through interaction with others be exposed to a range of viewpoints. This allows the individual to critically reflect upon and appraise scientific concepts and ideas (Linn, Davis & Eylon, 2004).

(ii) Development and assessment of knowledge of scientific literacy

The Framework for Scientific Literacy developed in this thesis describes three types of knowledge contributing to scientific literacy (Figure 6-1). The findings from case studies with secondary school teachers and their students showed a focus on knowledge of scientific content. Two types of knowledge, both of which are types of content knowledge, were identified: *recall and application of scientific knowledge* and *implications of scientific knowledge for society* (Figure 6-1 yellow boxes). These knowledge types are outlined in the following paragraphs and discussed in terms of how they contribute to the individual's interactions with society (Figure 6-1 light grey boxes). This section will also discuss the influence of the pedagogical approach taken by the teacher in the secondary school case studies on the knowledge types developed. Details of knowledge types and pedagogical approaches, including type and level of inquiry, and SSI context, for each of the secondary school case studies are shown in Table 6-1.

The scientifically literate individual has acquired a range of content knowledge of science, including knowledge of key scientific concepts, principles, laws and explanatory theories (DeBoer, 2000). From the secondary school case studies, the content knowledge of science that students developed and demonstrated was wide ranging and spanned the three science disciplines of biology, chemistry and physics. The use of content knowledge of science underpinned performance of the skills. For example, students described the science underlying their inquiry when they gave scientific explanations, drew conclusions or proposed solutions to societal issues. These findings are supported by the literature and policy which describe the importance of content knowledge of science for performance of skills relating to scientific literacy, e.g. giving scientific explanations and linking these to the implications for society (OECD, 2013), and also for argumentation and decision making (Zeidler & Nichols, 2009).

Students demonstrated their scientific content knowledge either by describing the implications for society or by stating facts out of context, simply referring to the scientific ideas without linking them to societal implications. Research suggests that it is important for students to understand how the concepts they learn in science are relevant and useful to their lives (DeBoer, 2000). This will aid the individual when using their knowledge, in their interactions with society. SSI contexts, which are controversial and contemporary, are particularly useful because they represent complex, real-life situations that the individual is likely to come across in their daily interactions with society (Zeidler & Nichols, 2009).

The pedagogical approaches used by the teachers in the secondary school case studies influenced the scientific content knowledge that was developed by the students. As discussed earlier in this section, it is important that students recognise the implications of the content knowledge they learn to their lives and wider society. However, in two of the three case studies, knowledge was mainly demonstrated by the students out of context and students acquired scientific knowledge without discussion of the implications for society. In Thistle Wood School the pedagogical approach was an open or guided secondary research and experimental inquiry with little emphasis on SSI contexts. In Clover Field School, the students carried out an open experimental inquiry and the SSI contexts were not emphasised. These pedagogical approaches resulted in knowledge being developed without consideration for the implications for society. Daisy Park School case study took a guided discussion and secondary research-based approach to an authentic SSI context. The SSI context was placed at the centre of the inquiry. This resulted in students demonstrating their knowledge of scientific content by discussing the implications of this scientific knowledge for society. Both Thistle Wood School and Daisy Park School used a secondary research approach to inquiry but the resulting content knowledge acquired by students differed. This indicates that the discussion approach into authentic SSI contexts is the key factor for the development of knowledge with an appreciation of the implications for society.

The approach taken in Daisy Park School could be considered a typical approach to inquiry in the context of SSI, with a focus on developing skills relating to critical evaluation and knowledge of the implications for society. This approach has been advocated in the literature as a way of encouraging students to use their "scientific knowledge for informed decision making" (Zeidler & Nichols, 2009, p. 49). The approaches taken in Thistle Wood School and Clover Field School were more concerned with the development of procedural inquiry skills relating to experimentation or research and did not highlight the relevance of the knowledge being developed to the students' lives or society.

Knowledge of scientific content (Figure 6-1 yellow boxes) allows the scientifically literate individual to participate in society, gain personal enrichment through science and develop a sympathetic and critical attitude towards science (Figure 6-1 light grey boxes) (Miller, 1983; DeBoer, 2000; OECD, 2013). Knowledge of scientific theories and concepts allow a person to understand the science that they come across in their day-to-day lives, such as in the media (DeBoer, 2000). Knowledge of scientific content is important to allow the individual to participate in society through policy decision making (Miller, 1983; DeBoer, 2000). In the example discussed earlier, the Irish referendum on the regulation of termination of pregnancy, the individual's knowledge of scientific content would allow them to understand the various arguments and claims made and make informed decisions when voting. Knowledge of scientific content allows an informed view of science which is neither uncritically positive nor hostile (AAAS, 1994; DeBoer, 2000). The individual has enough knowledge of the scientific content underlying reports that they can critically evaluate the claims made (OECD, 2103). They will not be "put off" by scientific terminology that they don't understand.

6.2 Development and assessment of scientific literacy in initial teacher education

An initial teacher education module for pre-service science teachers was designed that aimed to develop the skills and knowledge of scientific literacy in the PSTs as *learners* and provide explicit instruction relating to pedagogical approaches as *teachers.*

The PSTs developed a range of skills as *learners*. However, there was an overemphasis on experimentation and less on secondary research and critical evaluation of sources and information. The PSTs also developed knowledge of the content of science and mainly described this in terms of implications for society.

The module also aimed to develop PSTs' skills and knowledge of pedagogical approaches of inquiry in the context of SSI as *teachers*. The PSTs described inquiry in much the same terms as had been presented to them in the module. Inquiry was described as student-centred, collaborative and described in terms of levels. There was evidence of a shift in the PSTs' descriptions of inquiry from the beginning to the end of the module, from structured to guided approaches. However, they generally avoided discussing open approaches to inquiry, describing them as only suitable for more able or experienced learners. When they did discuss open inquiry, their descriptions of the role of the teacher were naïve and overly simplistic.

6.2.1 The PSTs' role as learner

In pilot versions of the module, the PSTs carried out an inquiry in the context of SSI as learners and there was no explicit discussion of how this may be implemented in their classroom. This could be referred to as the implicit approach (Lederman *et al.,* 2001) and much of the research carried out with PSTs takes this approach (Topcu, Sadler & Yilmaz-Tuzun, 2010; Bencze & Sperling, 2012). However, research suggests that an approach that takes account of the dual role of PSTs as both a *learner* and a *teacher* is more effective in preparing PSTs to facilitate inquiry in their own classrooms (Lederman *et al.,* 2001; Michalow, 2015). These dual roles may be dealt with simultaneously within the same module or programme, or separately (Lederman *et al.,* 2001). In the PST case study (Chapter 5), a module was planned and implemented that aimed to address the dual roles of the PSTs as *learners* and as *teachers* simultaneously within the same module.

The PSTs developed a range of skills as *learners*. Figure 6-1 shows the different types of skills developed and the pedagogical approach taken by the teachers at secondary school level, leading to the development of those skills. The pedagogical approach taken by the facilitator in the initial teacher education module was an open experimental, secondary research and guided discussion inquiry approach. A range of experimental, secondary research, communication and personal and interpersonal skills (see Figure 6-1) were developed by the PSTs as *learners*. These skills contributed to the PSTs own scientific literacy.

The PSTs developed all the experimental skills described in Section 6.1: propose investigatable questions, plan and carry out experiments, evaluate and make changes to investigations, and present and analyse data. This is likely to be because of the large emphasis on experimental inquiry pedagogical approaches by the facilitator.

However, the emphasis on these procedural, experimental skills came at the expense of the development of other skills contributing to the PSTs' scientific literacy. The PSTs developed research as a procedural skill but there was no evidence of critical evaluation of evidence. In the secondary school case studies these were developed through guided discussion approaches and this may indicate a lack of emphasis on guided discussion pedagogical approaches in the initial teacher education module.

The PSTs demonstrated their communication skills as they explained their findings scientifically. They were not asked to produce a scientific report of their findings and so the skill of presenting information scientifically, which focusses on scientific reporting styles, was not observed. However, the skill of explaining their findings, rather than just presenting them, is arguably more challenging. As discussed in Section 6.1.1, this skill is a fundamental skill that is developed when using inquiry pedagogical approaches.

PSTs also developed their personal and interpersonal skills by showing self-management and planning to take-action as a result of their inquiry. Their planned actions aimed to make changes that would benefit their community and wider society (Bencze & Sperling, 2012). The PSTs worked in pairs to carry out their inquiry but their focus was on self-management, rather than collaboration. As with the secondary school case studies, this is likely to indicate that the facilitator provided insufficient opportunities for guided discussion about their inquiry. Instead, the focus was on the development of procedural experimental skills using an experimental inquiry approach. The PSTs' planned actions were not carried out and did not always relate to their experience as *learners.* If the PSTs were given more time to discuss and carry out their actions this may have resulted in an increased focus on this aspect.

The PSTs also developed scientific knowledge that contributed to their scientific literacy (DeBoer, 2000; OECD, 2013). They developed knowledge of the content of science and mainly discussed this in terms of implications for society. The facilitator encouraged the PSTs to place authentic SSI contexts at the centre of their inquiry. While all PSTs discussed implications for society, not all PSTs used authentic SSI contexts. Some of the chosen contexts simply described an application of science with an effect on society, rather than a controversial topic. Findings from the secondary school case studies indicated that using experimental inquiry approaches created a barrier for the exploration of authentic SSI contexts. This is because the focus on some skills such as stating hypotheses or drawing conclusions (as part of giving scientific explanations) conflicts with the unpredictable and inconclusive nature of controversial SSI (Oulton, Dillon & Grace, 2004). However, two of the four PSTs successfully integrated experimental and secondary research inquiry with SSI contexts. It is possible that by making some changes to the initial teacher education module, e.g. less focus on experimental inquiry and more focus on guided discussion, that more PSTs would successfully integrate experimentation, secondary research and SSI contexts.

Research indicates the importance of the teachers' scientific literacy, i.e. a sound basis of scientific skills and knowledge, to effectively teach using inquiry approaches (Lederman *et al.*, 2001; Roehrig & Luft, 2004). Conclusions from the PST case study and published research carried out at tertiary level (Topcu, Sadler & Yilmaz-Tuzun, 2010; Bencze & Sperling, 2012; Grooms, Sampson & Golden, 2014), suggest that the pedagogical approaches used when developing these skills and knowledge in secondary school students can also be used with PSTs. The PSTs developed a range of skills but focussed overly on procedural skills relating to experimentation and less so on critical evaluation of evidence as part of their research. While knowledge was developed with consideration for the implications for society, not all the PSTs explored an authentic SSI context. Changes to the pedagogical approach taken by the facilitator, namely a decreased focus on experimental inquiry and an increase in guided discussion, are likely to address some of these issues. However, as discussed earlier, development of PSTs' scientific literacy alone is unlikely to translate directly into classroom practice. Pedagogical approaches to inquiry must also be explicitly dealt with in initial teacher education to prepare PSTs to use these approaches with their own students (Lederman *et al.*, 2001; Roehrig & Luft, 2004; Buck & Trauth-Nare, 2009).

6.2.2 The PSTs' role as teacher

The initial teacher education module aimed to develop PSTs' scientific literacy as *learners* and skills and knowledge of pedagogical approaches to develop scientific literacy in their own students (as *teachers*). As part of the initial teacher education module, PSTs were given opportunities to reflect on the teaching approaches used and discussed in the module, and how these may be implemented in their own teaching practice. PSTs participated in discussion about inquiry pedagogical approaches as part of the labs. They were also asked to plan inquiry lessons, provide written reflections relating to pedagogical approaches to inquiry and comment on videos showing teachers using various inquiry approaches. The aim was to increase the PSTs' self-awareness of their beliefs and conceptions of teaching and to make explicit the implicit processes and gut instincts that experienced teachers often rely on when planning and implementing inquiry (Lederman *et al.,* 2001; Buck & Trauth-Nare, 2009).

The module aimed to provide the PSTs with the knowledge and understanding to implement student-centred and collaborative inquiry approaches. This requires the PSTs to develop "student-centred" beliefs and to translate these into their classroom practice (Roehrig & Luft, 2004, p. 20). The module aimed to provide PSTs with an understanding of inquiry as investigative. In the secondary school case studies, inquiry was carried out using three approaches: experimental inquiry, secondary research inquiry and guided discussion inquiry. The module aimed to familiarise the PSTs with these three investigative inquiry approaches. Inquiry can be described according to levels and this was evidenced in both literature research (Colburn, 2000; Wenning, 2005) and the secondary school case studies, which showed open, guided and structured approaches to inquiry. The module aimed to familiarise the PSTs with these pedagogical approaches to inquiry. Inquiry has been widely described in the literature as being assessed formatively and summatively (Black *et al.,* 2004; Wenning, 2007). In the secondary school case studies the teachers discussed assessment of inquiry, particularly in Thistle Wood School where the inquiry was carried out as part of a summative assessment. The module aimed to provide opportunities for the PSTs to develop their understanding of assessment of inquiry pedagogical approaches. The module also aimed to familiarise the PSTs with pedagogical approaches to inquiry that use SSI as contexts.

Overall, the PSTs' view of pedagogical approaches to inquiry in the context of SSI aligned with the view of inquiry presented in the module. However, accommodating the various aspects of inquiry, particularly in SSI contexts, is challenging even for experienced teachers. There was evidence that the PSTs lacked pedagogical skills and knowledge relating to these approaches and/or lacked self-efficacy relating to implementing these approaches (Ratcliffe & Grace, 2003; Roehrig & Luft, 2004; Bencze, 2010). This was evidenced by the aspects of inquiry that were not successfully described in their discussions or planned approaches.

The PSTs described and presented inquiry pedagogical approaches as student-centred and collaborative and described the full range of levels of inquiry. However, they focussed mainly on guided inquiry. The PSTs either did not present open approaches to inquiry at all or presented them naïvely. They justified their lack of focus on open inquiry approaches by describing these as only suitable for the more experienced or able students, which they did not feel their students (hypothetical or otherwise) were. This may indicate that the level of challenge was too high for the PSTs (as *learners*) in this module or they may see themselves as "experienced" and are incredulous about their own students' ability to conduct such an inquiry. This prevailing misconception, that open inquiry is only for advanced learners (Colburn, 2000), was not addressed or challenged during discussion of pedagogical approaches in the module because it was only observed after data analysis.

While the PSTs successfully described pedagogical approaches to inquiry as investigative, they focussed mainly on experimental inquiry approaches with very little focus on guided discussion. This was similar to the findings from the secondary school case studies where two of the three case studies focussed on experimental inquiry (or a combination of secondary research and experimental inquiry). This also matched the PSTs' experience as *learners* during the module, where the focus was inadvertently on experimentation rather than secondary research and discussion. The changes recommended, namely an increased focus on guided discussion, would change their experience as *learners* but this alone may not necessarily change their understanding of pedagogical approaches to inquiry (Lederman *et al.*, 2001; Roehrig & Luft, 2004). There should also be an increased focus on explicit, reflective discussion of alternative investigative approaches, not just experimentation.

The PSTs focussed little on assessment approaches in their discussion and presentation of inquiry pedagogical approaches. This may also be an area for increased focus in the explicit, reflective approach taken in this module (Lederman *et al.*, 2001).

The PSTs discussed how they would encourage students to consider the implications for society but there was no evidence of inquiry using authentic SSI contexts in their discussion of pedagogical approaches to inquiry. As *learners*, the PSTs had some success in integrating experimental and secondary research inquiry with SSI contexts but this did not translate into their described pedagogical approaches. Research suggests that development of skills and knowledge as a learner does not necessarily translate to classroom practice (Lederman *et al.*, 2001; Roehrig & Luft, 2004) and this appears to be the case here. This may indicate a lack of focus, during the module, on explicit reflective discussion around using SSI contexts in the classroom.

The initial teacher education module was lab-based and did not extend to observation of in-school placement. Interviews were carried out with a sample of the PSTs after their in-school placement, which took place shortly after the module. However, this was a sample of cohort of PSTs and was limited to the PSTs' self-reports. Therefore, there was little evidence to support the translation of what the PSTs learnt in the module, both as *learners* and as *teachers*, into classroom practice.

In what little published research there is relating to the use of inquiry in the context of SSI with PSTs, specific recommendations relating to planning and implementing initial teacher education modules are few and far between. Research suggests that PSTs should take part in explicit discussion of pedagogical approaches to inquiry in the context of SSI and should plan lessons for implementing these approaches (Lederman *et al.*, 2001; Michalow, 2015). These recommendations were implemented in this initial teacher education module.

Further specific recommendations for this module, based on the case study, include a decreased focus on experimental inquiry and an increased focus on explicit, reflective guided discussion of pedagogical approaches. Increasing the PSTs' own skills and knowledge of inquiry in the context of SSI, through discussion about how to implement it in real-life classrooms, should also begin to tackle the misconception held by the PSTs, that inquiry is only suitable for advanced or experienced learners (Colburn, 2000). This misconception should be dealt with explicitly during discussion.

Research suggests that to develop skills relating to teaching using inquiry approaches, PSTs should be required to integrate inquiry approaches into their teaching in practice (Michalow, 2015). This is something that was lacking in the initial teacher education module developed as part of this thesis. While the PSTs were required to plan inquiry approaches, they were not expected to implement these in practice. This is an area of development for the module and for the research.

The initial teacher education module aimed to develop PSTs skills and knowledge relating to inquiry in the context of SSI, as a way of increasing their own and their students' scientific literacy. The module aimed to cater for the dual role of the PST as a *learner* and as a *teacher*, and do so within the same module (i.e. simultaneously). Some research suggests this may be too much to expect of novice teachers (Lederman *et al.*, 2001). However, the case study carried out as part of this thesis showed some success in overcoming barriers that PSTs face when implementing inquiry approaches, such as lack of their own scientific content knowledge and skills relating to inquiry, lack of pedagogical skills and knowledge of inquiry approaches and lack of self-efficacy relating to their use in the classroom (Ratcliffe & Grace, 2003; Roehrig & Luft, 2004; Bencze, 2010). As *learners*, the PSTs developed a range of skills of scientific literacy and when demonstrating their content knowledge they did so by considering the implications for society. As *teachers*, they began to plan less structured and more guided and open approaches to inquiry, and discussed and presented how they planned to use inquiry approaches with their own students.

However, there was very little evidence of how this would translate into teaching on placement or in the early years of teaching. Practicing teachers face barriers that the PSTs did not consider in their planned approaches, such as lack of time, lack of materials and resources and lack of permission or support in school (Ratcliffe & Grace, 2003; Roehrig & Luft, 2004; Bencze, 2010). Further research carried out within the secondary school contexts, similar to the secondary school case studies carried out as part of this thesis, may provide more information on how these barriers may be overcome by these PSTs as they move from initial teacher education into their teaching careers.

Changes in the science curriculum of countries around the world have increased the focus on the development and assessment of scientific literacy and introduced assessments using inquiry in the context of SSI (NCCA, 2015; SQA, 2016). In addition, research suggests that there is still limited use of inquiry approaches at university level education (Grooms, Sampson & Golden, 2014) while they are increasingly being recommended by policy-makers for use in secondary schools. This indicates a gap between policy recommendations and practice at tertiary level education. The studies presented in this thesis indicate that by implementing an initial teacher education module using inquiry in the context of SSI, with some of the recommended changes of focus, that PSTs can be better equipped to develop scientific literacy in their own students. This may go some way to helping teachers implement recommended practice (of inquiry in the context of SSI) in secondary schools and narrow the gap between recommendations from policy and teachers' classroom practice.

6.3 Limitations to the research and implications for practice, policy and further research

This research presented an extended Framework for Scientific Literacy (Figure 6-1), which described how the skills and knowledge that an individual has acquired impact their interactions with society. The literature and research informed framework also showed how the pedagogical approaches used by teachers in secondary schools developed and assessed the individual skills and knowledge contributing to scientific literacy (Figure 6-1). This has clear implications for policy and practice in secondary schools and for the preparation of pre-service teachers. Recent changes to the curriculum of Scotland and Ireland have been driven by a desire to increase scientific literacy in students (Scottish Government, 2010a; NCCA, 2015). However, the best way to achieve this goal remains contentious. How teachers should approach the development and assessment of scientific literacy, in terms of day-to-day learning and assessment, is not clearly described or universally agreed in policy or literature. This research aimed to explore how scientific literacy could be developed and assessed in practice, in secondary schools, relating this to current literature and policy. These findings were then used to plan, implement and evaluate an initial teacher education module that aimed to prepare PSTs to develop the skills and knowledge of scientific literacy in their own students.

However, there are limitations to this research. The secondary school case studies were carried out with a relatively small number of participants and only one or two cases were observed in each context. Case studies in educational settings explore complex real-life situations in detail. However, this level of detail and depth was at the expense of the kind of large samples and ability to generalise that would be associated with quantitative research. This means that the case studies are not directly comparable or generalisable (Bassey, 1999). The aim of this research was to provide evidence of what was happening in a small number of secondary school and tertiary level contexts, and possible implications of these. The recommendations from the case studies then invite researchers, policy-makers and teachers to explore these further by carrying out their own research and trying them out for themselves.

When leaving Thistle Wood School, having conducted research over two years, the teachers were keen to discuss the changes proposed to the National 5 Assignment (SQA, 2017b). Namely, the move towards experimental inquiry and away from use of SSI contexts. A further study would examine the impact of this policy change.

In Ireland, the research focussed on the development of skills and knowledge in preparation for the Science in Society Investigation but the assessment itself will not be carried out within the time-frame of this research. Further studies relating to the implementation of the Junior Cycle

Science in Society Investigation should explore the skills and knowledge assessed and the pedagogical approaches taken.

The studies carried out at both secondary school and tertiary education level aimed to contribute to the literature relating to the development of scientific literacy in secondary school students, but also undergraduate level learners, using inquiry in the context of SSI as the pedagogical approach. This is an approach advocated by policy but there was evidence from the secondary school case studies carried out in this thesis that teachers faced difficulties in implementing these approaches in practice. This was particularly evident when these approaches were part of a summative, high-stakes assessment. This resulted in a gap between the recommended curricular policy and the practice of teachers on the "chalk-face". The findings from the secondary school case studies informed the design of an initial teacher education module for pre-service science teachers. The PSTs participating in the module showed some success in overcoming the barriers such as lack of their own skills and knowledge of science (as l*earners*), lack of pedagogical skills and knowledge relating to inquiry in the context of SSI, and lack of self-efficacy using these approaches (as *teachers*). Research suggests that overcoming these barriers will go some way to increasing the PSTs ability to implement inquiry approaches (Ratcliffe & Grace, 2003; Roehrig & Luft, 2004; Bencze, 2010). Changes were recommended to the module as a result of evaluation, that changed the focus by emphasising both experimental and secondary research approaches, and increased the focus on guided discussion. This is likely to result in the development of skills relating to experimental inquiry as well as skills relating to critical evaluation of evidence in the PSTs as *learners*.

The PST case study did not focus on the translation of these newly developed skills into classroom practice, and this is an area which requires further research. In the PST module, there was evidence that the PSTs' views towards the pedagogical approaches to inquiry shifted. Where they had originally planned structured approaches, these moved towards more guided approaches in later plans. However, there was evidence of resistance to the open inquiry approaches they experienced in the module as they deemed them only suitable for more able or experienced learners. A further longitudinal study would follow the PSTs through their undergraduate studies and their early teaching careers to explore how the PSTs implement inquiry in the context of SSI into their classroom practice.

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Appendices

Appendix A Sample of data collection instruments

Teacher Questionnaire

Instructions for completion of the questionnaire

When answering the questions, please focus on the student experience and the skills and knowledge you wish to develop and assess in your students. You may attach any additional documentation e.g. extracts from planners, examples of student work. Please store your reflections securely on the server. Any attachments should also be stored securely on the server and named with your initials and a descriptive title. Any paper based documentation should also be stored securely.

Teacher Questionnaire: National 5 Assignment

1. Provide a brief description of lesson activities, learning intentions and success criteria. Please also include an extract from your planner or other material as relevant.

2. What do you think the students learnt from this lesson/series of lessons for this stage of the assignment? Please give examples and include any evidence as relevant.
   Selecting relevant information from texts. Referencing. Drawing valid conclusions.

3. What about this lesson/series of lessons was successful in terms of student experience? Please give examples and include any evidence as relevant.
   Students working independantly using research skills. Accessing a variety of sources to support learning.

4. What about this lesson/series of lessons was particularly challenging for the students? Please give examples and include any evidence as relevant.
   Processing data. Comparing data. Drawing conclusions.

5. If you were to repeat this lesson, what changes, if any, would you make? You may wish to think about timing/pace, skills development, ethos, student interactions, feedback, questioning, materials/equipment etc. No changes.

6. When carrying out the Assignment, did your students give scientific explanations? Yes/No
   Describe when or how. Yes. When they described the application + effect on society, conclusion and underlying biology.

7. When carrying out the Assignment, did your students evaluate or design scientific investigations? Yes/No
   Describe when or how. No.

8. When carrying out the Assignment, did your students explain scientific data and information? Yes/No
   Describe when or how Yes. Comparing data and drawing conclusions based on evidence and scientific knowledge.

1

Figure 1 Sample Thistle Wood School case study teacher questionnaire part one

Which of the following skills do you think your students used in this lesson?

National 5 Assignment Scientific Literacy Answer Grid

	Competency or Knowledge type	**Skill used (✓ if used)**	**Give examples of when/how this was used or demonstrated by students during the lesson/series of lessons.**
a	Recall and apply appropriate **scientific knowledge**	✓	Use of previous knowledge of enzymes. Use of experimental results.
b	Identify, use and generate explanatory **models** and **representations**	✓	Identifying sources (1+2) Processing of sources into graph/table etc.
c	Make and justify appropriate **predictions**		
d	Offer **explanatory** hypotheses		
e	Explain the potential implications of scientific knowledge for **society**	✓	Impact on society of using biological detergents.
a	**Identify the question explored** in a given scientific study		
b	**Distinguish questions** that are possible to investigate scientifically;		
c	**Propose a way of exploring** a given question scientifically	✗	
d	**Evaluate ways of exploring** a given question scientifically		
e	Describe and evaluate a range of ways that scientists use to ensure the **reliability** of data and the **objectivity** and **generalisability** of explanations		
a	**Transform data** from one representation to another	✓	Processing of data (graph → table) etc.
b	**Analyse and interpret data** and draw appropriate **conclusions**	✓	Comparison of data. Conclusion of assignment.
c	Identify the assumptions, evidence and reasoning in **science-related texts**		
d	Distinguish between **arguments which are based on scientific evidence** and theory and those based on other considerations		
e	Evaluate scientific arguments and evidence from **different sources** (e.g. newspaper, internet, journals)		

Figure 2 Sample Thistle Wood School case study teacher questionnaire part two

Think about your experience of the National 5 Assignment as a whole from the introduction to the research to the report-writing stage. The following questions ask you to talk about your own experiences and how you felt the National 5 Assignment went for you. This includes the skills and knowledge you feel you personally developed through carrying out the Assignment.

START OF QUESTIONS

1. From your experience of carrying out the National 5 Assignment, list the top 3 things you learnt? This may be knowledge or skills or something else. Give an example for each.

   I have learnt more about enzymes and there structure and also biological detergents and there optimum temperature.

2. What about the National 5 Assignment went particularly well for you? Give examples.

   I think that my source 1 went well as I had completed it myself and knew what it was about.

3. What about the National 5 Assignment was particularly challenging for you? Give examples.

   I think that my source 2 was quite challenging as I didnt have it for long and had to write about it

4. If you had the chance to complete the Assignment again, what changes, if any, would you make to how you carried out your assignment?

   I would do more research for underlying biology & source 2.

5. When carrying out the Assignment, did you give scientific explanations? (Yes) ~~No~~
   Describe when or how.

   I gave scientific explanations in underlying biology found in books or the internet.

6. When carrying out the Assignment, did you evaluate or design scientific investigations? (Yes) ~~No~~
   Describe when or how.

   I had to evaluate my source 1 as it was a past experiment we had done before.

7. When carrying out the Assignment, did you explain scientific data and information? (Yes) ~~No~~
   Describe when or how.

   In my source 2 that I chose I had to explain the data collected in the table and how that relates to the topic & aim.

1

Figure 3 Sample Thistle Wood School case study student questionnaire part one

Please complete the following table individually.
Which of the following **skills** do you think you used when doing the National 5 Assignment?

National 5 Assignment Scientific Literacy Answer Grid

	Competency or Knowledge type	Skill used (✓ if used)	If skill was used, give examples of when or how you used this skill during the Assignment
a	Recall and apply **scientific knowledge**	✓	underlying biology
b	Identify, use and make **models, diagrams, graphs** etc.	✓	Source 1/2 & undelying biology
c	Make **predictions**	✓	Source 1/2
d	Use your science knowledge to **explain why** or **how** something happens	✓	undelying biology
e	Explain how science impacts **society** (personally, nationally or globally)	✓	in effects on society and environment
a	Identify what **question the investigation aims to find out**	✓	in the aim
b	Choose between **questions that can be investigated through science** and those that can't	✓	
c	**Plan an investigation** to explore a scientific question	✓	
d	**Evaluate investigations**	✓	
e	Describe and evaluate how scientists make investigations and data **fair, reliable, objective** and fit into a **wider context.**	✓	Selection of sources
a	**Transform data** from one representation to another e.g. table to graph	✓	processing data
b	Analyse and interpret **data** and draw **conclusions**	✓	conclusion
c	Identify the assumptions, evidence and reasoning in **scientific reports, articles etc.**		
d	Choose between **arguments which are based on science** and those which are not		
e	Evaluate scientific arguments and evidence from **different sources (e.g. newspaper, internet, journals)**	✓	source 2

2

Figure 4 Sample Thistle Wood School case study student questionnaire part two

Teacher interview agenda and questions

Firstly I'd like to thank you for agreeing to take part in the research and interview. The research is looking at the curriculums of Scotland and Ireland, specifically how they use scientific research tasks, such as the new Science in Society Investigation, as assessment methods and the skills that such methods develop and assess.

Firstly I'd like to ask a few background questions about your teaching career so far?

How long teaching?

Where?

What subjects do you/have you teach/taught?

A few months ago I observed lessons you taught to your second year class. I observed you teaching a second year group, the "Transport Problem" and "Letters to Trump". I'd like to focus on these lessons in particular.

1. Describe for me how you approached these lessons with your class this year.

Plan - Learning intentions, success criteria, skills and knowledge (aimed for), resources, timing

Implementation - flexibility, differentiation

Have you taught these lessons before? In what context? How is this year different to last year?

If you were to advise another teacher how to teach these lessons what would you tell them?

2. Tell me about the class themselves

behaviour

ability

3. What do you feel your students learnt from these lessons, this may be knowledge, skills or something else?

4. What do you think your students found particularly challenging?

5. As part of these lessons do you feel that your students had to:

Give scientific explanations?

Evaluate and design scientific enquiry?

interpret data and evidence scientifically?

(give examples of how/when/where if not volunteered)

The next few questions focus on the new Junior Cycle Science course more generally,

6. The new Junior Cycle Specification has been introduced to first years this year. Have you made any changes to your teaching in response to this? (including assessment?)

7. What are your plans for the students as they develop through second and third year, in preparation for the SSI?

(Daisy park only: 8. The students were asked to state 3 things they felt they learnt in each task (transport task/ letters to trump). I looked at their answers and formed these broad categories. How does this compare to your expectations, for example what you planned or wanted them to learn? Is there anything you feel is missing?)

9. Is there anything I haven't asked that you would like to add?

Figure 5 Clover Field School and Daisy Park School case studies teacher interview questions

Thinking about the series of lessons **The Transport Problem**, list the top 3 things you learnt? This may be knowledge or skills or something else. Give an example for each.

Thinking about the series of lessons **Letters To Trump**, list the top 3 things you learnt? This may be knowledge or skills or something else. Give an example for each.

Figure 6 Daisy Park case study student questionnaire

Think about your experience of the module as a whole. The following questions ask you to talk about your own experiences and how you felt the module went for you. This includes the skills and knowledge you feel you personally developed through completing the module and all associated assignments.

START OF QUESTIONS

1. From your experience of carrying out the module, list the top 3 things you learnt? This may be knowledge or skills or something else. Give an example for each.
(1) Planning - research plays a big part.
(2) Making things relate to society (ie - effects of tanning beds)
(3) Analysing and interpretting data collected.

2. What about the module went particularly well for you? Give examples.
I liked planning an experiment from start to finish and carrying it out.

3. What about the module was particularly challenging for you? Give examples.
I didn't know what to put into my logbook and at first I found choosing an investigatable question difficult.

4. If you had the chance to complete the module again, what changes, if any, would you make to how you carried out your assignment? I would have done more secondary research. It would have benefited my logbook & experiment.

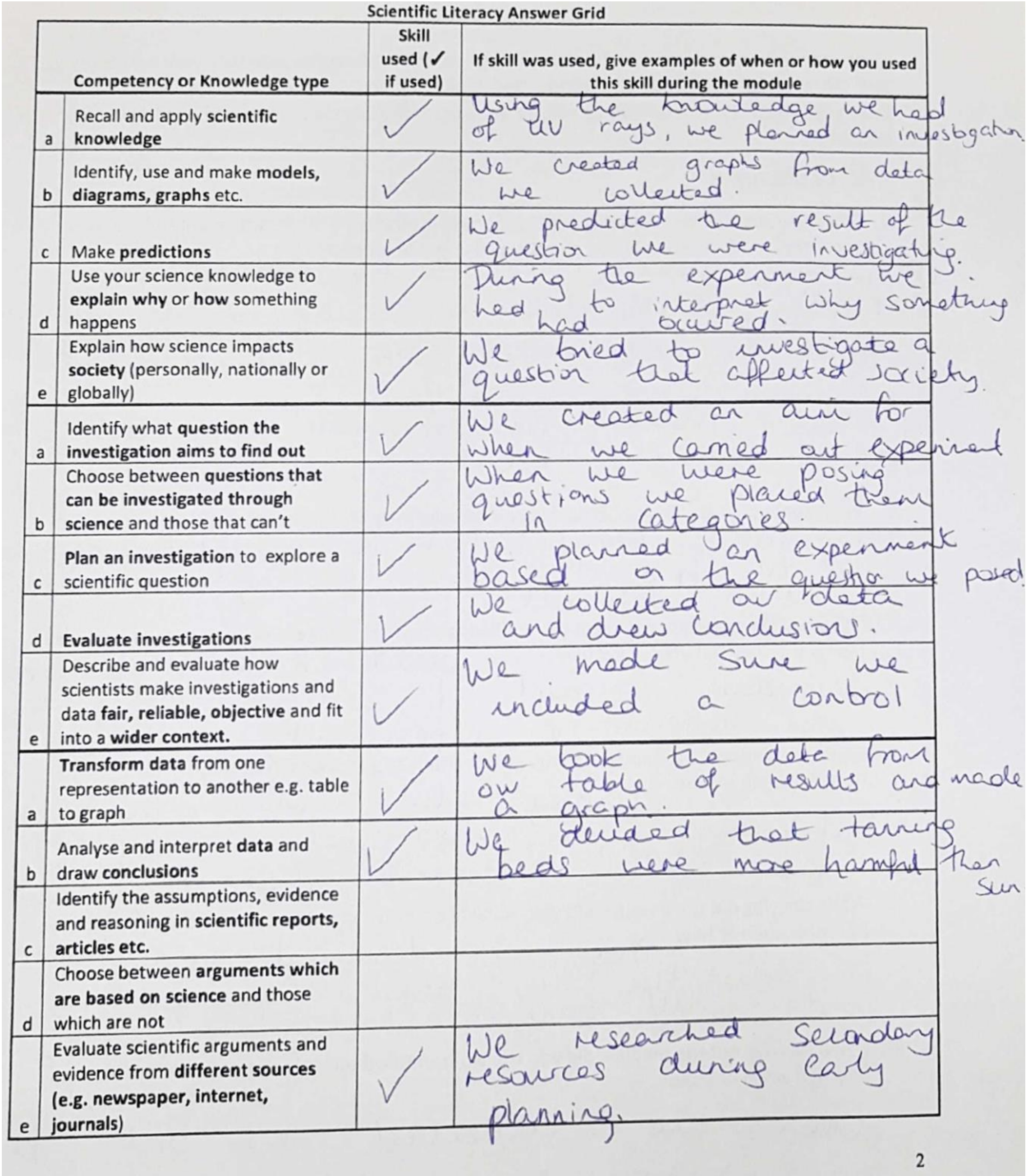
5. When carrying out the module, did you give scientific explanations? (Yes)/No
Describe when or how. During class when we were discussing our investigatable questions & how we would research them.

6. When carrying out the module, did you evaluate or design scientific investigations? (Yes)/No
Describe when or how. Yes I designed an investigation to how the UV beads changed colours under UV tanning lights and the sun.

7. When carrying out the module, did you explain scientific data and information? (Yes)/No
Describe when or how.
When we collected the data from our experiment, we analysed it, interpretted it and explained how it was relevant to the posing question.

1

Figure 7 PST case study questionnaire part one



Scientific Literacy Answer Grid

	Competency or Knowledge type	Skill used (✓ if used)	If skill was used, give examples of when or how you used this skill during the module
a	Recall and apply **scientific knowledge**	✓	Using the knowledge we had of UV rays, we planned an investigation
b	Identify, use and make **models, diagrams, graphs** etc.	✓	We created graphs from data we collected.
c	Make **predictions**	✓	We predicted the result of the question we were investigating.
d	Use your science knowledge to **explain why** or **how** something happens	✓	During the experiment we had to interpret why something had occured.
e	Explain how science impacts **society** (personally, nationally or globally)	✓	We tried to investigate a question that affected society.
a	Identify what **question the investigation aims to find out**	✓	We created an aim for when we carried out experiment
b	Choose between **questions that can be investigated through science** and those that can't	✓	When we were posing questions we placed them in categories.
c	**Plan an investigation** to explore a scientific question	✓	We planned an experiment based on the question we posed
d	**Evaluate investigations**	✓	We collected our data and drew conclusions.
e	Describe and evaluate how scientists make investigations and data **fair, reliable, objective** and fit into a **wider context.**	✓	We made sure we included a control
a	**Transform data** from one representation to another e.g. table to graph	✓	We took the data from our table of results and made a graph.
b	Analyse and interpret **data** and draw **conclusions**	✓	We decided that tanning beds were more harmful than Sun
c	Identify the assumptions, evidence and reasoning in **scientific reports, articles etc.**		
d	Choose between **arguments which are based on science** and those which are not		
e	Evaluate scientific arguments and evidence from **different sources (e.g. newspaper, internet, journals)**	✓	We researched secondary resources during early planning.

2

Figure 8 PST case study questionnaire part two

Intro: Thanks for meeting me. I wanted to follow up with you now that you have been out on placement and have a chat relating to the research I am carrying out on the module you took last semester.

Did you teach any lesson or lessons while on placement that you feel developed students' inquiry skills? Describe the lesson or series of lessons.

Plan -

Learning intentions,

success criteria,

skills and knowledge (aimed for),

resources,

timing

Implementation

flexibility,

differentiation

While on placement, can you think of any occasions in your lessons where students were given the opportunity to:

Give scientific explanations

Evaluate and design scientific enquiry

Interpret data and evidence scientifically

Questions on themes….

Thinking back to the module you completed in semester two of last year, where you planned and carried out an investigation into the implications of UV light on society. Having examined the whole class's work, questionnaires etc. These are the general themes that I feel sum up the student experience of the module. Hand out themes.

Do you feel that this sums up the module or do you think there is anything missing or there that shouldn't be?

Figure 9 PST case study interview questions

Appendix B PISA levels of scientific literacy

The descriptions of levels are adapted from PISA 2015 (OECD, 2013)

Level 6 Descriptor	**Level 5 Descriptor**	**Level 4 Descriptor**	**Level 3 Descriptor**	**Level 2 Descriptor**	**Level 1a Descriptor**	**Level 1b Descriptor**
Provide explanations, evaluate and design scientific enquiry and interpret data	Provide explanations, evaluate and design scientific enquiry and interpret data	Provide explanations, evaluate and design scientific enquiry and interpret data	Provide explanations, evaluate and design scientific enquiry and interpret data	Provide explanations, evaluate and design scientific enquiry and interpret data	Provide explanations, evaluate and design scientific enquiry and interpret data	Provide explanations, evaluate and design scientific enquiry and interpret data
Content, procedural, epistemic knowledge used consistently	Content, procedural, epistemic knowledge used	Content, procedural, epistemic knowledge used	Content, procedural, epistemic knowledge used	Content, procedural, epistemic knowledge used	A little content, procedural, epistemic knowledge used	A little evidence of content, procedural, epistemic knowledge used
Variety of complex life situations	Variety of life situations	Variety of given life situations	Some given life situations	Some given familiar life situations	A few familiar life situations	A few familiar life situations
High level of cognitive demand	High level of cognitive demand	Medium level of cognitive demand	Medium level of cognitive demand	Low level of cognitive demand	Low level of cognitive demand	Low level of cognitive demand
Draw appropriate inferences from a range of complex data sources	Draw inferences from complex data sources	Draw inferences from different data sources	Draw a few inferences from different data sources	Make a few inferences from different sources of data	Use a few simple sources of data	Identify straightforward patterns in simple sources of data
Variety of contexts	Variety of contexts	Variety of contexts	Variety of contexts	A few contexts	A few contexts	A few contexts
Explain multi-step causal relationships	Explain multi-step causal relationships	Explain causal relationships	Partially explain simple causal relationships	Describe simple causal relationships	Describe some very simple causal relationships	Attempts at describing simple causal relationships

Consistently distinguish scientific and non-scientific questions	Generally distinguish scientific and non-scientific questions	Distinguish scientific and non-scientific questions	Distinguish some scientific and non-scientific questions	Distinguish some simple scientific and non-scientific questions	Distinguish some simple scientific and non-scientific questions	N/A
Explain the purpose of enquiry	Explain the purpose of enquiry	N/A	N/A	N/A	N/A	N/A
Control relevant variables in a given scientific enquiry or any experimental design of their own	Control relevant variables in a given scientific enquiry or any experimental design of their own	Control variables in some but not all scientific enquiry or in an experimental design of their own	Control some variables in a given scientific enquiry or in an experimental design of their own	Distinguish between independent and dependent variables in a given scientific enquiry or in a simple experimental design of their own	Identify the independent variable in a given scientific enquiry or in a simple experimental design of their own	Identify the independent variable in a given scientific enquiry or a simple design of their own
Transform data representations	Transform some data representations	Transform data	Transform simple data	Transform simple data	Partially transform simple data	Attempt to transform simple data
Interpret complex data	Interpret complex data	Interpret data	Interpret simple data	Describe simple data	Describe simple data	Attempt to describe simple data
Demonstrate an ability to make appropriate judgements about the reliability and accuracy of any scientific claims	Demonstrate an ability to make appropriate judgements about the reliability and accuracy of any scientific claims	Have some understanding about the confidence held about any scientific claims	Able to comment on the confidence of scientific claims	Identify straightforward errors, and make some valid comments on the trustworthiness of scientific claims	N/A	N/A

Demonstrate advanced scientific thinking and reasoning requiring the use of models and abstract ideas	Show evidence of advanced scientific thinking and reasoning requiring the use of models and abstract ideas	Show evidence of linked scientific thinking and reasoning	Show some evidence of linked scientific thinking and reasoning	N/A	N/A	N/A
Unfamiliar and complex situations	Unfamiliar and complex situations	Unfamiliar situations	Unfamiliar situations	* situation not described in PISA	A few familiar situations	A few familiar situations
Develop arguments to critique and evaluate explanations , models, interpretations of data and proposed experimental designs	Develop arguments to critique and evaluate explanations , models , interpretations of data and proposed experimental designs	Develop simple arguments to question and critically analyse explanations, models, interpretations of data and proposed experimental designs	Develop partial arguments to question and critically analyse explanations, models, interpretations of data and proposed experimental designs	Develop partial arguments to question and comment on the merits of competing explanations , interpretations of data and proposed experimental designs	Comment on the merits of competing explanations, interpretations of data and proposed experimental designs	N/A
Range of personal , local and global contexts	Some but not all personal, local and global contexts	Some personal, local and global contexts	Some personal, local and global contexts	Some personal, local and global contexts	Some very familiar personal, local and global contexts	N/A

Appendix C Codebook for content analysis of curricular exams

Competency	Question Type or Description	Example	Justification
1A	Students are asked to "name" or "describe" with little or no reference to a situation or the question can be answered without reference to the situation described and elicit the same response.	Irish JC Sample Q5a (OECD, 2013 p89)	The student uses recall of scientific knowledge.
1B	Cases where conclusions or explanations are sought from a question stem including and requiring understanding of a diagram. E.g. atom structures and molecular bonding diagrams, Electronics and circuit diagrams, biological diagrams, ionic formulae.	Nat 5 Chem SQP Section 2 Q7b	Understanding the diagram or representation is essential to be able to correctly answer the question
1C	Questions where students are asked to make a prediction based on information given in the question. This may be to do with an experiment or a prediction of an outcome of a situation. The word "prediction" need not necessarily be included.	Nat 5 Chem SQP Section 1 Q18	Students are asked to "predict" based on the information in the question rather than recall.
1D	Students are asked to provide an explanation for a situation using their knowledge of science.	Irish JC Physics 2014 Q1e	Students offer explanatory hypotheses in a given situation
1E	Questions that refer to environmental impact, either positively or negatively, e.g. renewable energy, recycling etc.	Irish JC Higher 2014 Chem Q4d	Students must relate their answer to environmental impact.
2A	Questions that asks students to describe the aim of an investigation or question being investigated in a described inquiry/investigation.	PISA 2006 "sunscreens" Q2	Students must identify the question, which is unknown, in the given scientific study.
2B	Questions that ask: "Can these claims be investigated scientifically?" and give a list of possible questions and students distinguish which can be investigated scientifically.	PISA 2006 "clothes" Q1	Students are required to distinguish scientific from non-scientific questions. Distinguish means to recognise as different, i.e. choose from a list.
2C	Questions where students are asked to come up with an investigation or experiment in their own words. "Describe how you would", "What equipment would you need?" "How would you investigate?"	Irish JC Sample Q2c (OECD Sept 2014 p79)	Students must propose ways of exploring a question/inquiry.

2D	Questions including a description of an investigation and students are asked to questions about it, possibly using the words “explain”/“justify”/ “why”.	Irish JC 2014 Higher Biology Q3	Students must evaluate an investigation. Evaluate means “make judgments about ideas, solutions or methods” (NCCA Sept 2014).
2E	Questions that refer to “fair test”, controlling variables, repeating experiments.	Irish Junior Cert Sample Q1b (EK)	Students must describe and evaluate the investigation using their knowledge of the common ways that scientists “ensure the reliability of data and objectivity and generalisability of explanations”.
3A	Questions that ask students to turn one form of data into another e.g. table into graph, numerical data into text summary. Not including inserting data into a formula.	Nat 5 chemistry 2014 Section 2 Q1bi	Students must transform data into one representation to another. Representations (ways of representing data) include: graphs, tables, visually (pictures), text summary.
3B	Questions that require formulae to be used to analyse given data (common in physics and some chemistry), including known situations.	Nat 5 Physics Section 2 Q10a	Students must “analyse and interpret data”. This is analysis using formulae.
	Questions that ask students to describe the relationship between two variables when given data (e.g. in the form of a graph).	Nat 5 Bio Section 2 Q12ai	Students must “analyse and interpret data and draw appropriate conclusions”. This requires students to interpret the information given in the data and draw a conclusion. The conclusion may be basic.
	Questions involving any form of analysis and interpretation, such as drawing conclusions, making comments, of data using basic numeracy skills.	Irish JC ordinary Bio Q2a	Students must analyse and interpret data.
3C	Questions with a passage of text and information where students are required to read the passage and choose the correct information or make comments and interpretations. The text must be clearly related to science and require some scientific knowledge to answer question.	Nat 5 Physics Section 2 Q11a	Students are required to “identify” information from the “science-related text”.
3D	Questions where claims are made and students must decide if they are based on scientific evidence or belief.	JC Sample Nature of Science Q2a (OECD Sept 2014 p78)	Students must understand the difference between claims based on scientific evidence and those based on other considerations.

3E	Questions where information from different sources is given and students are asked questions about it e.g. a passage from a newspaper.	JC Sample Nature of Science Q2b (OECD Sept 2014 p79)	Evaluate evidence from different sources such as newspaper, internet, journals.

Knowledge Type	Question Type or Description	Example	Justification
CK	"Name" and "state" questions that do not rely an explanation from a question stem.	JC Sample Biology Q5a	Students must rely on their knowledge of scientific information, theories and concepts in order to answer questions from a range of competencies.
PK	Questions which ask students about a given investigation, e.g. to suggest an improvement to the experiment; propose a way of measuring or investigating; without reliance on discipline specific content knowledge	Nat 5 Chemistry SQP Q9bii	Students need knowledge of scientific enquiry procedures without content knowledge.
	Questions requiring basic numeracy skills without specific disciplinary knowledge. Recognising patterns in data. Numeracy skills such as percentage change, changing a table into a graph or recognising relationships and patterns that do not require subject specific knowledge.	Nat 5 Bio SQP Q12ai	Students require knowledge of numeracy procedures used in scientific context. In the Curriculum for Excellence, many numeracy skills are the responsibility of all teachers and therefore do not categorise a content knowledge. There are, however, many formulae in physics and chemistry that are subject specific and as such require content knowledge specific to that science discipline. These would be categorised as CK.
EK	Questions where students are asked to justify or give reasons for a conclusion.	PISA Semmelweis' Diary (2000) Q1, PISA Greenhouse Q1	"Students may be asked to identify whether conclusions are justified or what peice of evidence best supports the hypothesis" (OECD, 2013 p21)

Appendix D Thistle Wood School Case Study Codebook for Thematic Analysis

Skills	**Skills used and developed while carrying out the Assignment**
Present and analyse data	References to analysing data and presenting data, and presentation of raw and processed data in student work. Presenting raw data e.g. photographs Processing/analysing raw data into tables and graphs Presentations of raw or analysed data from the student work Raw and analysed data from research and experiments in student work Exclusions: Conclusions/explanations of data should go into *explain scientifically* category
Explain scientifically	References to explaining data and evidence/information and drawing conclusions, explanations and conclusions given by students in their work. Conclusions drawn from data gathered as part of experimentation Interpretation of analysed data. Findings from research (doesn't need to come at the end) Explanations in their own words Exclusions: If students do not use their own words (e.g. copied and pasted) or simply summarise data without interpretation
Research	Any references to gathering data and information through research References to carrying out research Evaluation of sources of secondary information and data Exclusions: References to gathering data from experimentation will go into *plan, carry out and evaluate experiments*, findings from research are likely to go into *explain scientifically*
Present information	References to layout and structure of a scientific report and referencing/recording sources in a bibliography References to structure/layout of a report (headings etc) References to referencing (without evaluation) Student work showing biblioiography/references (without evaluation) Exclusions: Bibliography/references with evaluation goes into *research*
Self-management	References to managing one's own learning: References to time limits and time pressure References to organising workload and planning References to feelings related to carrying out the assignment e.g. pressure, building confidence, stress, satisfaction

Plan, carry out and evaluate experiments	References to planning, carrying out, evaluating and making changes to experimental investigations References to how experiment was carried out e.g. method, variables Simple descriptive statements , e.g. we carried out the experiment/we gathered our data through experimentation References to evaluating the experiment, e.g. control variables, repeat experiment Student work detailing experiment including variables, equipment, controls etc Student work showing evaluation of experiment method, e.g. repeated experiment to make it reliable, control variables Exclusions: Evaluation of sources of information should go into *research*, aim of the experiment goes into *propose investigatable questions*
Propose investigatable questions	References to the “aim” and “aims” in student work References to coming up with/deciding an aim Student work showing the aim of the overall investigation Student work showing the aim of the experiment Exclusions: References to linking back to or relating data and conclusions to the aim should go into *explain scientifically*

Knowledge	**Knowledge used and developed when carrying out the Assignment**
Recall and application of scientific knowledge	References to knowledge without context and facts given without reference to implications for society or the environment References to improving knowledge or learning information Description of a scientific phenomena without application or implications being stated Student work describing the underlying science Student work showing aims based on science Conclusions in student work Exclusions: statements of fact or knowledge linked *to implications for society*

Implications of scientific knowledge for society	References to inks between content knowledge and implications for society or the environment in a range of personal, local/national and global contexts. References to application and effect on society and the environment Description of an application of biology/ chemistry/ physics in student work Description of the effect of an application on society/environment in student work Conclusions in student work Exclusions: Implications for society or the environment must be explicit. It is not enough to say “enzymes are used in bio washing powder” without stating the implications.

Pedagogical Approach	**This theme is only found in teacher data sources – References to the pedagogical approach used to facilitate the Assignment**
Phase two – open inquiry	References to the student in control of the inquiry, with “reasonable assistance” from the teacher This sub-theme contains references to the student in full control of the inquiry, with teacher support, from start to finish. Not all aspects need to be stated. Student chooses their own question and designs own investigation. Exclusions: Teachers telling student what to do
Phase one – instruction	References to instructing students in preparation for the Assignment Step by step guide through the Assignment process Discussion of each section Peer assessment of exemplar materials
Phase three- supervision	References to writing up the report under exam conditions. Not asking any questions Writing a report individually

Appendix E Clover Field School Case Study Codebook for Thematic Analysis

Skills	
Plan and carry out experiments	This sub-theme contains references to planning investigations, including how the experiment was carried out and student work detailing experiment including variables, equipment and set up, controls etc. Exclusions: Specific references to changes made to the investigation should go in *evaluate and make changes to experiments*
Evaluate and make changes to experiments	This sub-theme contains references to reflecting on the investigation and making changes based on observations and discussion/comparisons with peers and/or facilitator, revising or changing the question or hypothesis, refining the plan/ method.
Propose investigatable questions	This sub-theme contains references to coming up with a question for investigation and student work evidencing investigation questions or aims (which are not necessarily in question format).
State justified hypotheses	This sub-theme contains references to stating hypothesis (or prediction) and hypotheses (or prediction), student work evidencing students' hypotheses (or prediction).
Explain scientifically	This sub-theme contains references to writing conclusions and student work showing conclusions drawn from results of experiments and justified with scientific knowledge. Indicators: Explain, describe, conclusion , detail, own words, Exclusions: Simple presentation of work without explanations (e.g. copied and pasted) or no scientific justification should go into *present information* (this sub-theme was not observed in this case study)
Present and analyse data	This sub-theme contains references to presenting, processing and analysing data, including statements of raw data and results (should include numerical values/proportions), tables and graphs in student work. Exclusions: Conclusions drawn and explanations of raw or processed data should go into *explain scientifically*
Self-management	This sub-theme contains references to self management through self-assessment, topics that are personally relevant, managing time and organising workload and understanding or knowing one's own opinion or viewpoint.

Knowledge	
Recall and application of scientific knowledge	This sub-theme contains references to subject specific content knowledge and remembering/recall, statements of specific science facts, without explicit reference to implications for society. Exclusions: Any description of scientific information that explicitly relates to its impact/implications on society or the environment

Implications of scientific knowledge for society	This sub-theme contains references to the ethics of science and scientists and students working as scientists in terms of following ethical standards Exclusions: Any description of scientific information that *does not* explicitly relate to its impact/implications on society or the environment

Pedagogical Approach	
Guided discussion	The teacher facilitates whole class and group discussion on a topic chosen by the teacher. The teacher provides the topic and question for the inquiry (discussion based).
Open inquiry	This sub-theme contains references to the student in full control of the inquiry, with teacher support, from start to finish. Not all aspects need to be stated. Student chooses their own question and designs own investigation. Indicators: Student poses question

Appendix F Daisy Park School Case Study Codebook for Thematic Analysis

Skills	
Explain scientifically	This sub-theme contains references to scientific explanations, using own words, writing conclusions, student work containing scientific explanations and diagrams Indicators: Explain, describe, conclusion, detail, own words, Exclusions: Simple presentation of work without explanations (e.g. copied and pasted).
Work together	This sub-theme contains references to working with classmates and in groups, communicating and discussing with others and how an individual's choices may affect others in the group.
Research	This sub-theme contains references to carrying out research including selecting evidence from a range of appropriate sources and evaluating sources of information.
Distinguish between arguments based on scientific evidence	This sub-theme contains references to reasoning behind arguments being made, description of different reasons for decisions and arguments such as scientific, economic, political.
Evaluate solutions	This sub-theme contains references to students making judgements about ideas, solutions and proposals, describing the pros and cons of solutions and ideas. Indicators: Pros and cons, ideas, solutions Exclusions: Should *evaluate* the solution not simply state the solution
Present information	This sub-theme contains references to presenting to rest of class, letter writing, excluding anything that would be better placed in the more demanding competency "explaining". Exclusions: Any references that would be better placed in explaining scientifically

Knowledge	
Implications of scientific knowledge for society (and the environment)	This sub-theme contains references to scientific information (facts, evidence) which is explicitly related to the implications for society or the environment. Exclusions: Any description of scientific information that *does not* explicitly relate to its impact/implications on society or the environment
Recall and apply scientific knowledge	This sub-theme contains references to subject specific content knowledge and remembering/recall, statements of specific science facts, without explicit reference to implications for society. Indicators: Exclusions: Any description of scientific information that explicitly relates to its impact/implications on society or the environment

Pedagogical approach	
Medium teacher control (guided)	This sub-theme contains references to the teacher and student collaborating in designing an investigation, focus on a number of specific skills relating to inquiry, the teacher provides the problem and materials for the investigation.

Pedagogical Approach	
Guided discussion	The teacher facilitates whole class and group discussion on a topic chosen by the teacher. The teacher provides the topic and question for the inquiry (discussion based).
Guided inquiry (research)	This sub-theme contains references to the teacher and student collaborating in designing an investigation. The teacher provides the topic and question for the secondary research-based inquiry.

Appendix G Exemplar Student Profile- Jane

Appendix G can be read in conjunction with Chapter 5, it showcases the development of one PST throughout the module. A portfolio of evidence was compiled for each PST relating to the two aims of the module: development of skills and knowledge of inquiry as *learners*; and development of their pedagogical approach to inquiry as *teachers*. These portfolios were stored electronically in Google Drive. Evidence varied slightly between individuals due to absence or non-completion of tasks/assignments. Jane (pseudonym) was chosen as the exemplar PST profile because of her 100% attendance and conscientious attitude towards the work. This resulted in Jane's evidence portfolio containing the most comprehensive account of the work completed in the module. It is worth noting that Jane is not representative of the average student, in fact she is the highest scoring student in the class.

In week one, the PSTs were asked to draw a mind-map showing what "learning through inquiry" was. Jane's initial mind-map of *learning through inquiry* related to the two aims of the module. She described both development of skills and knowledge through investigation and inquiry as a pedagogical approach. Skills related to students posing questions (*what they wish to know*), investigating questions and hypotheses, and interpreting the evidence gathered and through this they would gain knowledge and understanding. In the final week, PSTs were asked to draw a second mind-map, without referring to the initial mind-map. The mind-map drawn after four weeks of instruction can be compared to that drawn in week one, prior to any instruction, to look for any changes in the PST's understanding of inquiry in terms of skills and knowledge development, and teaching approach. There were several developments in relation to the skills and knowledge of inquiry, between week one and four. More skills were focussed on compared to the initial mind-map and more detail was provided: testing hypotheses, in week one, became the need to "support or refute" a hypotheses; there was more detail provided regarding carrying out an investigation with the addition of understanding of variables and controls. However, Jane included "research" explicitly as a skill to be developed through inquiry in her initial vision and this was missing in the final vision. This may indicate an overall lack of focus on secondary research which will be discussed later in this chapter.

Janes initial and final mind-map of inquiry indicate her understanding of inquiry as a pedagogical approach. Comparison of the initial and final mind-map showed no major differences in Jane's understanding of inquiry teaching. Jane viewed inquiry as student-led and the role of the teacher was to facilitate learning who by asking probing questions (prompts). Inquiry as a teaching approach, according to Jane, has levels ranging from guided to open.

The module aimed to develop seven skills in the PSTs as learners:

1. Develop a question that is possible to investigate scientifically
2. Make and justify scientific hypotheses
3. Propose a way of exploring a question scientifically
4. Evaluate ways of exploring a question scientifically
5. Interpret data and evidence scientifically
6. Draw appropriate conclusions
7. Explain the potential implications of scientific knowledge on society

These skills were to be developed within the context of the SSI, implications of UV radiation for society. This sub-section explores the extent to which Jane developed the seven inquiry skills, the extent to which these were embedded within the SSI context and the scientific knowledge demonstrated by Jane. Evidence for the development of these skills was mainly identified within her logbook.

Evidence for the development of skills and knowledge can also be identified from Jane's logbook, including self and facilitator assessment. Evidence of Jane's development of each of the seven skills of inquiry focussed on in this module are presented below.

Jane included a range of possible questions for exploration before choosing a single investigatable question: **"**What colour changes are observed in UV beads placed behind and in front of a window and what does this tell us about the window's usefulness as protection from sunburn?"

Further evidence of the development of the skill can be identified in her logbook in her explanation of her understanding of what makes an investigatable question:

> "Not all questions can be investigated by scientists. It is therefore necessary to examine the initial questions I posed and decide which, if any, can be investigated scientifically. In order to do this, I have to first set out criteria for what I think allows a question to be investigated. These criteria are displayed in the image below."

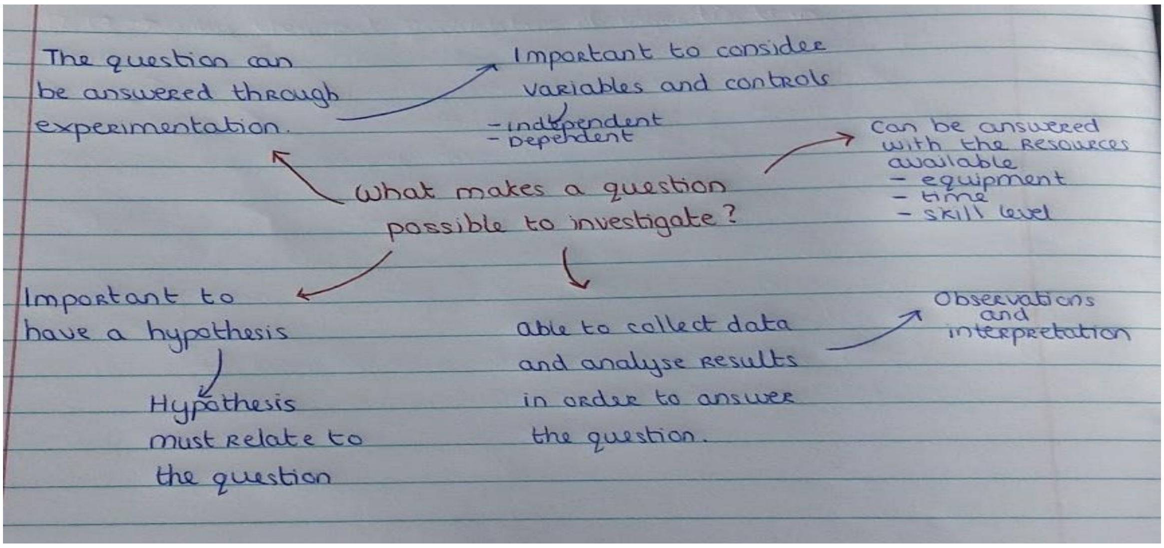


Figure 1 Development of Jane's ability to distinguish investigatable questions

Jane shows her understanding of the skill by including hypotheses, variables, the ability to gather analysable data and she clearly relates the question to implications for society. However, she only focuses on questions that can be answered through experimentation, reinforcing the lack of emphasis on secondary research based inquiry which was also omitted from her final mind-map.

Jane self-assessed her logbook as the highest level of self-direction. She felt she had posed her *own* investigatable question with an appropriate level of facilitator support. It is worth noting that the PSTs worked in pairs or groups and for the most part wrote the same investigatable question but were not penalised for having the same question as the others in their group.

The facilitator (researcher) assessment matched that of Jane's and the following written feedback was given: "The question is clearly stated and related to an impact on society." Verbal feedback was also given to Jane in which the facilitator recommended at least three conditions for the independent variable, not two as the question stated and his was acted upon by Jane in later weeks.

> "After deciding on a question that is possible to investigate, I have to make a hypothesis that I will use throughout the investigation. It is vital that this hypothesis is linked to my question.
>
> Hypothesis: The beads will show the same extent of colour change on both sides of the window and it can be deduced from this that windows offer no protection against sunburn." (Jane's logbook)

Jane's hypothesis relates to the question for investigation and implications for environment but does not explicitly justify the prediction using scientific knowledge.

In Jane’s self-assessment of this skill she chose the second-top level of performance, showing that she understood that her hypothesis was not “justified with sound scientific reasoning and prior knowledge”.

The facilitator’s (researcher’s) assessment matched Jane’s and the following written feedback was given: “You have stated your prediction. You have linked it to your prior knowledge (i.e. sunburn) but without detail.” Lack of justification with prior knowledge prevented Jane being awarded the highest level of performance.

Evidence from Jane’s logbook shows Jane proposing and evaluating plans and making changes based on evaluation. Due to overlapping evidence for these two skills in Jane’s logbook, these skills are presented together. She states explicitly all relevant variables (independent, dependent and controlled) and materials/ equipment required. She questions whether the chosen method is suited to the question. However, her focus is on experimental investigation and does not consider how secondary research could be used to support her investigation, particularly in relation to the SSI context explored.

Jane engages in a planning cycle in which she describes an initial plan, evaluates this and makes changes, forming a final plan (Exploratorium, 2006):

Initial Plan (Plan 1):

Separate beads from the same pack into two groups - A and B - ensure the number of beads in A equals the number of beads in B

Cover both A and B so that no light reaches the beads.

Place A on the window sill and B on the window ledge (see diagram below).

Remove the covers from both at the exact same time and begin timer.

Leave A and B for 10 minutes.

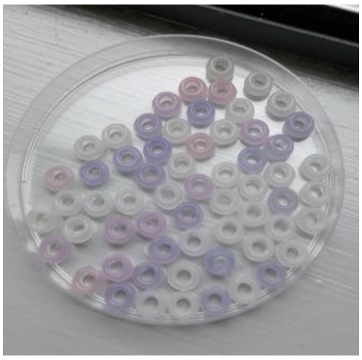
Instantly compare A and B by means of the UV sun index (see image below).

Recover both sets.

Swap positions after allowing 20 mins for beads to resume their neutral colour and repeat.

Results from Plan 1:

Window Ledge Beads



Window Sill Beads

The beads on the window ledge turned a darker shade of colour than the beads on the window sill. This means the beads on the window ledge had a greater value on the UV index than the beads on the window sill.

Figure 2 Evidence from Jane's logbook - proposing ways of exploring a given question

> "Evaluating Plan 1:
>
> The UV sun index does not describe the beads that change to yellow and green when subjected to UV light. We could not find any index online that would solve this problem. We have instead decided to eliminate these colours from the remainder of the investigation.
>
> It is difficult to compare the two groups fairly - photos were taken with the same camera but not at the exact same time. Photos may also differ because background lighting was different for each photo. We need to think about how we can record results as fairly as possible." (Jane's logbook)

Revised Plan (Plan 2):

Separate beads based on colour when subjected to UV light (5 colours as yellow/green cannot be compared quantitatively).

Divide each colour into two groups with the same number of beads in each group.

Select the first colour (group 1)

Cover the two sets of beads from group 1 so that no light reaches the beads.

Place one set on the window sill and the other set on the window ledge.

Remove the covers from both at the exact same time and begin timer.

Leave in position for 5 minutes.

Instantly compare the two sets by means of the UV sun index.

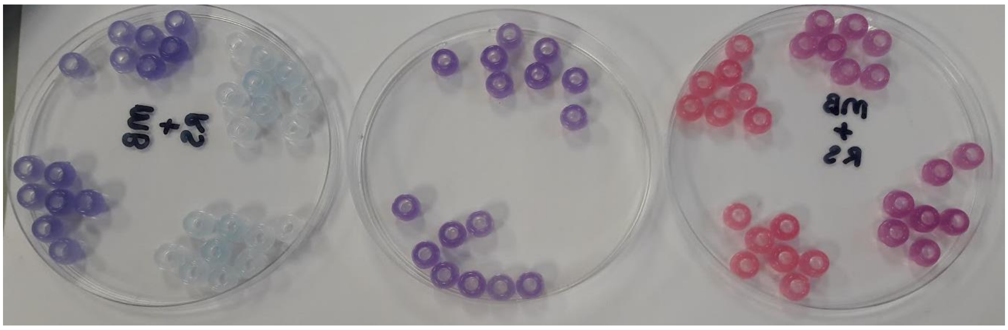
Quantitatively compare both sets by determining where every bead in the group lies on the UV sun index.

Recover both sets.

Repeat for each of the remaining four groups.

Construct a table displaying the UV sun index of each bead and its location.

Graph the UV sun index of each bead with respect to its location



Beads split into 5 groups based on colour with these 5 groups further divided in two

Figure 3 Evidence from Jane's logbook – revised plan

Revisions were made to the initial plan based on the evaluation described by Jane in her logbook. While Jane recognised some difficulties with her measurements (dependent variable) and made changes to solve these, e.g. separating colours and removing those that did not change colour. The final plan was overly complex in terms of measurements. These would be taken repeatedly for a multitude of colours and each bead was to be measured individually and tabulated. Other aspects of the revised plan, however, remained overly simplistic in design. It still only had two conditions for the independent variable (inside/outside). Jane continued to evaluate and make changes to her plan until the final week of the module and carried out extra experiments at home to implement these changes:

> we are not happy making a decision as to whether we will support or refute our hypothesis based on one set of measurements. (Jane's logbook)

Jane extended her experiment to include a range of different types of glass, which showed clear evidence of evaluation, identification of changes and action required. Jane's overall focus remained on planning and carrying out experimental investigation but in this extract there is evidence of justification using scientific knowledge gained through secondary research.

As part of the method of investigation, Jane carried out research relating to background information on UV radiation focussing on three background questions: "What causes sunburn? What is the UV index? What are UV beads?" (Jane's logbook)

She listed nine separate sources of evidence, all were websites, and evaluated these in terms of reliability, described in terms of "verification" between multiple sources and authorship, e.g. "scientific sites", "national weather sites". Hiwever, Jane did not evaluate the method of secondary research, for example in terms of the questions researched, and did not propose any changes based on evaluation.

Jane self-assessed her logbook at the highest level of performance for the three aspects of *propose ways of exploring a question scientifically*.

The facilitator (researcher) assessed Jane's logbook, after week three, as follows:

Identify variables giving consideration to fair testing (dependent, independent and controlled variables) was assessed as top level of performance and the following feedback was given:

> "Your description is very detailed and carried out over a number of investigations. You have described all variables and controls and explicitly stated them in your mind-map."

Identify appropriate materials required was assessed as the top level of performance and he following feedback was given:

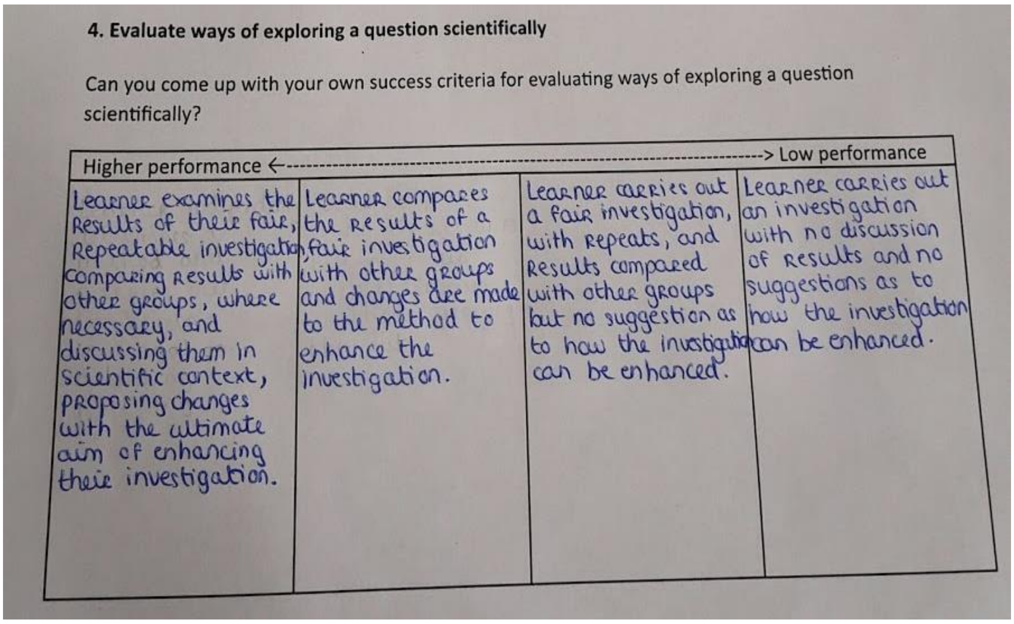
> "Your description is highly detailed and carried out over a number of investigations with a range of equipment."

Describe a method of collecting accurate and precise data was assessed as the second-from-top level of self-direction and the following feedback was given:

> "Some direction was given by lab facilitators."

As discussed earlier in this section, the assessment criteria focus mainly on experimental investigation, this meant that despite the lack of integration of high quality secondary research or evaluation of secondary research Jane achieved highly in this skill.

The PSTs devised their own assessment criteria for skill four: evaluate ways of exploring a question scientifically. Jane's assessment criteria is shown in Figure 4 below although she did not judge her work against the criteria she devised.



4. Evaluate ways of exploring a question scientifically

Can you come up with your own success criteria for evaluating ways of exploring a question scientifically?

Higher performance ←--> Low performance			
Learner examines the results of their fair, repeatable investigation, comparing results with other groups, where necessary, and discussing them in scientific context, proposing changes with the ultimate aim of enhancing their investigation.	Learner compares the results of a fair investigation with other groups and changes are made to the method to enhance the investigation.	Learner carries out a fair investigation, with repeats, and results compared with other groups but no suggestion as to how the investigation can be enhanced.	Learner carries out an investigation with no discussion of results and no suggestions as to how the investigation can be enhanced.

Figure 4 Jane's assessment criteria for skill four

Jane's assessment criteria focus mainly on experimental investigation, using terms such as repeatable and results, which would not apply to secondary research. However, she does state the importance of situating the findings within the scientific context which could be findings from secondary research although this is not explicitly stated.

Jane was very diligent in her approach to data presentation and analysis. Initially, data was presented in a detailed but overly complex table and graph. She reflected and made changes to the method of presentation and analysis as she progressed through her inquiry. Based on these evaluations her original table and graph were simplified by combining the results from different coloured beads:

> Graph 2 was our second attempt at representing our data. We decided to ignore the colours (blue/purple/pink) that the beads changed and instead focused only on the extent of the colour change. (Jane's logbook)

	Quantity of Beads		Quantity of Beads		
UV Index	Inside	Outside	UV Index	Inside	Outside
0	10	0	6	0	10
1	0	0	7	0	8
2	4	0	8	0	9
3	7	0	9	0	1
4	8	3	10	0	0
5	7	8			

Figure 5 Jane's simplified table of data (logbook)

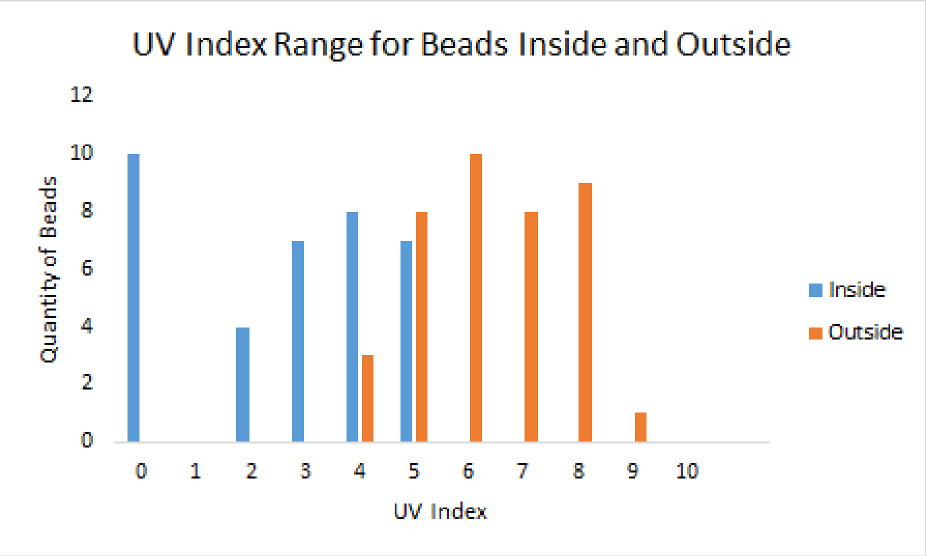


Figure 6 Jane's simplified graph of data (logbook)

Jane was also very reflective with her self-assessment and she explained why she felt she had not yet reached the highest level of the assessment criteria and what could be done to improve her data analysis and presentation:

> I was not satisfied with my overall performance in relation to skills 5 and 6. I had not completely analysed my data and the graphs that had been plotted were not fully labelled… I knew the areas where I was being brought down in and knew how I would succeed in improving my mark. (Jane's week three reflection)

These comments were reflected in her self-assessment against the assessment criteria, where she assessed her performance to be at the highest level of achievement. The facilitator (researcher) also assessed Jane at the highest level of performance and gave the following feedback: "Your analysis is detailed and appropriate to the data."

Jane referred to the gathered and presented data to draw conclusions relating to her question for investigation and related her conclusions to the implications for society, recommending the use of sun cream when seated near windows.

Jane self-assessed herself as the highest level of performance for drawing conclusions. The facilitator also assessed Jane's logbook as the highest level of performance and gave the following feedback:

> You have made conclusions based on your analysed data and related this to the initial question. You have backed this up with some scientific reasoning. You could have referred back to your earlier research into what causes sunburn and made this explicit for the reader.

Jane's conclusions would have been stronger if she had linked her background research to her question for investigation and then referred to this background research in her conclusions. However, she achieved the highest level of performance in both self and facilitator assessment. In future iterations of the module the assessment criteria should include references to background research in the highest level of performance.

Skill seven was an overarching focus of the workshops and related the inquiry to the SSI context. But it was the main focus of the final workshop only. Evidence for this skill was found throughout Jane's logbook.

In week one, Jane chose a question that clearly related to impact on society. The second part of the Jane's question and hypothesis demonstrate this:

> What colour changes are observed in UV beads placed behind and in front of a window and *what does this tell us about the window's usefulness as protection from sunburn?*
>
> The beads will show the same extent of colour change on both sides of the window and it *can be deduced from this that windows offer no protection against sunburn.* (Jane's logbook)

Jane's secondary research provided opportunity explore evidence that linked the topic of investigation to its implications for society:

> Sunburn is caused by exposure to UV light. The energy in UV radiation damages molecules in the skin. UV radiation is composed of UVA, UVB and UVC. UVC is completely blocked by the atmosphere. UVB is responsible for the majority of sunburns. UVA also contributes towards sunburn but not as much as UVB. (Jane's logbook)

Jane's background research clearly related the implications for society in terms of the dangers of UV radiation to human health. However, her scientific explanations were relatively weak and did not reflect the high level of scientific explanation that would be expected from a second year undergraduate science student. Jane could have extended her scientific explanations by going into a higher level of detail and possibly linking her research to her investigation question by considering the method by which UV radiation travels through different materials.

Jane then related her background research to the experimental investigation:

> We know that UV radiation causes sunburn. If we can show that there is no difference in bead colour that will imply that windows do not block any UV light. (Jane's logbook)

Jane's question for investigation was designed to explore implications for society and so the conclusions she drew commented on this. The conclusions clearly discuss how the different windows protect against UV radiation to differing extents and make recommendations based on the findings (see skill six). However, as discussed previously as Jane focussed on the implications for society, the conclusions lacked justification with in-depth scientific knowledge of UV radiation.

In the final week, Jane described actions she could take to address the SSI context. She described personal actions she could take (wear sun cream) and actions that aimed to educate others (advise others, write letters home). The main focus of her actions is to educate others to wear sunscreen when next to a window and this is solely based on the results of her small investigation.

Jane did not include her self- assessment in her logbook as evidence. The facilitator assessed Jane's logbook as second-from-top level of performance and provided the following feedback: "You have clearly related your experiments to implications for society (i.e. should wear sunscreen). It should be made explicit in your conclusions how this relates back to earlier research (UV light = sunburn)".

Jane considered her investigation in terms of implications for society from question to conclusions. However, further background research and in-depth scientific explanations of the scientific basis for her assertions would have made her conclusions stronger.

Jane's performance in the skills and knowledge of inquiry was excellent. However, overall there was a lack of focus on secondary research and scientific explanations to back up her experimental findings.

The module advocated an approach to teaching inquiry that was:

1. Student centred and collaborative
2. Comprised of different levels
3. Assessed both formatively and summatively

4. Situated within SSI contexts

This sub-section presents evidence of the development of Jane's understanding of inquiry as a pedagogical approach. Evidence is drawn from a range of sources, including reflections, lesson plans (initial and final), video analyses and mind-maps of inquiry (Table 5-2). As discussed earlier, comparison of the initial and final mind-map gave little evidence of changes in Jane's understanding of inquiry. However, other evidence showed Jane's development in terms of inquiry as a teaching approach.

There was evidence of development of Jane's view of inquiry teaching as student-centred and collaborative. According to Jane's initial and final mind-maps, she viewed inquiry as student-led and the role of the teacher was to facilitate learning who by asking probing questions (prompts). This is also evidenced in her week one reflection: "If I were to use this experiment as a group of lessons, I would *prepare a range of questions* so that I would be able to *prompt students*". Jane emphasised students taking responsibility for their inquiry and again emphasised her role in asking questions and guiding them (in this case towards an experimental method). She used the term "help students" several times when referring to her role as facilitator; the students are doing the action with "help" or guidance from the teacher.

> … help students work on these skills themselves. I could ask students questions that would encourage them to think about their experimental method – how will you record your results? Why have you included this step? (Jane's week two reflection)

> … help students present data themselves in an appropriate manner. I would be able to discuss with them the importance of doing so and would be able to discuss with them why one method of presenting data may be favoured over another for a particular data set. (Jane's week three reflection)

She stated that she would "discuss" with the students but does not give details of how this will be carried out. It is likely that the discussion is teacher-led instruction.

Comparison of the initial and final lesson plan shows a slight shift from teacher-led student experience to a more student-centred and collaborative approach. The initial lesson included teacher-led discussion, experimental demonstration and a structured inquiry, where the method of investigation was proposed by the teacher. The final lesson plan included facilitated group discussion, using images and a variety of questions as prompts, and a guided inquiry where students devised their method for investigation.

In Jane's initial and final mind-maps she described the levels of inquiry as guided, partially guided and open. There was evidence in Jane's lesson plans of a slight shift in her understanding of the levels of inquiry. Comparison between her initial and final lesson plans showed a change in the level of inquiry from structured to guided, increasing the level of cognitive demand on the students. Initially, there was mainly teacher-led instruction and where inquiry learning was evident, the level was structured; the teacher devised the question and method, and the students carried out the investigation, gathered data and evidence and drew conclusions. In her final lesson plan, she planned a guided inquiry where students were asked to make predictions/ state hypotheses, propose a method of investigating a given scientific question (and carry it out), present and analyse data and evidence and draw conclusions. In asking students to propose the method for their investigation, rather than follow a set method given by the teacher, the level moved from structured to guided. However, Jane's proposed approach was to guide students, with a high level of support, towards the same method: "Groups will probably devise the same plan based on the available apparatus." (Jane's final lesson plan). This calls into question the true level of inquiry aimed for.

When discussing levels of inquiry teaching, Jane considered the different levels of inquiry to be more or less appropriate based on students' ability or previous experience with inquiry:

> The level of inquiry shown in the activities of this lesson is quite structured and guided… This group of students had *not previously been exposed to inquiry so I feel it is necessary to guide them* (Jane's accompanying explanation of final lesson plan)

> … some of the students may need more guidance than others based on the level of inquiry that suits them…I also think if I had not done a lot of inquiry with students previously, that they would benefit from discussing UV light as a class before being assigned this task. (Jane's week one reflection)

Jane believes that a lack of previous experience with inquiry may create a barrier for students to acquire content knowledge through inquiry approaches and therefore she would resort to a more teacher-led approach ("discussing UV light as a class before").

Jane gave some consideration to formative assessment strategies in her teaching approach to inquiry. She Jane included a variety of questions, shared learning intentions and success criteria and "traffic lights". She did not discuss summative assessment of inquiry in the context of SSI.

Jane described verbal questioning:

> I could ask students questions that would encourage them to think about their experimental method (Jane's week two reflection),

> verbal assessment throughout the lesson - both higher and lower order question (Jane's final lesson plan)

She also included lists of questions in her lesson plans.

Jane included learning intentions in her lesson plans and stated that she would "allow students define the success criteria of the entire lesson themselves." (week one reflection).

At some points, Jane stated planned assessments without going into sufficient level of detail. She stated that students would be "assessed on their lab skills as they carry out their investigations" but provided no description of how this would be assessed. Jane stated that the she, as the teacher, would "assess understanding using traffic lights" but again did not go into detail.

Jan considered SSI contexts in her approach to teaching inquiry and this focus increased as the module progressed. However, the SSI contexts lacked elements of moral or ethical concern and were not controversial so were closer to everyday examples than SSI.

Jane considered inquiry in the context of SSI in her reflection after week four:

> I will ask students how the data collected from their investigation impacts on society. I will also ask them what this means – should they change their behaviour as a result of knowledge gained or should we inform people about this knowledge. (Jane's week four reflection)

This quote also shows evidence of Jane's understanding of SSI contexts as activism/action based, i.e. making personal changes or educating others regarding the SSI.

In the initial lesson plan, some real-world examples were given, e.g. hot air balloons, radiators in the home. In her final lesson plan, Jane stated that she would ask students how the "data" impacts society and used everyday examples, e.g. "which pot conducts heat best?"

Overall, Jane's planned pedagogical approach to inquiry in the context of SSI was similar to the approach advocated in the module. She recognised the approach as student-centred and consisting of levels that vary according to the locus of control, including assessment and can be carried out in SSI contexts. There was evidence of development in her teaching approach; the lesson plans showed a slight shift in the locus of control from teacher to student. However, these lesson plans showed a limited range of the levels of inquiry and included only structured and guided inquiry. Jane believed that structured and guided inquiry should be the approach taken with students who have little or no previous experience of learning through inquiry and that open inquiry is not suitable for these students. Jane's approach to assessment lacked sufficient detail to show how she would assess inquiry in her teaching. The SSI contexts referred to in her reflections and lesson plans are more akin to everyday examples than true SSI contexts as they lack controversy.

Appendix H PST case study codebook for thematic analysis

Skills	**Students discuss the skills they *personally* gained and used.** **Exclusions: references to skills of their students would go into pedagogical approach**
Plan and carry out experiments	References to planning experimental investigations References to how experiment was carried out Student work detailing experiment including variables, equipment, controls etc Simple descriptive statements , e.g. we carried out the experiment/we gathered our data through experimentation Exclusions: Specific references to changes made to the investigation should go in *evaluate investigations*
Propose investigatable questions	References to questioning as part of investigations and questions in student work initial questions, investigatable questions, research questions Exclusions: Questioning as a teaching method should go into the *pedagogical approach* theme
Present and analyse data	References to analysing data and presenting data and presentation of raw and processed data in student work. Presenting raw data e.g. photographs Processing/analysing raw data into tables and graphs Presentations of raw or analysed data from the student work Answering the research question (without explicitly referring to conclusion) Exclusions: Conclusions/explanations of data should go into *draw conclusions* category
Evaluate and make changes to investigations	Reflecting and making changes based on observations and discussion/comparisons with peers and facilitator. Revise/change question/hypothesis based on findings from initial experiments Refining method based on trials Evaluation of sources of information e.g. reliability Exclusions:

Explain scientifically	References to drawing conclusions or explaining data and evidence and conclusions given by students in their work. Conclusions drawn from data gathered as part of experimentation Conclusions may come at the end of a section of the experiment (e.g. prior to changes made due to evaluation) or the whole experiment Overall conclusions of the investigation taking account of experimentation and research Interpretation of analysed data. Findings from research (doesn't need to come at the end) Likely, and acceptable, overlap between *Skills: Draw conclusions (explain scientifically)* and the two *knowledge* categories. Exclusions:
State justified hypotheses	References to making a prediction/hypothesis and predictions/hypotheses from student work
Research	Any references to gathering data and information through research References to carrying out research Stating references/bibliography (without evaluation) Exclusions: Evaluation of sources of information should go into *evaluating investigations* category References to gathering data from experimentation Findings from research
Take action	References to taking action on the socioscientific issue Specific actions described (posters, demonstrations etc.), recommendations based on investigations. There is likely overlap with *implications* knowledge category. Exclusions: Explanations that describe implications to society should go in *drawing conclusions* skills category
Self-management	References to self-management Self-assessment Motivation through learning about topics that are personally relevant Managing time and organising workload Exclusions: Anything that would fit better in evaluate investigations

Knowledge	**Students discuss the knowledge they *personally* gained,** **Exclusions: references to knowledge of students (not themselves) would go into pedagogical approach**

Implications of scientific knowledge for society	Links between content knowledge and life - contexts include health, forensics, other personal context, local/national (references to UV in Ireland). Statement or descriptions of applications of UV radiation with implications, e.g. UV radiation is used in tanning beds which many people use but can have harmful effects on health Health effects of UV radiation (sunburn, eye damage, melanoma, vitamin D production) and ways to minimise impact on health (e.g. sunscreen, sunglasses) Increasing awareness – e.g. advising others to wear sunscreen National context – References to UV radiation in Ireland Personal context – e.g. tanning, health Indicators: Exclusions: references to the PSTs own students rather than themselves as learners.
Recall and application of scientific knowledge	Statements of "used prior knowledge" without context, facts given without implications Description of UV radiation or EM spectrum without application E.g. statement of ingredients in sunscreen without stating implications Application without statement of implications e.g. UV light used in forensics Indicators: Exclusions: statements of fact or knowledge linked to implications for society

Pedagogical Approach	**When the PSTs talk about how to approach inquiry with their students or critiquing others' teaching. Skill and knowledge development in students (not themselves).**
Guided inquiry	The teacher and student collaborate in designing the investigation, gathering data and evidence, analysing findings and drawing conclusions. This is likely to be the biggest, most wide ranging category encompassing most references to inquiry Teacher poses question, leads students towards a method but leaves some aspects (e.g. quantities, temperature, time) up to the students, students gather and analyse data and draw conclusions with teacher support Teacher poses question but leaves method, analysis and concluding up to students. Students carry out discrete aspects of an investigation but do not plan from start to finish e.g. carry out research and present findings Indicators: Teacher poses question but not method Exclusions: Statement of "semi-guided" alone is not enough, the description of the activity decides the category.

Structured inquiry	There is some evidence of inquiry but the teacher is in control the majority of the time and makes to majority of decisions Teacher sets question and (step by step/cookbook) method without student input or flexibility , students gather data and analyse results and draw conclusions Indicators: Exclusions: Statement of “guided” alone is not enough, the description of the activity decides the category
No inquiry	Does not fit with the vision of inquiry put forward in this module. No inquiry focus: label diagrams, answering teacher questions, recall of facts, watching a PowerPoint relates to pedagogical approach but not specific or describing to this vision of inquiry – student centred, collaborative, questioning, active learning Indicators: Exclusions: PSTs discussion of developing skills in students (relating to this vision of inquiry) is considered to be inquiry and should be placed in one of the other pedagogical approach categories.
Open inquiry	The student is in control of the inquiry, with teacher support, from start to finish. Not all aspects need to be stated. It is enough to say that student chooses own question and designs own investigation without detailing analysis. Student poses question with support or prompts from teacher, designs method, gathers data and analyses, draws conclusions. Indicators: Student poses question Exclusions: Statement of “open” alone is not enough, the description of the activity decides the category.