Exploring the Impact of Teaching Science through Socioscientific Issues on Upper Primary School Children's Scientific Literacy: A Multiple-Site Case Study

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Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Doctor of Education is entirely my own work, and that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

Signed: Nicola Broderick Nicola Broderick

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List of Abbreviations

AAAS	American Association for the Advancement of Science
CPD	Continuous Professional Development
DCU	Dublin City University
DES	Department of Education and Skills
EU	European Union
GUI	Growing Up in Ireland study
IBSE	Inquiry Based Science Education
NoS	Nature of Science
NCCA	National Council for Curriculum and Assessment
NVivo	NVivo is a qualitative data analysis computer software package
NRC	National Research Council
OECD	Organisation of Economic Co-operation and Development
PA	Performance-based skill Assessment
PDST	Professional Development Service for Teachers
PISA	Programme for International Student Assessment
RoI	Republic of Ireland
SPSS	Statistical Package for the Social Sciences
SSI	Socioscientific Issues
SSIBL	Socioscientific Inquiry Based Learning
SSIPSC	Socioscientific Issues through the Primary Science Curriculum intervention
SSR	Socioscientific Reasoning
STS	Science Technology Society movement
STSE	Science Technology Society Environmental movement
STEM	Science Technology Engineering and Mathematics
TAP	Toulmin's Argumentation Pattern framework.
TCI	Teaching Council of Ireland
TIMSS	Trends in Mathematics and Science Study
UK	United Kingdom
USA	United States of America
UNESCO	United Nations Educational, Scientific and Cultural Organisation

Abstract

Exploring the Impact of Teaching Science through Socioscientific Issues on Upper Primary School Children's Scientific Literacy: A Multiple-Site Case Study

Nicola Broderick

Scientific literacy is widely regarded as one of the most important goals of Science Education. Scientific literacy relates to how an individual uses their scientific knowledge and skills to participate as active citizens in society. Research indicates that teaching science through Socioscientific Issues (SSIs) has the potential to achieve this goal. However, there is a dearth of international literature on the impact of SSIs-based education on the development of primary/elementary students' scientific literacy. Within an Irish context, SSIs-based education is not a feature of the Irish primary science curriculum and therefore its potential is not fully realised and is under examined in the teaching of science.

This study sought to explore whether the teaching of primary science through SSIs has an impact on enhancing upper primary school students' scientific literacy competencies; namely the development of student interest in science, scientific inquiry skills, conceptual understanding of science, Nature of Science (NoS) understanding, socioscientific argumentation and socioscientific reasoning. Seven primary school teachers participated in a professional learning course aimed at developing teacher confidence and competence pertaining to the teaching of primary science through SSIs and associated pedagogies. These teachers and the students in their classes (n=158 students) participated in this multiple-site case study whereby they taught primary science through SSIs over a six-month period. A mixed-methods pragmatic research design was utilised to assess its impact on students' scientific literacy where multiple data sources were collected concurrently including student questionnaires, student focus group interviews, student practical science skill assessment and teacher semi-structured interviews.

Findings indicate that teaching primary science through SSIs had a positive impact on the development of primary school students' science content knowledge, NoS understanding and scientific inquiry skills. Students were found to have more informed perceptions of school science and its relevance to their everyday lives. Students demonstrated enhanced ability to engage in socioscientific argumentation and in most cases students were able to apply their science content knowledge and skills to socioscientific reasoning whereby students made informed decisions pertaining to SSIs relevant to their everyday lives. Furthermore, some classes participated in student-led active citizenship as they took informed action in response to the SSI. The findings suggest that teaching primary science through SSIs has the potential to develop upper primary school aged students' scientific literacy competencies where students become prepared and empowered for active and responsible participation in a complex, democratic society. This study recommends that SSIs-based education and scientific literacy competencies be an explicit feature of primary/elementary science curricula both nationally and internationally and that this be supported by teacher professional learning opportunities.

1.0 Introduction

The overall aim of this research is to explore the extent to which teaching science through Socioscientific Issues (SSIs) has an impact on Irish primary students' scientific literacy. The potential of SSIs to develop scientific literacy is widely accepted. However, internationally there is a paucity of research pertaining to SSIs in a primary/elementary school context, while nationally in the Republic of Ireland (RoI) no such research exists. This chapter begins by presenting a background context to the developments of scientific literacy. The position of science education and curricular and policy development in the RoI context will be discussed. The rationale for, and overall aim of, the research is articulated. Finally, an overview of the dissertation structure is provided.

1.1 Scientific Literacy

Today, science represents a dominant and pervasive aspect of the lives of individuals and societies (Bencze & Carter, 2011). This is exemplified by everyday issues in public discourse such as climate change, sustainable development, water shortage, world pandemics and other critical issues that demand the public's immediate attention. The impact and reach of these issues extend beyond science to include political, economic, cultural and social dimensions (Sadler, 2009), and therefore they are typically termed socioscientific issues. Corresponding to these issues, today's society is awash with information, misinformation and disinformation which is read, interpreted, evaluated, responded to, acted on, or indeed ignored. Decisions made can lead to economic, environmental or social chaos (Paul & Elder, 2009; Zeidler, 1997). It is imperative that all citizens strive to gather knowledge related to these issues and, subsequently, engage critically and responsibly to offer scientifically informed solutions where social implications appear to exist (Kolstø, 2001; Zeidler, Sadler, Simmons, & Howes, 2005). Fostering scientific literacy amongst the population has never been more essential (Siarova, Sternadel, & Szonyi, 2019).

Scientific literacy has been defined as "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" (OECD, 2013, p. 7).

Scientific literacy is a term that has been used since the late 1950s to express diverse goals ranging from a broad knowledge of science to a particular purpose of science education (Bybee, 1997). At its inception, scientific literacy was used to emphasise the importance of science in society and that science education should be used to prepare individuals to participate in human and civic affairs (DeBoer, 2000). Prior to this, science education tended to be centred on text-books that portrayed science as a body of information, facts and generalisations that required rote memorisation (Smith, 2012). International influence in the form of the 'Space Race' of the 1960s, which saw the United States of America (USA) fall behind the Union of Soviet Socialist Republic (USSR) when they launched the world's first artificial satellite into the Earth's orbit, spurred policy makers to invest in science education and the development of national science curricula in the USA and across Europe (Bybee & Fuchs, 2006). Here, the goal of science education focused on the need to promote science and produce future scientists and engineers (De Jong, 2007; Yore, 2012). In the 1960s and 1970s economies grew and education changed from that of the privileged to education for the majority (Fensham, 1988). The percentage of students remaining at school considerably exceeded the number of students required to meet the demand for future science-based professionals (Fensham, 2016). The 'Space Race' was no longer a concern and the technological nature of society, domestic issues and environmental problems ranked high on many national agendas (Smith, 2012). It was proposed that science educators should work to support citizens who understood science, had the ability to seek information pertaining to the positive and negative impacts of science and technology on their lives, and were sympathetic to the work of scientists. However, correspondingly there were concerns that science education was not paying sufficient attention to science as a discipline (DeBoer, 2000; Laugksch, 2000). As Kromhout and Good (1983) asserted teaching science through science-based social issues "does not convey any real understanding of the structural integrity of science" and "the basics simply do not get taught" (p. 649). In addition, the perceived need to expand the number of potential scientists and engineers was upheld (Smith, 2012). Over the last two decades the mainstream use of the term scientific literacy refers to the acquisition of knowledge and meeting content standards in science education, with a focus on science in social contexts as well (Siarova et al., 2019).

Synthesising the above, the most prevalent discussion on the meaning of scientific literacy is the ‘science for scientists’ versus ‘science for all’ debate (Siarova et al., 2019). On the one hand it is essential for economic development that young people are interested and engaged in future developments of science and technology (Bybee & Fuchs, 2006); on the other it is crucial that citizens have a basic understanding of science if one is to understand everyday issues and make informed decisions (Chiu & Duit, 2011). Roberts (2007) summarised this dichotomy and presented two visions of scientific literacy, referred to as Vision I scientific literacy and Vision II scientific literacy. Vision I scientific literacy focuses on decontextualized science subject knowledge and preparation for careers in science, while Vision II scientific literacy connects science to students’ everyday perspectives and develops their ability to make decisions on societal and environmental issues as informed, active citizens (Haglund & Hultén, 2017; Osborne, 2012; Roberts, 2007). In recent years, researchers have proposed an additional vision, Vision III, which moves beyond preparing individuals for participation in society towards a politicised vision of science education aimed at dialogic emancipation, critical global citizenship, and socio-ecojustice in which controversial, relevant issues, for example from the sustainability debate, become the drivers for the curriculum (Hodson, 2003; Sjöström & Eilks, 2018).

Building on the above, Liu (2013) suggests that an ‘expanded notion’ of scientific literacy which encapsulates Vision I, II and III scientific literacy is required. Congruent with other science educators (for example Dillon, 2009; Haglund & Hultén, 2017; Roberts, 2007), this notion emphasises the importance of scientific knowledge and skills and their relevance to particular contexts, critical thinking and engagement with society. A minority of citizens will be producers of scientific knowledge, but all citizens will be consumers of scientific knowledge as they read or hear about science-based knowledge claims or use processes that are based on scientific knowledge (Millar, 2009). Science education that promotes Vision I, Vision II and Vision III scientific literacy is crucial to developing students' interest, knowledge and skills in science. Such knowledge includes scientific content knowledge but also an understanding of the Nature of Science (NoS) and consideration of social, economic and political influences that underpin an issue (Zeidler & Sadler, 2011). Skills such as developing students' inquiry skills are key to scientific literacy but students must also be supported to apply their inquiry skills and use them to interpret and evaluate scientific knowledge presented in the media and elsewhere. The development of argumentation and reasoning skills are also necessary if students are to engage in discussion and debate pertaining to societal issues. Furthermore, students must be provided with opportunities to make informed decisions and take action in response to real-world issues of the 21st century. Only then will science education be useful for all students, whether or not they are bound for scientific or technical careers (Feinstein, 2011). The next section will examine developments pertaining to scientific literacy in primary science education in the RoI from a curricular, policy and student learning perspective.

1.2 Primary Science Education in RoI: Policy Development and Implementation

1.2.1 Historical Developments of the Irish Primary Science Curriculum (1884 – 1999)

Ball argues the importance of tracking the trajectory of policy throughout its historical development in order to analyse patterns of influence and practice (1993; 1994). He further asserts that the historical development of educational policy forms a necessary context to the analysis of current and future education policy and practice (Ball, 1993; 1994). It is clear from its inception that science education in the RoI has been affected by government preoccupation and priorities prevalent during that time (Walsh, 2016). The inclusion of science in Irish primary school education dates from 1855 brought about by a political concern that the RoI was lagging behind other countries in terms of industrial development. The 'payment by results system' of the 1860s drove a narrowing of the primary curriculum as reading, writing and arithmetic were prioritised with didactic pedagogical approaches dominating classroom practice (Palmer, 2001; Walsh, 2016). Science was then removed from the curriculum in 1922 for 50 years during the period of nationalist revival whereby government priorities lay in the promotion of Irish language and culture above all else. This was followed by a pattern of increased international influence: for instance, the 'Space Race' of the 1960s (Coolahan, 1981; Walsh, 2016). In 1971 science was introduced into the primary curriculum under Social, Environmental and Science Education. The 1971 curriculum was poorly implemented, with little effect on students' learning of science due to a lack of resources, limited pre-service science education and in-service teacher professional development opportunities (INTO, 1992; Walsh, 2007; Smith, 2012). Most primary teachers had little to no knowledge of science or experience of science as learners (INTO, 1992; Palmer, 2001). Thus it is therefore unsurprising that less than half of primary school teachers taught science (INTO, 1992; NCCA, 1990). This enduring lack of emphasis on primary science in schools was reflected in the poor comparative results in international tests such as Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS). This, along with a decline in the numbers of students pursuing science beyond the compulsory years, heightened government concerns (Beaton, Mullis, Gonzalez, Smith, & Kelly, 1997).

Several expert groups set about transforming the state of the Irish economy with a focus on science education (Murphy, Broderick, & Mallon, 2020). For instance, the Irish Council for Science and Technology Innovation (1998) and Forfás (1999) called for the introduction of a new primary science curriculum, claiming that the availability of more people with science training was a prerequisite for future competitive advantage and the development of an economy capable of maintaining its citizens into the 21st century. An economic-educational discourse was constructed (Cuban, 2004) and primary science was introduced as a subject in its own right in 1999.

1.2.2 The 1999 Primary Science Curriculum (1999 – Present)

The 1999 primary science curriculum aims to develop primary students' scientific content knowledge and working scientifically skills. Teachers are required to implement the science programme from junior infants to sixth class (4 years – 12 years). Science is allocated forty-five minutes per week in infant classes and one hour per week in all other classes. This equates to approximately 4% of instructional time in Irish primary schools being allocated to science which is one of the lowest primary curriculum allocations of science worldwide (Murphy et al., 2020). When it comes to classroom practice, TIMSS (2015) revealed that Irish teachers are only teaching 32 hours of science per year, the lowest teaching hours of all participating TIMSS countries.

Content in the science curriculum is organised under four content strands: Living Things, Energy and Forces, Materials and Environmental Awareness and Care. The development of skills include prediction, questioning, observing, investigating, recording and communicating. Design and make skills include exploring, planning, making and evaluating. Learning through hands-on activities and discovery is strongly emphasised as is practical investigation and providing students with opportunities to test and develop their ideas. It should be noted that 'scientific literacy' is not explicitly mentioned in either the Primary Science Curriculum (Department of Education and Skills (DES), 1999a) or Primary Science Teacher Guidelines (DES, 1999b), though the notion of developing students' scientific literacy is implicitly supported through the aims of the curriculum: "science education equips children to live in a world that is increasingly scientifically and technologically oriented" (DES, 1999a, p. 6). Whilst the curriculum's aim supports Vision II scientific literacy, this did not materialise into the more specific curriculum objectives where traditional knowledge-based understanding of science dominates and contextualised understanding of science including references to engagement and critical thinking is absent from both the curriculum objectives (DES, 1999a) and primary science teacher guidelines (DES, 1999b). Similar de-prioritisation of Vision II competencies when it comes to science objectives have been found in school science curricula throughout Europe (Siarova et al., 2019). Fensham (2016) concludes that it is now common to find new intentions pertaining to Vision II and III scientific literacy listed in the introductory rationale for school science with "this rhetoric largely ignored in the continued listings of detailed disciplinary content for teaching and learning" (p. 168).

Science is one of eleven subjects in the primary curriculum and therefore Irish primary school teachers are considered subject matter generalists rather than specialist science teachers (Zangori, Foulk, Sadler, & Peel, 2018). After the introduction of the 1999 primary science curriculum, teachers were provided with two days of in-service to support its implementation. Follow-up support for teaching science was available (when requested) through the Professional Development Service for Teachers (PDST). Notwithstanding the availability of this support, data gathered from teachers in the latest two TIMSS cycles (2011 and 2015) reveal that the percentage of fourth-class (9-10 year-old students) primary school teachers who had recently participated in science education professional development was considerably lower than the TIMSS centrepoint (Clerkin, Perkins, & Chubb, 2017; Murphy, 2014). In terms of initial teacher education programmes in the RoI, students take mandatory courses in STEM education. However, the amount of time and credit allocated to compulsory science education varies from 2.5 credits to 7 credits which is 1% - 3% of the overall Bachelor of Education (B.Ed.) degree (approximately 250 credits). Some B.Ed. degrees offer science specialisms but these are only offered to approximately 7% of students each year (Murphy et al., 2020). Furthermore, Murphy and Smith's (2012) study found that over 80% of initial teacher education students had not studied Physics or Chemistry to Leaving Certificate level[1]. The authors raised concerns as to whether the student teachers had sufficient content knowledge to effectively teach the 'Energy and Forces' strand (Physics component) and 'Materials' strand (Chemistry component) of the primary science curriculum (Murphy & Smith, 2012).

A number of large scale reviews and smaller studies have evaluated the implementation of the primary science curriculum. On a positive note, there is evidence that teachers have positive attitudes towards the teaching of science (Murphy et al., 2020). Findings also suggest that teachers are providing students with opportunities to engage in 'hands-on' science (DES, 2012; Murphy et al., 2012; Smith, 2014). However, concerns have been raised regarding low teacher confidence and insufficient content and pedagogical knowledge which often results in a dominance of teacher-directed prescribed activities, an over-reliance on science text-books, limited opportunity for students to apply scientific skills and few opportunities for students to

[1] The Leaving Certificate Examination is the university matriculation examination in the Republic of Ireland and the final exam of the Irish secondary school system (students aged approx. 19).

engage in child-led-investigations (DES, 2012; Dunne et al., 2013; Murphy et al., 2020; Varley et al., 2008). A number of reviews and reports concluded that teachers require support in the form of comprehensive professional development if the aims of the curriculum were to be achieved (DES, 2012; Murphy et al., 2019; Varley et al., 2008; Smith, 2015a, 2015b). However, these concerns were never addressed and additional government-led professional development opportunities were not provided.

It is important to note that there is no scientific literacy test for primary school students but national and international studies give some indication of primary students' level of scientific literacy. In 2015, Irish fourth class students participated in TIMSS, performing above the TIMSS centrepoint. TIMSS, whilst not a scientific literacy test, assesses student scientific content knowledge and method and thus could be considered a measure of Vision I competencies (Naganuma, 2017). Furthermore, over 80% of fourth class students who participated in TIMSS (2015) indicated that they have positive attitudes towards school science. Other Irish studies and national reviews concur with this finding regarding Irish primary students' positive attitudes towards school science (Varley et al., 2008; Murphy et al., 2019; Smith, 2014). From a scientific literacy perspective students' positive attitudes towards science are seen to be conducive to promoting engagement in decision-making processes related to science and technology (Lee & Kim, 2018), as well as a key requirement for students who aspire to a scientific career (Osborne et al., 2003).

In terms of scientific literacy competencies, there is evidence to suggest that students enjoy hands-on science and appear to have opportunities to work collaboratively in small groups (DES, 2012; Varley et al., 2008). However, there are concerns regarding the nature and frequency of the 'hands-on science', with Irish students tending to be involved in more prescriptive, step-by-step, hands-on investigations than the child-led inquiry approach advocated by the curriculum (DES, 2016; Murphy et al., 2015; Smith, 2014; Varley et al., 2008). Correspondingly there are concerns regarding the development and application of students' science skills with older primary students operating at skill levels similar to that of students in the younger classes (DES, 2012; Varley et al., 2008). In order to be able to understand and engage in critical discussions about science related issues, scientific knowledge needs to go in combination with scientific inquiry skills where students are able to explain and design scientific inquiries as well as interpret data and evaluate evidence (OECD, 2017). Argumentation and socioscientific reasoning, considered key competencies of scientific literacy, are not explicit features of the Irish primary science curriculum with the latest TIMSS (2015) data indicating that students have limited opportunities to engage in discussion as part of their science lessons (Clerkin et al., 2017). It is also of significant concern that many Irish primary students are failing to see the relevance of science to their everyday lives (DES, 2016; Varley et al., 2008; Murphy et al., 2011; Smith, 2012, 2014). According to Siarova et al. (2019) scientific literacy cannot be understood in today's society outside the context in which scientific issues arise, thus, without a contextual component 'science for all students' as an educational aim cannot be achieved (Siarova et al., 2019).

The current Irish primary science curriculum is due to be redeveloped by 2024 to align with a new Primary Curriculum Framework which was published in 2020 (NCCA, 2020). Whilst work on the science curriculum redevelopment is yet to commence, it is important to note that 'Being an Active Citizen' is one of the seven key competencies underpinning the Primary Curriculum Framework. This competency highlights the importance of developing children's knowledge, skills, concepts and attitudes to empower children to take positive action and live justly in today's society at local and global levels (NCCA, 2020). Developing primary students' scientific literacy is key to this competency. Thus it could be argued that science is one of the subjects best positioned to prepare students to become active, global citizens (OECD, 2018a).

1.2.3 The Irish STEM Education Report and Implementation Plan

Alongside the redevelopment of the primary curriculum, science education has emerged as a government priority under the umbrella of Science Technology Engineering and Mathematics (STEM). The STEM Education in the Irish School System Report (DES, 2016) and STEM Education policy documents (DES, 2017a; DES, 2017b) instigated the focus on STEM education in the RoI.

The report was commissioned by the DES, driven by concerns regarding the "quality and quantity" of STEM graduates (DES, 2016, p. 3). The report explicitly references the RoI's Strategy for Research and Development (DES, 2015) which highlights STEM as critical to ensuring the continuous development of a 'pipeline' of talent to support both foreign direct investment and indigenous start-ups. Concurrently, other government reports projected a shortfall of labour-market needs in STEM (Behan, McNaboe, Shally, & Burke, 2015; Condon & McNamee, 2016; Higher Education authority (HEA), 2014). According to Osborne, Simon and Collins (2003) "there is a clear association between economic performance and the number of engineers and scientists produced by society" (p. 1053). As a result, a high supply of people qualified in STEM is now accepted as a key determinant of the RoI's future economic success (Lauder, Brown, & Ashton, 2008; DES, 2001). This was further emphasised with the STEM report citing that the RoI would lose its economic competiveness unless "we secure and sustain a sufficient supply of high-quality scientists, engineers, technologists and mathematicians" (DES, 2016, p. 22). Framed within this discourse, students' continued success in STEM is increasingly linked to the perceived needs of the economy and international competiveness (Akalu, 2014; Ball, 2006; 2008; Cowie & Cisernos-Cohernour, 2011; Lynch, Grummell & Devine, 2012; Rizvi & Lingard, 2010), echoing Vision I scientific literacy competencies.

Notwithstanding the economic rhetoric presented above, the principles and vision of the STEM policy documents (DES, 2017a; DES, 2017b) allude to Vision II and III scientific literacy, combining the importance of the development of learners' curiosity, scientific skills and knowledge with authentic global and societal issues (DES, 2017a). The policy documents highlight the necessity of scientifically-literate citizens "in order to make well-informed decisions regarding major global issues such as climate change, sustainability, energy, and food security" (DES, 2017b, p. 7). One of the aims of the STEM Policy Statement (DES, 2017b) is that young people will gain the skills and aspirations to participate in an increasingly scientific society, and, contribute to a society as active citizens informed of the pivotal role of science and technology in the well-being of society; thereby encapsulating Vision I, Vision II and Vision III scientific literacy. However, when it comes to targeted objectives in the STEM Implementation plan (DES, 2017a), Vision II, and III scientific literacy are marginalised with short-term policy objectives immediately reframed in terms of Vision I priorities: RoI leading STEM in Europe; increasing our ranking in international studies and the importance of attracting a growing number of school leavers into STEM (DES, 2017a, p. 12). Adopting a critical perspective, Carter (2003) argues that “science education improvement discourses are often more representative of national responses to global economic restructuring and the imperatives of the supranational institutions than they are of quality research into science teaching and learning” (p. 573).

The ‘average’ international performance, in PISA and TIMSS has driven a STEM crisis discourse in the Irish media (O’Brien, 2016a; 2016b; Rogers, 2016) with government reports citing that the results were not good enough (DES, 2016). The STEM report claimed that our “nation’s children’s futures are at risk if we do not improve our performance in STEM and sustain our economic ambitions” (DES, 2016, p. 20). This is in spite of the fact that science results in PISA and TIMSS have generally remained just above average for the past 30 years (Eivers & Clerkin, 2013; Perkins, Shiel, Merriman, Cosgrove, & Moran, 2013; Murphy, 2014; Spotlight, 2009). Other countries have indicated their intention to be a leading international innovator in STEM education by 2026 (for example the Scottish Government, 2016; Education Council, 2015 (Australia); Department of Education, 2016b (USA); Morgan & Kirby, 2016 (UK)). While the ‘Race to Space’ may have sparked the science ‘crisis’ in the 1960s, it appears the race to the top of the PISA ‘leader-table’ may be a strong catalyst for the current crisis. Agreeing with Cahill (2015) and Mansfield, Welton and Grogan (2014) the implicit danger here is that the global-race becomes the goal and focus on students’ learning and well-being as engaged citizens of society is lost.

Far less ambiguous than the ‘STEM crisis’, are the enormous societal crises of climate change, loss of biodiversity, poverty and abuses of human rights. Humans are having a profound impact on our planet (DES, 2014; UNESCO, 2014). Many Irish students are not making connection between science and their everyday lives and they are in danger of not developing the higher-order, critical-thinking skills required for active participation in the 21st century (Varley et al., 2008; Matthews, 2007; TIMSS, 2015). This fundamental importance of science education receives tokenistic reference in the STEM report (DES, 2016) or the media (O'Brien, 2016a; 2016b). Serious questions about the purpose of education, its content and emphasis warrant asking (Millar, 2009). Many fear that an economic emphasis is prevalent as many curricula focus on skills and competencies required for a skilled and flexible workforce (Vision I competencies), the needs of the minority, to the neglect of educating children for participation in a democratic and socially just society (Antunes, 2012; Millar, 2009; Priestley & Biesta, 2013; Walsh, 2016). The acquisition of skills that are required in all walks of life are under threat in a society where STEM education, with an overemphasis on Vision I scientific literacy, is seen as key to economic success (Rocard et al., 2007). Fundamental to equipping every citizen with the skills needed to live and work in society is giving young people the motivation to learn and the opportunity to develop scientific reasoning and critical thinking skills that will enable them to make well-informed decisions (Rocard et al., 2007; Beernaert et al., 2015). Speaking about school science in the RoI, Matthews (2007) asserted that school science needs to change but needs to stand independent of whether it leads to wealth creation in the global economy. New strategies for increasing young peoples' interest and knowledge in science and their ability to use science outside school are needed (Osborne & Dillon 2008; Rocard et al., 2007).

1.3 Socioscientific Issues

Many studies assert that SSIs education can enhance scientific literacy as well as citizenship education and students' moral development; developing the knowledge, skills and attitudes fundamental to participation in debates and decision-making on issues that affect students' everyday lives, both inside and outside of school, issues that affect their lives both now and in the future (Burek & Zeidler, 2015; Presley, Sickle, Muslu, Merle-Johnson, Witzig, & Sadler, 2013; Zeidler, 2015; Zeidler & Sadler, 2009; Zeidler & Kahn, 2014). SSIs' literature base has grown extensively over the past 15 years (Hancock, Friedrichsen, Kinslow, & Sadler, 2019). SSIs are complex, multifaceted issues underpinned by science but also have a social, economic, political and ethical considerations. They are tentative in nature and are often subject to ongoing inquiry where no definitive answer exists. There are numerous SSIs, such as those focused on climate change, water shortage, and habitat loss, that are drawn from real world science faced by citizens and that are relevant and appropriate for primary school students.

With respect to teaching methods, SSIs-based education supports a process of inquiry and negotiation where students ask questions and gather evidence pertaining to complex issues (Levinson, 2018; Sadler, Barab, & Scott, 2007; Sadler & Zeidler, 2004) developing the scientific inquiry skills underpinning the primary science curriculum (DES, 1999a) but also their ability to apply these skills to authentic contexts. SSIs-based education fosters the development of students' argumentation skills where they engage in evidence-based, reasoned discussions pertaining to SSIs. Important teaching strategies include discussion in which students have the opportunity to share their ideas with others, explore different courses of action, and form their own views on issues (Ratcliffe & Grace, 2003; Zeidler, 2014). Furthermore, students' ability to make informed decisions and take informed action, a key competency of both citizenship education, education for sustainable development and Vision III scientific literacy, can also be fostered through SSIs-based education (Hodson, 2002). Indeed, it is for this reason that Sadler (2011c) and Zeidler (2007) argue that is imperative that students are exposed to SSIs within formal and informal learning environments.

SSIs education is theoretically appealing but empirical research in a primary/elementary context is limited from an international perspective while no Irish research has been published to date. Few empirical studies have focused on the relationship between SSIs and student learning in a primary/elementary context (Zangori, Foulk, Sadler, & Peel, 2018). Those that have, have focused on discrete variables such as SSIs and primary school students' argumentation skills (Evagorou, 2011), SSIs and primary school students' science content knowledge (Yager, Yager, & Lim, 2006; Wongsri & Nuangchalerm, 2010). Many of the studies in a primary/elementary context presented positive findings while others presented challenges in terms of developing students' argumentation skills (Evagorou, 2011) and socioscientific reasoning ability (Sadler, Klosterman, & Topçu, 2011). Some have argued that while SSIs-based education promotes positive attitudes towards science, it could be the pedagogical approach employed rather than the SSI that fosters student engagement (Evagorou, 2011; Sadler, Klosterman & Topçu, 2011). In addition, an examination of students' ability to transfer scientific knowledge and skills to 'outside of school' contexts are rare. Furthermore, other science educators have expressed concern that SSIs education detracts from development of basic science content knowledge and principles and are wary of its benefits (Hughes, 2000; Orpwood, 2001; Pouliot, 2008).

Reiser et al. (2007), maintain that opportunities to apply scientific ideas and reasoning to SSIs should begin in elementary/primary school as it lays critical foundations for more complex understandings and competencies. Zeidler (2011) and Burek and Zeidler (2015) assert that more classroom-based research studies on SSIs implementation and outcomes are required to determine the suitability and impact of SSIs-based education in a primary/elementary school context. Sadler (2011c) warns that SSIs could be considered too complex and contentious for younger students in that some SSIs may not be developmentally appropriate for primary school students. He acknowledges that the connection of science to real world issues would serve to motivate young learners but raises concerns regarding the complexity of these issues. Evagorou (2011), who examined how SSIs could be incorporated into primary/elementary classrooms provided evidence that SSIs can be used productively with upper primary school students serving to motivate and interest them in science education. However, she also expressed some concerns regarding the effectiveness of SSIs education with students younger than 10 years old. Holbrook and Rannikmae (2009) concluded that primary school students tend to have positive attitudes towards school science and thus proposed that SSIs-based education was more applicable to a secondary school context than primary/elementary context. This study argues that SSIs-based education moves beyond the development of primary/elementary school students' interest in science with results providing a strong rationale for the inclusion of SSIs in primary science education in terms of the development of student scientific literacy competencies.

1.4 Aims and Rationale for this Study

An important aim of science education for all students is to empower and prepare them for taking part in debates and decision-making and for taking action in relation to contemporary SSIs (Hodson, 2010; Sadler, 2011a). Furthermore, science education should motivate, encourage and inspire students who are interested in pursuing science related careers (Beernaert et al., 2015; DES, 2017a). These aims are emphasised in reports and science curricula in many countries worldwide and reflect Vision I, II and III competencies (Siarova et al., 2019). For instance, in their European Commission Report Science Education for Responsible Citizenship, Beernaert et al. (2015) argue that "Science education is vital…to empower responsible participation in public science conversations, debates and decision-making as active engagement of European citizens in the big challenges facing humanity today" (pp. 14-15). If this is the goal of science education, then science educators must be more deliberate about achieving this goal (Sadler, 2011a).

The aim of this study is to explore the impact of teaching science through SSIs on Irish primary school students' scientific literacy (Vision I, II and III). Development of students' scientific content knowledge, inquiry skills, NoS understanding, argumentation and socioscientific reasoning skills will be examined. Students' ability to apply this knowledge and skills to real-world contexts will be explored. Furthermore, changes in students' attitudes towards, and perceptions of school science will be observed. The current study provides a different context for SSIs educational studies and shifts the positioning of SSIs studies from a secondary and tertiary environment to a primary/elementary context. In addition, current SSIs studies situated in a primary/secondary context are generally short-term and focus on one SSI-unit in one class (Zeidler, Bell, Sadler, & Eastwood, 2011). This study investigates the impact of SSIs-based education over a six-month period, using six SSI units, in seven different primary school contexts.

From a national perspective, a new primary science curriculum is due to be published in 2024. At present, there are concerns pertaining to Irish primary students' levels of scientific literacy (Varley et al., 2008; Murphy et al., 2020). Scientific literacy or SSIs are not explicitly referenced in the current primary curriculum but are features of the compulsory Junior Cycle[2] science curriculum since 2017. At an international level, this research adds to the limited research available in the field of SSIs in a primary/elementary context. It investigates concerns that some have regarding the suitability of SSIs education for a younger audience in primary/elementary school. On a broader scale, this study bridges the theory-practice gap between theoretical discussions of scientific literacy and the development of students' scientific literacy in classroom practice. There is a need for this research, particularly regarding the impact of SSIs-based education in a primary/elementary context, to support the SSIs education movement and promote much needed growth and reform within science education (Dolan, Nichols & Zeidler, 2009; Sadler, 2011c). To note, research questions will be presented in Chapter 3 following their further justification in a review of the literature in Chapter 2.

1.5 Personal and Professional Rationale

The researcher in this study is an Assistant Professor in the Institute of Education at Dublin City University. Prior to this, the researcher worked as a primary school teacher and Deputy Principal and has experience teaching children from ages 4 to 12 years old in a multi-class setting. In the researcher's current position, she lectures student teachers in primary science education on the Bachelor of Education and Professional Masters in Education Programme in DCU. Here, the researcher coordinates and lectures on a number of modules across the programme which focus on the development of student teachers' content knowledge, pedagogical knowledge and confidence with the teaching of science. The researcher also works with in-service teachers through the provision of professional learning in science education. The researcher has been involved in previous research projects on a national and international level pertaining to Science Education, the Nature of Science, Inquiry Based Science Education and Education for Sustainable Development. The researcher's teaching and research, both as a primary school teacher and current position in higher education, is underpinned by constructivist,

[2] The Junior Cycle covers the first three years of secondary school in the RoI. Children begin their second-level education around the age of 12 or 13. The Junior Cycle examination is held at the end of the Junior Cycle in post-primary schools and students normally sit the exam at the age of 15 or 16.

inquiry-based approaches to teaching and learning where providing children with opportunities to develop and apply skills that they require in their everyday lives is of key importance.

It is from the researcher's perspective that this research study was born. This perspective made the researcher aware of the opportunities and challenges related to the teaching of primary science: for instance, children's enjoyment and engagement with science, teacher pedagogical difficulties with inquiry based approaches, lack of opportunities to engage in professional learning in primary science, the disconnect between school science and the development and application of scientific literacy competencies. In the researcher's current role in DCU, she became aware of research in SSIs and the dearth of research in a primary school context, both nationally and internationally, despite it's potential for developing scientific literacy competencies. This doctoral study afforded the researcher the opportunity to examine the literature related to SSIs and associated pedagogies and subsequently explore the impact of teaching primary science through SSIs on the development of upper-primary school children's scientific literacy competencies.

1.6 Outline of Dissertation

Chapter 2 details the literature underpinning this study. It operationalises scientific literacy and SSIs for the purpose of this study and describes the key benefits of learning science through SSIs. Chapter 2 also presents the conceptual framework, which highlights the design and underpinning theories which are deemed important for this study. Chapter 3 outlines the methodology utilised, the rationale, limitations and the ethical considerations adopted for this study. Chapter 4 analyses the data gathered in this mixed methods, multiple site case-study. Chapter 5 relates the findings to existing research and literature in this field while Chapter 6 offers a series of conclusions in relation to the research and how the research questions have been answered. Here, specific actions and recommendations are put forward as well as the identification of areas requiring further research.

2.0 Literature Review and Conceptual Framework

In Chapter 1 the rationale for exploring the potential of SSIs-based education to develop primary/elementary students' scientific literacy was presented. This chapter explores literature in the field of SSIs and primary science education. It begins with a discussion on scientific literacy and presents key competencies underpinning scientific literacy. The current Irish primary science context and students' levels of scientific literacy is examined and explicated. The emergence of SSIs-based education as a movement in science education and its role in developing scientific literacy competencies is considered. This is followed by a discussion of relevant studies pertaining to SSIs and science content knowledge, NoS, Inquiry Based Science Education (IBSE) and socioscientific argumentation. The impact of SSIs on the development of socioscientific reasoning and fostering student-led citizenship is also investigated. Finally, the conceptual framework guiding this research study is presented. This chapter begins by outlining the parameters for this literature review.

2.1 Organisation of Literature Review

A body of research pertaining to SSIs-based education has been growing for the past 20 years. This review of literature initially involved the identification of key topics in the field of study. A keyword-focused search was conducted using Summon, Google Scholar, Science Direct, Wiley Online Library, and Sage databases. The search involved electronically searching databases for pertinent literature using a combination of key terms including: Scientific literacy, Socioscientific Issues, elementary, primary, argumentation, reasoning, content knowledge, NoS, attitudes towards science, citizenship, students, children. Books were retrieved from the library at Dublin City University (DCU) and through interlibrary loans where necessary. Following an initial screening, a number of studies were retained and full-text articles examined. It should be noted that whilst primary/elementary school students were the focus of this study, only a limited number of studies have examined SSIs education in a primary/elementary school context. Therefore, the parameters of the literature search were broadened to include literature which referred to lower secondary school students. In Ireland primary school students transition to secondary school aged 12 whereas in the United Kingdom (UK) and the USA the transition age is 11. However, it should be noted that international studies that refer to middle school (USA)/key stage 3 (UK) are set in a secondary school context where science is taught by a specialist science teacher. Subsequently, SSI literature for inclusion in this literature review included sources which: (1) focused on SSIs, (2) were situated within a primary/elementary or lower secondary school context and where (3) students were the participants. Research that focused on the effects of SSIs-based interventions on specific learning outcomes were prioritised (i.e., science content knowledge, NoS, interest and motivation, argumentation). In addition, although there are no studies that have focused on SSIs in a RoI primary science context, studies that examined the teaching and learning of primary science in the RoI were also included which served as a baseline for the current study. The literature was then thematically organised which informed the structure of this chapter. The next section presents a key concept underpinning this study and is considered to be the goal of SSIs-based education, scientific literacy.

2.2 Scientific Literacy

An internationally accepted aim of science education is to enable all students to develop deeper understanding of the world around them, and to use their understanding of science to contribute to public debate and make informed and balanced decisions about science-related issues that impact their lives (American Association for the Advancement of Science (AAAS), 2000; DES, 2017a; Beernaert et al., 2015; National Research Council (NRC), 2012; UNESCO, 2016). This broad objective is often referred to as scientific literacy and is considered by many as the goal of science education (Beernaert et al., 2015; Bybee, 2015; Eurydice Network, 2011; NRC, 2012; Osborne & Dillon, 2008; Roberts & Bybee, 2014). The term scientific literacy was first introduced by Hurd (1958). Hurd described scientific literacy as an understanding of science and its application to an individual's experience as a citizen (1958). Hurd made clear connections between scientific literacy and education, highlighting the importance of providing students with opportunities to apply science to social, economic, political and personal issues and develop an appreciation of science as a human endeavour and intellectual achievement (Hurd, 1958).

Since then, many have attempted to define scientific literacy but no universally accepted definition has emerged. Consequently, there is a lack of consensus regarding the knowledge, skills, attitudes and competencies that constitute scientific literacy (Laugksch, 2000). For instance, Norris and Philips (2003) contend that the term is so broad that it has been used to include variations of a number of the following competencies:

(a) Knowledge of the substantive content of science and the ability to distinguish from non-science;

(b) Understanding science and its applications;

(c) Knowledge of what counts as science;

(d) Independence in learning science;

(e) Ability to think scientifically;

(f) Ability to use scientific knowledge in problem solving;

(g) Knowledge needed for intelligent participation in science-based issues;

(h) Understanding the NoS, including its relationship with culture;

(i) Appreciation of and comfort with science, including its wonder and curiosity;

(j) Knowledge of the risks and benefits of science; and

(k) Ability to think critically about science and to deal with scientific expertise.

This lack of agreement regarding the definition of scientific literacy and/or its competencies is neither disconcerting nor surprising given the multifaceted nature and complexity of scientific endeavours. Indeed, Roberts (1983) states that the term "has had so many interpretations that it now means virtually everything to do with science education" (p. 22). On the other hand, Bybee (1997) considers the term to be so broad that it is now no more useful than a slogan to rally educators to support more and better science education with Durant (1994) declaring the term to be more fashionable than practically useful. Such is the conflict surrounding the term that some have called for the removal of the term 'scientific literacy' from educational policy and curricula, dismissing it as an ill-defined concept whose pursuit is ultimately pointless (Fensham, 2008a; Shamos, 1995). As early as 1983, Miller advised that any serious discourse on 'scientific literacy' should be framed within a clear and precise definition of the term because its meaning has evolved over time and means different things to different stakeholders. The way scientific literacy is understood has important implications for educational policy-making, practice and research (Sjöström & Eilks, 2018). Accordingly, the definition and competencies of scientific literacy underpinning this thesis will now be discussed.

2.2.1 Vision I, Vision II or Vision III Scientific Literacy

Holbrook and Rannikmae (2007; 2009) contend that there appear to be two divergent points of view when it comes to defining scientific literacy; a) those that advocate a central role for the knowledge of science and b) those who see scientific literacy referring to a society usefulness. Roberts (2007), as briefly discussed in Chapter 1, provides a useful heuristic framework for illustrating these views on scientific literacy and suggests that most definitions of scientific literacy fit along a continuum between two extremes referred to as Vision I scientific literacy ((a) above) and Vision II scientific literacy ((b) above). Vision I scientific literacy focuses on the knowledge, processes, and products of science (AAAS, 1993). It gives meaning to scientific literacy by looking inward at the "canon of orthodox natural science; that is the products and processes of science itself" (Roberts, 2007, p. 730). Within this vision, a scientifically literate person can be considered to have profound disciplinary content knowledge and understanding of scientific inquiry (Clegg, Hudson, & Steel, 2003; Roberts, 2007). Many others in the field (Osborne, 2007; Roth & Lee, 2004; Roberts, 2007; Sadler & Zeidler, 2009; Yore, 2012) maintain that such a vision solely focuses on careers in science or providing an academic background for specialisms in science. Holbrook and Rannikmae (2007) continue that the purpose of science education should not be focused on future scientists any more "than history is taught for students to become historians, or language is taught for students to become linguists" (p. 9).

Vision II scientific literacy includes the knowledge of science, but also extends to applications of this knowledge to make decisions about personal and societal situations that have science and non-science components (Lederman et al., 2014). Roberts (2007) considers Vision II to be literacy about science related situations which students are likely to encounter as citizens. It connects science to students' everyday perspectives and emphasises the relationship between science and society, how science may be seen in the real world and what students may encounter in the future (Haglund & Hultén, 2017; Jenkins, 1994; Osborne, 2012; Roberts, 2007). Vision II scientific literacy emphasises that science is for all students, not just those bound for scientific or technical careers (DeBoer, 2000; Feinstein, 2011; Holbrook & Rannikmae, 2009).

Some of the more recent conceptualisations of scientific literacy argue for scientific engagement or 'engagement in socio-political action' (Hodson, 2010; Santos, 2009; Sjöström & Eilks, 2018) to be part of scientific literacy. This is referred to as Vision III and entails 'proactive engagement' where students learn to "prepare for, and engage in, socio-political actions that they believe will make a difference" (Hodson, 2010, p. 199). This resonates with a politicised version of science education aimed at global citizenship and socio-ecojustice (Hodson, 2003; Sjöström et al., 2017).

It is evident that there are differences between these definitions with some, such as Dillon (2009), arguing that these visions of scientific literacy are underpinned by different philosophies and, at their most extreme, reflect competing interests; for instance, fostering scientific literacy for all students (Vision II) or providing a foundation for a more advanced study of science (Vision I) (Chiu & Duit, 2011; Dillon, 2009; Millar, 2009; Sadler, 2011a). However, others such as Donnelly (2006), assert that the visions of scientific literacy are intrinsically linked where, for example, an in-depth scientific content knowledge is necessary to negotiate complex real world issues and to separate them is to create an unnecessary chasm in science learning. In agreement with Donnelly (2006) and others, such as Liu (2013), this thesis considers Vision I, Vision II and Vision III scientific literacy not as rivals but as fundamentally linked and interdependent with one 'Vision' supporting the development of the other. Therefore, the definition of scientific literacy underpinning this research is based on the synthesis of research literature above and can be considered to support Vision I, Vision II and Vision III scientific literacy:

> Scientific literacy , as defined in this thesis, is the basic understanding of common scientific concepts and methods, the ability to critically examine and understand issues of science and technology as they are reported on and discussed in the media, the ability to use basic scientific methods to examine and solve problems and to apply sceptical, critical reasoning to complex situations and make rational, informed decisions and where necessary take informed actions in everyday life (Holbrook & Rannikmae, 2009; Hurd, 1958; Laugksch, 2000; OECD, 2015; Sadler & Zeidler, 2009; Showalter, 1974).

2.2.2 Scientific Literacy Competencies

Scientific literacy competencies can be considered a set of knowledge, skills and attitudes, which when applied in daily life, enhance the ability to interact with the world and participate in society (Laugksch, 2000). Chadwick (2018), Siarova et al. (2019) and PISA (OECD, 2013) presented scientific literacy frameworks that describe the competencies that are required by a scientific literate individual. These frameworks were synthesised and common competencies identified for use in this study. It should be noted that these are by no means a definitive list of scientific literacy competencies that an individual should possess but serve as a stipulative definition of competencies that align well with the definition of scientific literacy underpinning this thesis and the principles of SSIs-based education, to be discussed in Section 2.3.3. These scientific literacy competencies will now be briefly discussed:

- **Knowledge of Scientific Content.** Content knowledge of science relates to the main concepts and theories of science. This is necessary to develop conceptual understanding of the issues underpinning every day societal issues and also provides a foundation for students wishing to pursue a career in science (DES, 2017a; Klosterman & Sadler, 2010;

Sadler, Romine, & Topçu, 2016). A basic level of knowledge of scientific concepts, processes and their rationale is needed in order to be able to interpret, analyse and critically evaluate science-related issues (Siarova et al., 2019).

- **Knowledge of NoS.** An understanding of the NoS is essential for scientific literacy (Holbrook & Rannikmae, 2009; McComas & Olson, 1998; Schwartz, Lederman, & Crawford, 2004). It relates to the epistemology of science, science as a way of knowing, and the values and beliefs of scientific knowledge generation (Lederman, 1999). An individual with informed conceptions of NoS understands that science is empirical and evidence-based. Furthermore, informed NoS understandings foster an individual's understanding of the human, tentative, subjective NoS; this allows a scientific literate individual to recognise that a societal issue has multiple perspectives, is subject to change and evolve, and is also influenced by society and culture (Lederman, 1999; Matthews, 1994; Tsai & Liu, 2005).
- **Knowledge of Scientific Processes.** Scientific processes include asking questions, forming hypotheses, making predictions, testing the hypothesis by conducting empirical investigations or observations, and then comparing the evidence/observations to the hypothesis (Amos & Levinson, 2019; DES, 1999a, b). It is a rigorous process which involves careful observations and the application of scepticism regarding what is observed. It is expected that once an individual has a good understanding of the processes of science they should be capable of critiquing empirical evidence presented in the media, scientific reports and by other individuals in scientific discussions (Chadwick, 2018). Scientific processes as described here align closely with PISA 2015 description of procedural knowledge and does not include epistemic aspects which are better aligned with the NoS competency above (Chadwick, 2018; OCED, 2013).
- **Competencies and Skills of Science.** There is a wide range of competencies and skills related to scientific literacy (Chadwick, 2018). These include, but are not limited to, an individual's ability to read and understand scientific-based societal issues, engage in

discussion and debate, reason and make evidence-based decisions pertaining to every-day issues. Problem-solving and critical thinking skills are also fundamental to scientific literacy (OECD, 2015).

These competencies encapsulate the foundational features of scientific literacy that were pertinent to this study whilst also aligning well with the key principles of SSIs-based education. For example, argumentation and socio-scientific reasoning could be included within the 'skills and competencies' component. Furthermore, this overarching framework is broad enough to allow other scientific competencies to emerge, where and if necessary. The next section discusses the position of scientific literacy and the above competencies in an Irish primary school context. The national and international means of assessing students' scientific literacy is also explored.

2.2.3 Scientific Literacy within an International and National Context

International and national education policies have focused their attention on enhancing the level of scientific literacy that students achieve (Beernaert et al., 2015; Dillon, 2009; Eurydice Network, 2011; NRC, 2012; Roberts & Bybee, 2014). The current policy arena provides a 'lever' for the development of scientific literacy, as defined in this thesis. At a European level, The Science Education for Responsible Citizenship report calls for social, economic and ethical principles to be embedded into the teaching and learning of science in order to prepare students for active citizenship and the global societal challenges facing mankind (Beernaert et al., 2015). More recently the Science and Scientific Literacy as an Educational Challenge EU report highlighted a number of key challenges and recommendations for enhancing scientific literacy in Europe (Siarova et al., 2019). In the RoI, as discussed in Chapter 1, a number of educational policies and national reports provide legitimisation for the development of students' scientific literacy. For instance, the recently published STEM Education Policy Statement presents recommendations in relation to developing students' scientific literacy so young people have the knowledge, skills and attitudes "to be active citizens, to engage with modern communications and media in a critical way, to ensure personal well-being and to make informed choices about many aspects of their lives" (DES, 2017a, p. 10). Ireland's National Strategy for Education for Sustainable Development

(DES, 2014) also promotes scientific literacy principles with implications for science education. While the vision of scientific literacy underpinning the RoI policies remains ambiguous (as discussed in Chapter 1), these policies illustrate a movement towards the development of scientific literacy in science education which can be used as a vehicle to promote scientific literacy for all students. The next section will consider the current position of science education and scientific literacy within an Irish primary science context.

Scientific Literacy in an Irish Primary School Context. Measuring scientific literacy comprehensively continues to be a challenge (Sadler, 2011c; Siarova et al., 2019). At present there is no internationally recognised scientific literacy measurement tool for primary/elementary school aged students. Nevertheless, analysis of existing large-scale international assessment data such as TIMSS, national reports such as the Primary Science Review (Varley et al., 2008) and other national studies (Murphy et al., 2019; Murphy et al., 2020; Smith, 2015a) provide some initial insights into the scientific literacy of primary students in Ireland.

On an international level, TIMSS is the attainment test for fourth class primary school students (9 – 10 years old). Whilst not a scientific literacy test, TIMSS assessment content is jointly developed by participating countries based on detailed analysis of national science and mathematics curricula. The TIMSS assessment frameworks specify the scientific content knowledge (life science, physical science, earth science) and cognitive domains (knowing, applying, reasoning) that fourth grade (fourth class in Ireland, aged 9 -10) students are expected to be able to demonstrate. It includes the assessment of five scientific skills: asking questions, generating evidence, working with data, answering the research question, and making an argument from evidence (Mullis & Martin, 2013). Whilst no study has examined how TIMSS aligns with scientific literacy competencies, Fensham (2016) asserts that TIMSS' emphasis on the recall of scientific content knowledge through a multi-itemed questionnaire endorses a Vision I type of science curriculum. Nonetheless the content knowledge and in particular the cognitive domains give some indication of primary students' achievements in science education against an international scale, although the students' ability to apply these skills to everyday issues is not assessed. TIMSS 2015 is the most recent cycle of the study with Ireland previously taking part in TIMSS 1995 and TIMSS 2011.

In TIMSS 2015, fourth class students in Ireland achieved a mean score of 529, which was significantly above the TIMSS centrepoint and significantly above Ireland's mean scores in science in TIMSS 2011 and 1995. Irish fourth class students performed significantly higher than 22 countries and remained behind 15 countries (including for example Singapore, Finland, Poland, and Norway). In Ireland, fourth class students displayed a relative strength on earth science topics (much of this content is considered to be part of the geography curriculum in Ireland) and a relative weakness on physical science topics (including physical states and changes in matter, energy transformation and transfer, light and sound, electricity and magnetism, and forces and motion) (Clerkin et al., 2016). The DES found similar results when they evaluated primary school students' content knowledge in 2012 with approximately half of the students failing to complete tasks relating to physical sciences (energy, light, sound, heat) (DES, 2012). In terms of the cognitive content domains, fourth class students performed at a similar level across all domains: knowing (including skills such as recalling, recognising information, describing and providing examples), applying (including skills such as comparing, contrasting and classifying) and reasoning (including higher-order thinking skills such as analysing a problem, synthesising information, formulating hypotheses) (Clerkin et al., 2016). TIMSS 2015 reported positive findings regarding primary students' attitudes towards science, with 89% of students indicating that they like/very much like learning science. Other research concurs that Irish primary school students tend to hold positive attitudes towards learning science in primary school (Murphy et al., 2011; Murphy, 2014; Murphy et al., 2019; Varley et al., 2008; Smith, 2014).

In relation to the teaching of primary science, TIMSS 2015 reported that fourth class students receive 32 hours of instruction over the course of the school year (Clerkin et al., 2017). In fact, primary students in Ireland receive less time on science instruction than their peers in any other country that participated in TIMSS 2015. Furthermore, the time devoted to teaching science has almost halved since TIMSS 2011 (Clerkin et al., 2017). While no reason has been cited for this decrease, McCoy et al. (2012) reported a trade-off in time allocation between increased literacy and decreased geography, history and science as a result of the numeracy and literacy strategy introduced by the DES in 2011. Within science class, TIMSS 2015 found that over 50% of Irish fourth class students were asked to listen to their teachers explain new science content in almost every science lesson, with over 50% of students reporting engaging in conceptual and procedural elements of a science investigation on a regular basis. Furthermore, high percentages of the fourth class students were positive about their instruction in science class (95%), were confident about science (82%) and liked learning science in school (89%) (Martin et al., 2016).

A national review of primary science and a number of other Irish studies have reported an overemphasis on teacher-directed, text-book dominated, deductive approaches to science where Irish primary students are being afforded little opportunity to engage in child-led inquiry approaches to science (DES, 2012; Murphy et al., 2015; Varley et al., 2008; Smith, 2014). This has an impact on the development of scientific inquiry skills which have been found to be lacking in progression from the junior to senior classes (DES, 2012; Varley et al., 2008; Murphy et al., 2011; Smith, 2014). Moreover, primary school students were found not to relate school science to the wider world or to future aspirations (Varley et al., 2008). It seems that some Irish primary school students do not see the relevance of school science to their everyday lives (DES, 2012; Eivers & Clerkin, 2013; Murphy et al., 2020; Varley et al., 2008). Therefore, while TIMSS (2015) has found positive attitudes amongst fourth class primary students and regular engagement with investigations, other research identifies that the science education Irish primary students are experiencing is predominantly teacher-directed in nature with little opportunity for child-led inquiry.

Correspondingly, primary teachers' lack of competence and confidence, poor Pedagogical

Content Knowledge (PCK)[3] and insufficient provision of pedagogical courses at both pre-service and in-service levels have been frequently cited as concerns in the literature (Clerkin, 2013; DES, 2016; Murphy & Smith, 2012; Varley et al., 2008). These concerns have resulted in teachers' over-reliance on a text-book approach to the planning and teaching of science (Dunne, Mahdi, & O' Reilly, 2013; Varley et al., 2008). Dunne et al. (2013) evaluated the content and pedagogical approaches underpinning primary science textbooks in the RoI (three different publishers) and concluded that while these textbooks had potential to promote inquiry based approaches to the teaching and learning of science, teachers required professional learning to enable them to do so; professional learning which has not been provided.

From the above research and assessments, it is apparent that Irish primary school students are generally positive about science. However, national research continuously highlights concerns about the teaching of primary science, the lack of development of students' scientific inquiry skills and the apparent disconnect between school science and the students' everyday lives. While Irish secondary school students are performing above the international average in the international assessment test that measures scientific literacy, PISA 2015, their performance is still behind the highest performing countries. This is recognised by the Irish government who have set targets to be one of the top performing countries in PISA and TIMSS by 2030 (DES, 2017b). In some instances, 'success' equated to an increase in an international comparative test can reflect 'neo-liberal policy making' and raises a number of concerns for teaching and learning (Ball, 2003; Bourke, Lidstone & Ryan, 2015; DeBoer, 2011; Gleeson & O'Donnobháin, 2009; Sadler & Zeidler, 2009). Excellence and improvement rendered in terms of measurable outputs may become the driving force of teachers' practice resulting in 'teaching to the test', 'narrowing of the curriculum', and/or dominance of didactic teaching approaches (Baird at el., 2011; Ball, 2003; Hirsch, 2006; Mac Ruairc, 2009; Minner et al., 2010; Orpwood, 2007; Sadler & Zeidler, 2009). For instance, when Germany experienced a PISA shock in 2000, where they scored below the OECD average in

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[3] PCK represents the intersections between subject knowledge and pedagogical knowledge and was first identified by Shulman in 1986 as a key aspect of teacher knowledge and is now widely accepted.

reading, mathematics and literacy (Pongratz, 2006), the German Government's post-PISA agenda was found to be firmly focused on raising their score in the PISA league table to the neglect of other major problems identified by PISA, such as the strong correlation between the economic status of students and their educational achievement (Ertl, 2006). Sellar, Thompson and Rutkowski (2017) warn against government use of PISA as a high stakes report card which often leads to unjustified celebration or blame.

On a national level, high stake testing has also proved to be problematic. In Northern Ireland, Johnston and McClune (2000) found that teachers reverted to the use of didactic approaches with an emphasis on the transmission of factual knowledge when preparing students for transfer tests in the final years of primary education. Similarly, in the RoI, Madaus and Greaney (2005) in their analysis of the now abolished Primary School Certificate found that the teachers of sixth class students (final year) emphasised subjects covered in the exam to the neglect of a holistic curriculum. O'Breacháin and O'Toole warn that a narrow curriculum and standardised testing could be used to address perceived deficiencies in the performance of students in international tests such as PISA and TIMSS which may lead Irish teachers to "'teach to the test' or even 'cheat to the test'" (2013, p. 417).

In addition, while PISA is a scientific literacy test, studies which have analysed PISA test questions concluded that PISA does not align with Vision II scientific literacy competencies (Burek, 2012; Ratcliffe & Millar, 2009; Sadler & Zeidler, 2009). Sadler and Zeidler (2009) applaud the efforts of PISA to create an assessment that moves beyond traditional approaches to science testing which generally focus on low-level representation of science content knowledge but state that they have serious concerns about the extent to which the PISA assessment supports progressive aims of scientific literacy. They further purport that students' ability to make informed decision making, apply critical thinking skills, engage in argumentation and reasoning, all key characteristics of Vision II scientific literacy, are not measured by the test (Sadler & Zeidler, 2009). Sjoberg (2018) agrees concluding that important elements of scientific literacy are not measured by PISA although they do feature in PISA's definition for scientific literacy. Others such as Bidegain and Mujika (2020) and Bybee and McCrae (2011) have analysed the relationship between students' self-efficacy, interest in science and participation in science, and scientific literacy score as measured by PISA (2015) and reported a negative correlation; i.e. higher scores in PISA is negatively related to positive attitudes towards science. Furthermore, Sjoberg (2018) and Oliver, McConney and Woods-McConney (2019) have highlighted the problematic finding that PISA test scores correlate negatively with nearly all aspects of IBSE; IBSE is recommended by scientists, science educators and policy documents from a variety of institutions and organisations. Thus the unintended consequence of striving to climb PISA rankings could be that authentic, context-based and relevant science education pedagogy and content could be sacrificed (Sjoberg, 2018).

2.3 Movement toward Scientific Literacy

This section will explore three educational movements whose aim was/is to develop students' scientific literacy (Vision I, II and III). The first of these, the Science Technology and Science (STS) movement, emerged in the mid 1980s, followed by the Science Technology Society Environmental (STSE) movement and most recently the Socioscientific Issues (SSI) movement. Prior to these movements science education focused on the content and processes of science (Vision I scientific literacy) which was found to provide inadequate preparation for students to deal with future scientific and technological issues (Anelli, 2011). Each of these movements will be discussed in turn.

2.3.1 STS Educational Movement

STS was introduced as a movement in science education in the 1980s (Yager, 1996) and was strongly supported by educators worldwide. It became a major theme in reform documents nationally and internationally (Hodson, 2003; Pedretti & Nazir, 2011). Aikenhead (1994) summarised STS as teaching that "conveys the image of socially constructed knowledge. Its student-oriented approach…emphasises the basic facts, skills, and concepts of traditional science…but does so by integrating science content into social and technological contexts meaningful to students" (p. 59). STS was advanced as a means of making science more relevant to students by making use of real, important and often controversial issues as contexts for science learning developing students' capacities to become responsible citizens in a world increasingly affected by science and technology (Aikenhead, 2005).

However, despite curricular changes and policy directives, there is evidence that the teaching and learning as envisioned by the STS movement did not take root in the classroom (Osborne & Dillon, 2008). It would appear that a strong emphasis remained on delivering science content knowledge (Osborne & Dillon, 2008). Zeidler and colleagues explain that the societal components were presented as additional or anchoring stories for the main scientific content that remained disciplinary, standard-based and free of values (Zeidler et al., 2005). In essence, STS was reduced to a "context for a curriculum" (Yager, 1996, p. 13). Teachers had difficulty with the implementation of STS due to: the assessment still prioritised students' understanding of scientific facts; there was a lack of time and resources for STS education; and insufficient professional learning opportunities (Orpwood, 2001; Pedretti & Nazir, 2011; Tal & Kedmi, 2006).

2.3.2 STSE Educational Movement

STSE education originated from the STS movement. STSE is concerned with the relationship between science, technology, society and the environment and emphasises the interplay between social, political, environmental and ethical perspectives in relation to science related issues (Barrett & Pedretti, 2006; Pedretti & Nazir, 2011). Similar concerns were raised regarding STSE education as its predecessor, STS education: there was a lack of teacher professional learning opportunities and misalignment remained between STSE education and assessment practices (Zeidler, Sadler, Simmons, & Howes, 2005). Furthermore, Shamos (1995) noted that while STSE education typically stressed the impact of decisions in science and technology on society, it did not explicitly consider the associated ethical issues nor did it consider the moral or character development of students. Accordingly, Zeidler and colleagues (2005) maintain that STSE education did not directly address the individual, moral and ethical development of students and indeed most science educators did not see the subtle distinctions between STS and STSE.

It would now seem that STS(E) approaches have become somewhat marginalised in the curriculum and in practice. The once megatrend in science education (Roy, 1984) has been relegated to brief mentions as contexts in school science textbooks or as isolated courses addressing STS(E) issues (Chiappetta & Koballa, 2002; Pedretti & Hodson, 1995; Trowbridge, Bybee, & Powell, 2000). SSIs-based education has now emerged as the means of achieving the goals of scientific literacy, something previous STS and STSE movements failed to accomplish (Ratcliffe & Grace, 2003).

2.3.3 Socioscientific Issues Movement

Over the past decade a number of studies discuss (a) the need to develop students' scientific literacy with relevance to everyday issues (Holbrook & Rannikmae, 2009; Zoller & Levi Nahum, 2011) and (b) the challenges of how to 'get there' (Siarova, Sternadel, & Szonyi, 2019). SSIs-based education has come to the fore as a means of addressing these needs. SSIs are complex societal issues with substantive connections to scientific principles and ideas (Zeidler, 2014). While many argue that SSIs share similar features, principles, visions and pedagogies to STS(E) (for example Pedretti & Nazir, 2011), the distinguishing hallmark of SSIs education is its explicit consideration of scientific issues which have moral and ethical implications (Zeidler et al., 2005). It humanises science by bringing to the fore the human dimensions of the subject (Pedretti & Nazir, 2011). Zeidler et al. (2005) further explicate that the SSIs movement is different from previous efforts that concentrated on connecting science with everyday life, namely STS and STSE, since SSIs focus specifically on "empowering students to consider how science-based issues and the decisions made concerning them reflect, in part, the moral principles and qualities of virtue that encompass their own lives, as well as the physical and social world around them" (p. 360). Thus within SSIs-based education, scientific literacy is given a more comprehensive meaning to include the understandings and attitudes individuals need in order to become active, informed and responsible citizens in a rapidly changing and scientifically complex society (Sadler, 2011 a, b;

Zeidler & Sadler, 2011). Of note, some variation exists in the field between ‘socioscientific issues’ and ‘socio-scientific issues’. Some authors such as Zeidler (2015) deliberately exclude the hyphen stating that a hyphen unyokes the relationship between ‘science’ and ‘society’ while others deem the underlying concept to be more important than linguistic choice. In this thesis the hyphen is excluded to highlight the interconnectedness of the social and scientific aspects as embedded concepts rather than individual exploits (Sadler, 2011a).

There is general consensus regarding the prominent characteristics of SSIs-based education (Ratcliffe & Grace, 2003; Sadler, 2009; Zeidler, 2014). SSIs makes use of science-related social issues as contexts for teaching and learning. The issue must be of personal relevance to the students and can be presented in the form of a dilemma or a controversy (Amos & Levinson, 2019). However, to use SSIs as a context to relay content knowledge can be seen as simply masking Vision I scientific literacy goals and undermines the potential of SSIs education to develop Vision II and Vision III scientific literacy competencies. It could also be seen as repeating the mistakes of the past with the STS/(E) movements. SSIs cannot be reduced to a motivational ‘add-on’ but should provide students with opportunities to consider the issue from different perspectives, both social and scientific, through discussion and debate (Sadler, Barab, & Scott, 2007). Students should be provided with opportunities to question, test, gather and evaluate scientific evidence and use this, along with social and ethical perspectives, to make informed arguments and decisions and in some cases take informed actions. Therefore, while SSIs are informed by scientific data and evidence, students also need to consider moral, ethical and economic factors (Sadler, 2009; Robottom, 2012). It is imperative that students understand these differing perspectives to enhance their ability to reason (Eastwood, Schlegel, & Cook, 2011). Key to the negotiation of these multiple perspectives within a SSI is providing students with opportunities for argumentation, debate and discussion. Here, ideas are examined, tested, supported and refuted before making choices at a personal and societal level (Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Ratcliffe & Grace, 2003). This provides students with a context that encourages active reflection and examination of relevant connections among science, their own lives and the quality of life in their community (Driver, Leach, Millar, & Scott, 1996; Driver, Newton, & Osborne, 2000; Kolstø, 2001, 2006; Sadler, 2004). Consequently, SSIs-based education as conceptualised above epitomises scientific literacy, Vision I, II and III (Topçu & Genel, 2014; Yoon, 2011).

2.4 Components of and Potential Outcomes of SSIs-Based Teaching on Student Learning

A body of research is beginning to emerge providing empirical evidence of the benefit of SSIs-based education including: enhancing learning of disciplinary science content knowledge; developing argumentation skills; promoting positive attitudes towards science; and advancing socioscientific reasoning (Sadler, 2011c). On a broader level, many have argued that SSIs-based education can better prepare students for participation in society, developing their ability to make informed decisions and take informed actions in response to complex issues (Sadler, Klosterman & Topçu, 2011; Sadler, 2011a; Levinson, 2018). Overall students are said to become more scientifically literate as a result (Bartholomew, Osborne, & Ratcliffe, 2004; Presley et al., 2013; Sadler, 2011 b, c; Zeidler, 2015; Zeidler et al., 2019). Through a review of the literature pertaining to SSIs, the subsequent sections (Section 2.4.1 – 2.4.7) will explore the knowledge, skills and dispositions that are necessary for negotiating SSIs as well as the educational outcomes that can be achieved through SSIs-based instruction. It should also be noted that some studies focus on argumentation/socioscientific reasoning within the context of SSIs. These studies were deemed appropriate for discussion here once the studies were congruent with the principles of SSIs (see Section 2.3.3).

2.4.1 Science Content Knowledge

Research pertaining to scientific literacy suggests that students need at least some understanding of the science content relevant to the issue in order to be able to successfully negotiate complex SSIs (Baytelman et al., 2020; Osborne et al., 2013; Von Aufschnaiter et al., 2008). Roberts puts forth that “everyone agrees that students cannot become scientifically literate without knowing some science” (2007, p. 11). Indeed, in an international and national context where educators are under increased pressure to perform in international tests such as TIMSS and PISA, the development of students' science content knowledge is often considered a government priority (DES, 2017b; Sadler, Romine, & Topçu, 2016). The below studies will discuss the relationship between SSIs-based education and its impact on the development of students' science content knowledge and the reciprocal relationship between the impact of science content knowledge on students' ability to engage and reason within SSIs.

Yager et al. (2006) assessed content knowledge gains for students involved in a SSIs-related intervention. The researchers created case studies of two middle school classes (aged 11-13) in the USA. Over the course of a semester, one teacher structured her classes around exploration of a local SSI (i.e. determining the site for a new landfill), while the control group followed the standard science curriculum. Students in both classes completed pre/post science content knowledge tests, and both groups demonstrated large gains that were statistically significant. However, differences between groups were not statistically significant. Notwithstanding, students in the experimental SSIs group were able to apply science to new situations, developed more positive attitudes about science and learned to use science at home and in the community more than the students in the control group. This finding was based on qualitative data: teacher observation, parent interviews and analysis of classroom recordings of the science classes throughout the intervention.

In a similar study in Thailand, Wongsri and Nuangchalerm (2010) examined seventh grade students' (11-13 years) scientific content knowledge gains through SSIs. In this quasi-experimental research study, the science content learning gains of 38 students who received SSIs-based instruction were compared to 38 students using traditional didactic learning activities. Statistically significant differences between the two groups were reported with the SSIs group demonstrating higher levels of scientific content knowledge attainment, analytical thinking and moral reasoning than the comparison group.

While the above studies provided evidence of learning gains (Yager et al., 2006; Wongsri & Nuangchalerm, 2010), the assessment instruments used in these studies aligned directly with the content of the SSIs-based intervention, thus learning gains are expected and not surprising. Klosterman and Sadler (2010) examined the impact of a three-week SSIs-based intervention (approximately 15 contact hours) on controversies surrounding global warming on students' (14-18 years old) (*n*=83) scientific content knowledge in the USA. The study measured developments in content knowledge at different 'distances' from the content of the SSIs-based intervention; that is collected data closely aligned with the intervention (proximal assessment) whilst also using a national exam (distal assessment) to make inferences regarding science content knowledge attainment and knowledge transfer. Klosterman and Sadler (2010) argued that the multi-level, pre and post-intervention research design used, provided a more valid tool for assessing how the intervention affected general knowledge structures not specifically tied to the intervention. Results indicated significant student gains in the proximal assessment with modest gains in the distal assessment whilst the qualitative evidence demonstrated enhancements in students' ability to express more sophisticated understanding of the SSIs content. This study contends that SSIs are an ideal context for teaching science content knowledge aligned with science curricula and has the potential to have a significant impact on student performance in international assessments such as TIMSS and PISA (Klosterman & Sadler, 2010). A more recent study conducted by Sadler, Romine, and Topçu (2016) also explored the effectiveness of SSIs-based instruction for supporting secondary school students' (grade/class not provided, *n*=69) learning of content knowledge related to biology and genetics. This study mirrored the above research design (Klosterman & Sadler, 2010) and findings presented statistically significant gains in both proximal and distal assessments. However, these studies (Klosterman & Sadler, 2010; Sadler et al., 2016) had no control group so there is no way to determine what the content knowledge gains of these students would have been if they had not participated in the SSIs intervention. Nonetheless, findings from these studies purport that SSIs can serve as a curricular vehicle for students' learning of science content that transcends beyond the specific SSIs instructional unit (Klosterman & Sadler, 2010; Sadler, et al., 2016).

On the opposite side there exists a postulation amongst some educators, policy-makers and teachers that SSIs-based teaching dilutes students' exposure to basic scientific ideas and principles (Hughes, 2000; Orpwood, 2001; Pouliot, 2008). These educators could be considered to be of Vision I persuasion and assert that developing sophisticated understandings of basic science concepts is the goal of science education and indeed this is a view often reflected in state and national exams where scientific content knowledge is often prioritised. Others such as Ekborg, Ideland and Malmberg (2009) raise concerns that students can become distracted when dealing with SSIs with a resultant negative impact on the development of science content knowledge. Thus science teachers are often concerned that the social and ethical components of SSIs detract from the core scientific knowledge and understanding that is needed for passing science examinations (Levinson, 2018; Pedretti et al., 2007). In the context of a knowledgeable society where accountability in terms of measurement is at the fore, this could prove to be a contentious issue with teachers and curriculum developers.

Lederman et al. (2014) and Sadler et al. (2007) strongly assert that such concerns are misguided. Many contend that connecting science education to the lived experiences of students through SSIs provides motivation for cognitive engagement and deeper understanding of the underpinning science concepts (Blumenfeld et al., 2006; Dawson & Carson, 2020; Lewis & Leach, 2006; Sadler et al., 2007; Sadler & Fowler, 2006; Von Aufschnaiter et al., 2008; Zeidler, Applebaum, & Sadler, 2011). This is in line with the constructivist principles supporting the Irish primary science curriculum which advocate that any attempt to develop students' science knowledge should be related to students' prior knowledge and/or experience (DES, 1999a). Zohar and Nemet (2002) further assert that SSIs help students engage in higher-order cognitive operations that allow students to better understand, remember and apply science content knowledge to real-life contexts. This is particularly significant in an Irish primary science context where students have reported that they experience difficulty connecting school science to their everyday lives (Varley et al., 2008).

Conversely, literature also indicates that science content knowledge impacts the quality of student reasoning and argumentation pertaining to SSIs (Sadler & Fowler, 2006; Sadler & Zeidler, 2005b; Von Aufschnaiter et al., 2008; Zeidler et al., 2005). Well-structured science content knowledge has been found to sustain higher levels of reasoning and argumentation than poorly structured knowledge (Baytelman et al., 2020; Osborne et al., 2013; Sadler & Fowler, 2006; Von Aufschnaiter et al., 2008; Wu & Tsai, 2010). Von Aufschnaiter and colleagues (2008) conducted a study with lower secondary school students (aged 11-12) and concluded that students' ability to engage in argumentation pertaining to SSIs was dependent upon the students' level of science content knowledge. Indeed, inaccurate science conceptions (Harlen & Qualter, 2018; Lewis & Leach, 2006) also hinder the quality of student argumentation and reasoning within SSIs leading to flawed arguments and decisions. Within this, it is important to note that some students find it difficult to apply content knowledge to reasoning and argumentation within a SSI (Christenson et al., 2014; Wu & Tsai, 2010). Sadler and Fowler (2005) refer to this as the Threshold Model of Knowledge Transfer where a sufficient level of content knowledge is required before it can be transferred to other contexts. Baytelman et al. (2020) concur arguing that students must have well-developed conceptual schema in order to incorporate content knowledge in their different types of arguments pertaining to SSIs (Sadler & Fowler, 2006; Sadler & Zeidler, 2005a, b). Therefore, it is imperative that students have a good foundation of science knowledge before it can be meaningfully applied to SSIs.

2.4.2 Nature of Science

Research asserts that SSIs provide concrete, real world examples that allow for both the development, and application of students' NoS understanding (Bell & Linn, 2000; Khishfe, 2013; Zeidler et al., 2002). While there is no universally accepted definition of NoS, it typically refers to the ways in which scientific knowledge is developed and produced and the characteristics of the epistemology of science (Holbrook & Rannikmae, 2009). Principles or tenets of NoS include understanding that scientific knowledge is: tentative and subject to change in light of new evidence; empirically based; subjective where it can be partly influenced by a scientists' background knowledge and experience; involves human inferences, imagination and creativity and is socially and culturally embedded (Lederman, 2007; Lederman, et al., 2014). Many (Dagher & Erduran, 2016; Erduran & Dagher, 2014; Matthews, 2012; Osborne 2014) are critical of such 'a list of tenets/principles' and state that the activity of science is much more complex and nuanced than a generalised list can capture. It is important to note that in the context of this study, the tenets of NoS described above are not considered to be a comprehensive list or definition of NoS but rather a set of important ideas for students to learn about scientific knowledge as recognised by numerous reform documents and national and international research (Akerson & Donnelly, 2012; Kampourakis, 2016; Lederman, Antink & Bartos, 2014; Murphy et al., 2019; Rocard et al., 2007). In an Irish context, Murphy et al. (2019) argue that these tenets of NoS are suitable for primary school students and form a necessary starting point for more sophisticated understandings of NoS.

Internationally, primary school students have been found to hold limited NoS understanding (for example Akerson & Donnelly, 2012; Khishfe, 2013; Murphy et al., 2019). Most recently, Murphy et al. (2019) found that the primary school students (*n*=459) in the RoI held naive NoS understanding as measured using a quantitative measurement tool and qualitative student focus group interviews. NoS is not an explicit feature of many primary science curricula, including the Irish primary science curriculum (DES, 1999a), and many argue that NoS must be explicitly taught and planned for during classroom instruction, discussion and questioning (Khishfe, 2013; McDonald, 2010; Murphy et al., 2019). A plethora of studies propose that NoS can be taught more relevantly and fruitfully by embedding them into a SSI context (Bell & Linn, 2000; Bentley & Fleury, 1998; Eastwood, Sadler, Zeidler, Lewis, Amiri & Applebaum, 2012; Khishfe & Lederman, 2006; Sadler, Chambers & Zeidler, 2002; Sadler et al., 2007; Simonneaux, 2008; Yerrick, 2000; Zeidler, 2014). For example, Oh and Jonassent (2007) and Khishfe (2012) relate SSIs-based argumentation to the empirical, tentative and subjective tenets of the NoS whereby students take into consideration alternative perspectives as they construct counter-arguments. These alternative perspectives generate students' understanding of the subjective NoS whilst also emphasising the importance of supporting claims with empirical data. Thus, it is suggested that SSIs provide a natural context for NoS-instruction (Sadler, Chambers & Zeidler, 2004). Few studies, discussed below, have empirically examined the relationship between SSIs and NoS with the oft-presumed association being discussed conceptually much more than it has been tested empirically (Sadler & Dawson, 2012).

Khishfe (2013) examined the influence of explicit NoS instruction within a SSIs context at middle school level through the use of a pre and post open-ended questionnaire and focus group interviews. This USA study had 121 seventh graders (12-13 years-old) participate in an 8-week SSI unit about water use and safety. Group 1 had explicit NoS within SSIs instruction while Group 2 had explicit NOS instruction. Findings indicate that even though Group 1 and 2 developed more sophisticated NoS conception, SSIs enriched students' understanding toward some aspects of NoS. Furthermore, the SSI-NoS students were able to transfer their learning from familiar to unfamiliar contexts, as demonstrated in the student focus groups, something the decontextualized group were unable to do. In a different USA study Bell and Linn (2000) also concluded that SSIs were an effective means of enhancing students' NoS conceptions. The rationale for Bell and Linn's study was to determine whether NOS aspects were evident in 172 middle school students' (11-13 years old) SSIs arguments. The authors provided quantitative evidence that the explicit teaching of SSIs strategies resulted in heightened NOS understanding. These studies (Bell & Linn, 2000; Khishfe, 2013) provide some evidence that NoS understanding can be developed through SSIs-based education in a lower-secondary school context.

NoS understanding has also been found to influence engagement with SSIs argumentation and reasoning (Sadler, 2004; Zeidler, 2014). Research indicates that a sophisticated understanding of NoS can enhance the quality of decisions made regarding scientifically based issues that increasingly confront our society (Karisan & Zeidler, 2017; Sadler, 2011c). A realistic understanding of the possibilities and limitations of science has been emphasised as particularly important when negotiating SSIs (Kolstø, 2001; OECD, 2013; Oulton, Dillon & Grace, 2004; Zeidler et al., 2005; Sadler, 2011a). This involves careful evaluation of scientific claims by discerning connections among evidence, inferences, and conclusions; all key characteristics of NoS (Zeidler et al., 2005). Students with sophisticated understanding of the tentative and developmental NoS are also more likely to appreciate the complex, multidimensional nature of SSIs. Indeed, an understanding of the subjective NoS humanises the subject and provides a platform for the recognition of SSIs from multiple perspectives (Khishfe, 2013). Furthermore, sophisticated NoS understanding develops students' appreciation of the social and cultural biases that often influence an individual's perspective (Matthews, 1994; Tsai & Liu, 2005). Theoretically, it is apparent that NoS and SSIs share several connections. Indeed, from an empirical perspective, Bell and Linn (2000) found that middle school students with more informed views of NoS constructed more complex arguments. Other studies in a secondary school context also found that enhanced understanding of NoS influenced the quality of the students' decision-making pertaining to SSIs (Khishfe, 2012; Khishfe et al., 2017).

In summary previous research in an Irish primary context has reported that Irish primary students have naive understandings of NoS (for example Murphy et al., 2019). Literature proposes that NoS and SSIs are intrinsically linked whereby the very nature of SSIs-based education promotes the development of NoS understanding and that SSIs connect the NoS with the social enterprise of science (Bell & Linn, 2000; Khishfe, 2013; Soysal, 2015; Zeidler, et al., 2002). Informed NoS understanding has been found to support students in the negotiation of SSIs and enables students to apply their NoS understanding to real world contexts. Furthermore, explicit instruction on the NoS embedded within relevant SSIs provides concrete, real-world examples that are important to the students. Therefore, SSIs-based education provides a natural anchor for NoS through a cognitive framework that is readily accessible to a student (Zeidler et al., 2002). Indeed, informed NoS understanding without application to real world contexts could be seen to promote Vision I competencies whereby application and transfer to SSIs can support both Vision I and II scientific literacy. Khishfe asserts that such an approach has the potential to enhance scientific literacy whilst also allowing teachers to use their instructional time more efficiently (Yacoubian & Khishfe, 2018).

2.4.3 Inquiry Based Science Education

This section focuses on the potential of SSIs to provide authentic contexts for IBSE and the development of scientific inquiry skills. Reciprocally, in order for students to make informed decisions about SSIs they must be able to use an inquiry approach to uncover science knowledge for themselves whilst also using their understanding of inquiry to evaluate scientific evidence presented in the media and other sources pertaining to SSIs (Zeidler et al., 2005). It is widely supported that IBSE is an effective method of teaching both skills and knowledge required for a scientific literate society (Beernaert et al., 2015; Rocard et al., 2007). Furthermore, IBSE pedagogies have been shown to increase both students' interest in science and teachers' willingness to teach science (Gibson & Chase, 2002; Jiang & McComas, 2015; Rocard et al., 2007). In this section, a brief overview of IBSE as a pedagogy will be provided, including the use of a SSI as a context for the development and application of inquiry skills.

Investigations and inquiry are central to science (Cutting & Kelly, 2015). Prior to discussing IBSE, it is necessary to examine teacher-directed approaches to the teaching of science. Here, the teacher has control over the various aspects of the investigation including the question to be investigated, the expected outcome and how results are to be recorded and communicated. It can be defined as a deductive, transmissive approach to the teaching of science (Cutting & Kelly, 2015). According to the Irish primary science teacher guidelines (DES, 1999b) this approach is described as an illustrative or closed investigation where the teacher tells the students what to do and there is one expected answer. The aim of illustrative or closed investigation is for all students to have a similar experience and to enable students to develop understanding of a particular concept. It is also useful when teaching the students how to use particular tools or equipment. Cutting & Kelly (2015) consider this approach to be appropriate prior to children starting to investigate their own questions or to consolidate students' learning after an investigation.

Due to the student-centred principles of inquiry-based instruction, Hazari, North, and Moreland (2009) differentiate inquiry-based instruction from teacher-directed instruction by focusing on the unique role of the student: “learners construct personal interpretation of knowledge based on their previous experience and application of knowledge in a relevant context” (p. 189). Wolk (2008) further purports that inquiry-based teaching transforms the teaching of science from memorisation of facts into one of student-led questioning and investigating. Linn et al. (2004) define inquiry as the “intentional process of diagnosing problems, critiquing experiments and distinguishing alternatives, planning investigations, researching conjectures, constructing models, debating with peers and forming coherent arguments” (p. 16). In other words, it gets students asking questions and investigating possible answers, using a variety of skills to collect reliable and accurate data, draw conclusions, reason and debate (Wellcome Trust, 2012). It is often associated with ‘hands-on’, ‘problem-based’, ‘project-based’, ‘student-centred’, ‘inductive and dialogic’ approaches; these approaches are closely associated with learners actively engaged in the construction of their own knowledge (Anderson, 2002; Hayes, 2002). IBSE also facilitates collaboration and promotes problem-solving and critical thinking skills (Amos & Levinson, 2019; Artique et al., 2012; Harlen, 2013). According to Levinson (2018), IBSE through SSIs facilities authentic inquiries, provides students with opportunities to develop scientific inquiry skills whist enabling students to gather evidence to find solutions to authentic SSIs (Levinson, 2018). This is deemed essential for responsible citizenship and understanding environmental, economic, medical and other complex SSIs that confront modern societies (Beernaert et al., 2015; Rocard et al., 2007).

A number of Irish studies and reports have highlighted concerns over the lack of development of primary students’ scientific inquiry skills and limited experience of IBSE (DES, 2012; Murphy et al., 2019; Smith, 2014; Varley et al., 2008). Varley and colleagues (2008) reviewed the implementation of the Irish primary science curriculum and found that primary school students (*n*=1030) were being provided with limited opportunities to engage with inquiry-based, child-led approaches to science education with infrequent opportunities for students to ask and investigate their own inquiry questions (2008). While this finding was based on self-reported student questionnaire data, researcher classroom observation supported these findings whereby 15 science classes were observed in 10 different schools and only one of the classes observed included child-led inquiry, providing students with opportunities to ask their own inquiry questions. Subsequently, the DES reviewed the implementation of the primary science curriculum (DES, 2012) and reported similar concerns regarding the development, or lack thereof, of primary students' scientific inquiry skills (e.g. observation, investigating, predicting, communicating). These findings were based on an analysis of student performance assessment tasks (*n*=1813). In a Performance Assessment (PA), students perform small experiments by interacting with materials and are regarded as investigations that recreate the conditions under which scientists work (Kruit et al., 2018). According to the DES (2012) report, even though the performance assessments were not a standardised measure of achievement in science, they provided some indication of the extent to which students had developed and applied scientific inquiry skills (DES, 2012).

The Primary Science Review (Varley et al., 2008) and the DES report (2012) concluded that many students had not been given the opportunity to work scientifically, or to develop the procedural skills and understanding as envisioned in the Irish primary science curriculum. Murphy et al. (2019) and Smith (2015), from smaller scale RoI studies, also reported that primary school students had limited experience of inquiry-based approaches. These findings indicate that IBSE approaches in Irish primary classrooms are limited (Dunne et al., 2013). Indeed, similar concerns regarding students' limited experience of IBSE are echoed across Europe (Beernaert et al., 2015; Rocard et al., 2007). Within an Irish context, many primary teachers have been found to lack IBSE pedagogical knowledge and confidence with IBSE approaches (Murphy et al., 2020). This often results in an over-reliance on primary science text-books which often do not promote an inquiry approach (Dunne et al., 2013; Murphy et al., 2020). A recent Irish study found that teachers' IBSE pedagogical knowledge was enhanced through teacher professional learning which then had a positive impact on the students' experience of IBSE and development of scientific inquiry skills, as evident in the post-intervention IBSE scale data and student focus group interviews (Murphy et al., 2019).

From a SSIs perspective, inquiry in the context of SSIs provides students with an authentic relevant context for inquiry rather than a simulation inquiry or an inquiry with little connection to the student's everyday lives (Levinson, 2018). An IBSE approach provides students with opportunity to explore their own belief system about the SSI and makes the SSI personally relevant to the students (Outlon, Dillon, & Grace, 2004; Levinson, 2006; Zeidler & Nichols, 2009). As part of the inquiry based SSI approach, students engage in interpretation, analysis and evaluation of evidence from a variety of sources (Zeidler et al., 2009). Thus, it is expected that once students are cognisant of the inquiry process, they will be able to critique claims that are made about data and the approaches used by scientists in the generation of evidence (Monteira & Jimenez-Aleixandre, 2016). Furthermore, through the use of SSIs-based education, students should also be able to identify information sources, access information, evaluate information, and use this information effectively, efficiently and ethically to make informed decisions pertaining to SSIs (Julien & Barker, 2009; Zeidler et al., 2009). Thus, from a theoretical perspective, many have proposed that SSIs offer a platform for the development and application of scientific inquiry skills in an authentic real world context (Anderson, 2002; Lederman, Antink & Bartos, 2014).

In spite of the potential of SSIs to provide a natural, authentic context for IBSE and the necessity for students to explore SSIs through IBSE, research which focuses on merging scientific inquiry and SSIs is limited in both an international and national context. Levinson and colleagues produced a framework for supporting primary and secondary teachers in promoting inquiry through SSIs-based education (Levinson, 2018; Amos & Levinson, 2019). It comprised of three key components: an authentic question or problem with a scientific component; proposed actions which address the question; and enactions which encompass processes in enabling action (Amos & Levinson, 2019). However, the impact of using SSIs as a context for the development and/or application of scientific inquiry skills is absent from research literature and empirical research is warranted. In addition, SSIs-based education should reap the benefits of an IBSE pedagogical approach which has been proven to enhance student interest in science and enable them to see the relevance of school science to their everyday lives (Beernaert et al., 2015; Rocard et al., 2007; Murphy et al., 2019).

Of note, Oliver et al. (2019) and Sjoberg (2018) reported a negative correlation between students' experience with IBSE and their level of scientific literacy, as measured by PISA (2015). In other words, students with less experience of scientific inquiry had higher levels of scientific literacy, and vice versa. The same pattern emerged across a number of countries who participated in PISA (2015) including the RoI. Oliver et al. (2019) highlighted that it is difficult to ascertain the 'quality' of scientific inquiry being used and thus further research is required to clarify these results (Oliver et al., 2019). However, as alluded to earlier, it could add a question mark over the suitability or ability of a quantitative large scale assessment such as PISA to measure Vision II or III scientific literacy competencies (Sadler & Zeidler, 2009).

2.4.4 Socioscientific Argumentation

One of the aims of teaching science through SSIs is to help students develop argumentation skills whereby individuals will be able to discuss, debate and negotiate ill-structured problems underpinned by science (Zeidler et al., 2005). The development of argumentation skills through SSIs is referred to as socioscientific argumentation (Fleming, 1986; Fuller, 1997; Taylor, 1996; Yager & Tamir, 1993; Pedretti & Nazir, 2011) and is perceived to be a critical component of scientific literacy (Chowning et al., 2012; OECD, 2013; UNESCO, 1999). Argumentation is the process of arguing, in which the construction, justification, and refutation of arguments take place (Dawson & Clarke, 2020). The development of student argumentation in the context of SSIs is appropriate as argumentation is the "activity subjects engage in when discussing controversial themes" (Leitao, p. 333). It is seen as an individual or social process whereby individuals try to justify their claims by verbally presenting a rationale for their actions (Patronis, Potari, & Spiliotopoulou, 1999). Toulmin (1958; 2003) produced an argumentation framework, Toulmin's Argumentation Pattern framework (TAP), that has been adapted by many researchers in an effort to both enhance and assess student argumentation (Erduran et al., 2004; Jimenez-Aleixandre et al., 2000; Osborne et al., 2004; Zohar & Nemet, 2002). According to Toulmin (1958), the statements that make up an argument have different functions that can be classified into one of six categories including data (evidence), claim (theory), warrants (connection between evidence and theory), backing (support or explanation for the warrant), qualifier (specifies the conditions under which the claim is true) and rebuttal (specifies the conditions in which the claim is not true). Toulmin describes scientific argumentation as a process of using data, warrants and backings to convince others of the validity of a claim (Sampson & Clarke, 2008). According to Toulmin (1958), the strength of an argument is based on the presence of these structural components. Many assert that argumentation regarding SSIs is analogous to the process that scientists undergo when justifying scientific knowledge; scientists must construct persuasive and convincing arguments that relate explanatory theories to evidence (AAAS, 1993; Duschl & Osborne 2002; Lederman, 1992; Martin & Hand, 2009; Matthews, 1994; NRC, 1996). However, what counts as claim and evidence in the science community is different to that accepted in SSIs argumentation. In SSIs argumentation social, political, moral factors for example, along with scientific empirical evidence are acceptable arguments to support or challenge a perspective on a SSI (Jimenez-Alexandre & Erduran, 2008; Sampson et al, 2011). Consequently, providing students with opportunities for argumentation (i.e., evaluating evidence from scientific and social perspectives, assessing alternatives, establishing the validity of claims, and addressing counter-positions) are particularly important for science learning experiences (Driver et al., 2000; Evagorou, 2011; Ratcliffe & Grace, 2003).

A number of studies provide empirical evidence that SSIs are an appropriate context for the development and application of students' argumentation skills in an elementary/primary school context. For instance, McNeill (2011) examined elementary school students' (*n*=33) argumentation skills after a year-long intervention in the USA using an adaptation of Toulmin's model of argumentation to code student writing in terms of claim, evidence and reasoning. The study concluded that by providing elementary students with appropriate supports they can successfully engage in discourse in their classrooms developing strong argumentation skills and applying these skills to more complex contexts and content areas. Similarly, Naylor et al.'s (2007) study on primary school students (aged 7-9) in the UK found that young students are capable of engaging in meaningful argumentation. While this study was not set in a SSIs context, Naylor et al. asserted that worthwhile argumentation must be positioned in a relevant context, be engaging for the students and framed in terms of science conceptual development; all features of SSIs. Similarly, Hong et al (2013) used a quasi-experimental design which examined fifth grade Chinese students' (*n*=111) argumentation skills. After a 12-week intervention positive results in relation to the enhancement of students' argumentation skills in line with the TAP framework were found in the treatment group.

Evagorou (2011) examined the scientific argumentation process of 11-12 year-old Cypriot students (*n*=25). The purpose of the research was to explore how to support middle school students' argumentation and decision-making within a SSI using a modified version of Toulmin's TAP framework. After an explicit eight-lesson intervention aimed to develop argumentation skills, Evagorou's (2011) study found that participants displayed enhanced quality of arguments and used evidence to support claims when discussing the SSI. However, on a less positive note, Evagorou (2011) concluded that the quality of students' argumentation did not always improve from pre-intervention to post-intervention with limited evidence of counter-arguments or rebuttals present in the students' discussions. Another important finding indicated that students tended to ignore scientific evidence if it opposed their decisions post-intervention. It should be noted that this 'ignorance of science data' was in response to a field trip to a pig farm where the students reported that the excessive smell pushed them to ignore the scientific evidence they had collected when making a decision as to whether or not a pig farm should be located in their locality. Prior to this, the students were using a balance of scientific, social, environmental and financial evidence to support their arguments.

In 2013, Evagorou and Osborne evaluated UK students' (11-12 year-old) argumentation skills using a case study research design (Class A *n*=28; Class B *n*=27) where argumentation within SSIs was taught over four 40 minute lessons. Consistent with the studies above an adapted version of the TAP framework was used to analyse the students' argumentation skills. Findings from the study indicated that the SSIs-based intervention was found to increase student engagement and enhance the quality of arguments in both classes. However, students in Class A and B provided different decisions and justifications post-intervention. While the authors deduced that the students' personal and cultural identities impacted their decisions and justifications in response to the SSI, a conclusion that has been found in other studies (for example Zeidler et al., 2005), the teachers in both classes employed different instructional practices during the enactment of the intervention where Teacher A defined, explained and modelled argumentation throughout the intervention and Teacher B did not. Furthermore, Teacher A spent 85% of class time allowing the students to engage in discussions pertaining to the SSI with Teacher B only spending 45% of class time doing the same. Thus, further research in a more controlled study is required to substantiate the findings of this research study. Nonetheless the students in both classes were found to ignore the scientific evidence if it did not align with their opinions, a finding which supports Evagorou's (2011) earlier study.

Khishfe (2013) employed a quasi-experimental study to examine the effect of explicit (treatment group) and implicit (control group) argumentation instruction on US students' (12-13 year-old) argumentation skills within the context of a SSI. An eight-week SSI embedded intervention on water usage and storage was taught by two teachers to a total of 121 (12-13 year-old) students. Findings revealed that explicit argumentation instruction through a SSI led to improvements in the students' argumentation skills, namely students use arguments, counterarguments and rebuttals. While there were gains in the control group too, the treatment group were unable to transfer their argumentation skills to unfamiliar SSIs contexts, something the control group were able to do. However, this finding pertaining to students' argumentation skills was based on analysis of students' written responses to a SSIs scenario. It is difficult to see how students' level of argumentation, especially their ability to form rebuttals and counter-arguments, could be assessed in this individual written format when argumentation is perceived to be a social process where discussion is key and more easily found in dialogic argumentation (Evagorou, 2011).

While the above studies used different SSIs contexts over different periods of time with different argumentation analytical frameworks, these studies provide evidence that SSIs are effective contexts for developing students' argumentation skills. Within these studies, many have cited methodological concerns regarding the use of Toulmin's TAP framework (1958; 2003) to analyse students' argumentation skills. For instance, it is possible that an argument could include all of Toulmin's components but still contain false, irrelevant or illogical data and/or backings (Dawson & Carson, 2020). In other words, the TAP framework has been criticised for focusing on the structure of the argument to the neglect of the quality of the argument (Abi-El-Mona & Abd-El-Khalick, 2011; Simon, 2008). From a practical perspective, researchers have found it difficult to reliably distinguish between the different components of Toulmin's framework especially in terms of what can be categorised as a claim, data, warrant and backing and when the comments made by students can often be categorised into multiple categories (Erduran et al., 2004; Sampson & Clarke, 2008; Simon, 2008). Similar to other discourses, argumentation statements are both contextual and indexical and therefore claims, evidence, rebuttals and counter arguments can be hard to distinguish in an analytical way (Kelly, Drucker, & Chen, 1998). Indeed, Simon, Erduran and Osborne (2002) assert that nearly all researchers have found the application of Toulmin's framework problematic. Others raise concerns that reducing arguments to their structural components may compromise the dialectical features of the argument leaving them under-examined or under-emphasized (Robertshaw & Campbell, 2013). This is further emphasised by McDonald and Kelly (2012) who state that "narrowing the focus to one aspect of the discourse, in large part due to its analytical accessibility, can lead to missing the forest for the trees" (p. 277).

Many researchers acknowledge the above limitations in the TAP framework and have adapted Toulmin's framework in an effort to alleviate these concerns (Evagorou, 2011; Khishfe, 2013; McNeill, 2011; Osborne & Evagorou, 2013). For example, McNeill collapsed the TAP framework into three categories, 'claim, evidence and reason' to overcome the usability difficulties of Toulmin's framework. Along a similar line, Khishfe (2013) analysed student responses in terms of three components of argumentation, 'argument, counterargument and rebuttal', and categorised them according to three different levels 'naive, intermediate and informed' usage of argumentation components. Erduran et al. (2004) modified Toulmin's framework and devised five argumentation levels to measure or explain the quality of an argument. These levels were underpinned theoretically by Toulmin's framework and were informed by evidence on how young students construct arguments (e.g. Osborne et al., 2004). Evagorou (2011) applied Erduran et al.'s (2004) modified TAP framework and established that while it was not useful for measuring the argumentation quality of written arguments, it would be effective for dialogic argumentation. Furthermore, Evagorou (2011) stated that the number of pieces of evidence a student uses should be included in future argumentation analytical frameworks in order to assess the content as well as the structure of the argument. Simon (2008) concluded that while Toulmin's TAP framework has its limitations it is a useful basis for evaluating student outcomes related to argumentation.

Other studies have concluded that even with specifically designed instruction students do not construct the high quality argumentation that might be expected of them (Erduran et al., 2004; Evagorou, 2011). Some have suggested that students often rely more on intuition and personal values when devising arguments and justifying claims (Evagorou, 2011; Evagorou et al., 2012; International Council for Science (ICSU), 2011). This has led to significant discussion on the position or value of scientific evidence in SSIs argumentation in the literature (Lewis & Leach, 2006; Christenson, Rundgren & Höglund, 2012; Sadler & Donnelly, 2006). Lewis and Leach highlighted this concern in their study (*n*=200) in 2006 which examined the relationship between science knowledge and reasoning. They found that whilst scientific content knowledge was necessary to engage students (14-16 years), the students rarely explicitly drew on the content knowledge during their discussions. A recurring theme appears to be emerging from the literature in that students typically do not refer to scientific concepts and information in socioscientific debates (Christenson et al., 2012; Sadler, 2004; Sadler & Donnelly, 2006; Zeidler et al., 2002). Zeidler (1997) theorised this 'ignorance of scientific evidence' using a constructivist principle whereby most individuals do not easily accept evidence that contradicts their initial beliefs as people tend to assimilate any new information with existing theories; therefore, a stronger initial belief is harder to change. This explains why individuals allow ideas that align with core beliefs to become a part of their knowledge base while dismissing or ignoring evidence to the contrary (Pine et al., 2001; Sadler et al., 2007; Zeidler & Keefer, 2003). While respecting the other components of SSIs, for example social, economic, ethical, it is of concern for students' scientific literacy if the scientific element of socio*scientific* argumentation is being 'ignored' or 'diluted' by students instead of being weighed up against other forms of evidence in the process of argumentation.

The role of the teacher in the development of the argumentation strategies also needs to be considered (Evagorou & Osborne, 2013). International and national reports indicate that scientific argumentation or socioscientific argumentation are not common features in science education (Venville & Dawson, 2010). For instance, in TIMSS 2015, 4th class students reported that 42% of Irish primary school teachers rarely, if ever, allow the students to engage in discussion during science class (Clerkin, Perkin & Chubb, 2017). Argumentation is not an explicit feature of the Irish primary science curriculum (DES, 1999a) and Maloney and Simon (2006) contend that unless policy-makers make argumentation skills as part of curricula objectives, students will not achieve them. Others have found that even in spite of curriculum change and emphasis on argumentation, much of the classroom discussion in science classes is restricted to closed questions with little opportunity for student dialogue in small groups (Simon & Amos, 2011). This occurred in the UK with the implementation of the Twenty First Century Science curriculum for 14-16 year olds which placed greater emphasis on argumentation and SSIs. Prominent researchers in the field of argumentation and school science reported that teachers in the UK were not readily changing their practice because teachers were unfamiliar with the pedagogical practices required to help students engage in discussion in a social context (Osborne, Erduran & Simon, 2004; Simon

& Amos, 2011; Roth, 2014). It seems that if teachers are not provided with pedagogical support, then irrespective of curricular change, it is unlikely that students will be provided opportunities to develop and apply argumentation skills in school science.

2.4.5 Socioscientific Reasoning

One of the appeals of a SSI is that it not only serves as a context for developing scientific content knowledge and argumentation skills, it also serves as a catalyst for developing students' reasoning skills. One of the key components of scientific literacy is making informed decisions regarding SSIs. Thus, this section focuses on socioscientific reasoning; the values and attitudes used to negotiate and make informed decisions regarding science related social issues with ethical or moral implications (Wu & Tsai, 2007). Socioscientific Reasoning (SSR) differs from scientific reasoning in that socioscientific reasoning is not confined to domain-specific contexts where problems tend to be well-structured and reasoning employed by the learner is based on the application of scientific concepts and rules that lead to a solution (Kuhn & Franklin, 2006; Zimmerman, 2007). Whilst scientific reasoning should play an important role when making decisions regarding SSIs, studies revealed that scientific reasoning alone cannot resolve ill-structured problems (Kuhn, 1991; Sadler, Barab & Scott, 2007; Yang & Tsai, 2010; Zimmerman, 2000). SSR moves beyond trying to solve SSIs through, for example, linear cause and effect reasoning, to recognising that SSIs are complex social and scientific issues with multiple perspectives; the dynamic relationships within SSIs preclude simple linear solutions (Sadler et al., 2007).

In developmental psychology research, broad models of SSR are beginning to emerge (Kuhn & Franklin, 2006; Sodian & Bullock, 2008). Prior to this, models of scientific reasoning, often referred to as formal scientific reasoning, dominated the field (Kuhn et al. 1988, Kuhn 1991; Zimmerman 2000). Traditionally, developmental psychologists have highlighted the deficits in primary school children's thinking and reasoning as compared to those of experts, and have argued that students are only capable of scientific reasoning skills during adolescence (Koslowski, 2012). However, this Piagetian stage model has been widely criticised (Sodian et al., 1991;

Zimmerman, 2007). Zimmerman (2007) argues that this model presents what students are capable of with minimal support. Sodian et al. (2001) corroborate, claiming that students' reasoning skills can be improved through instructional support concluding that an early understanding of socioscientific reasoning was predictive of later strategy use in adolescence. This corresponds with psychological research which has found that the development of the ability to reason and act in accordance with beliefs starts in early childhood (Lee & Homer 1999; Wellman et al. 2001). In terms of classroom practice, Mayer et al. (2014) provided empirical evidence that fourth grade students (9-10 year olds; *n*=145) are competent in different scientific reasoning competencies. In 2007 the Committee on Science Learning: Kindergarten through to 8th Grade was established to devise a report on how students learn science (Reiser et al., 2007). The report was significant in that it was used to inform USA policy-makers, researchers and education practitioners on the future direction of science education (Reiser et al., 2007). The report concluded that all young children have the intellectual capacity to demonstrate casual reasoning, discriminate between reliable and unreliable sources of evidence and engage with scientific endeavours in a serious way.

The extent to which students demonstrate SSR competencies in the context of SSIs remains a relatively under-researched area (Karahan & Roehrig, 2017), particularly in the context of primary science education. Patronis, Potari, and Spiliotopoulou (1999), in their study with 14-year-old Greek students, concluded that they were capable of developing arguments and making decisions pertaining to SSIs once the SSI was relevant and engaging for the students. Post-intervention the students were found to be capable of forming arguments and opinions based on a number of different aspects of the SSI (Patronis et al., 1999). Furthermore, the researchers highlighted that explicit teacher instruction was required to scaffold the students' decision-making skills.

Barab and colleagues (2007) examined 4th grade USA elementary students' (9-10 years old; *n*=28) SSR competencies using Quest Atlantis, a virtual environment used to embed students in an aquatic habitat simulation. The study found that the students developed enhanced SSR skills particularly when balancing economic and ecological concerns, considering scientific data and multiple lines of evidence. However, some students demonstrated episodes of flawed reasoning whereby half of the students used inaccurate science content knowledge to support their proposed solutions.

In 2007, Sadler, Barab, and Scott operationalised socioscientific reasoning as a construct and captured specific practices associated with the negotiation of a SSI. Four sub-constructs were identified which the authors considered necessary components of socioscientific reasoning (Sadler et al., 2007). These sub-constructs refer to what students should know, do, and apply across different SSIs:

(i) *Recognise the inherent complexities of a SSI.* This involves recognising the different scientific and social components of the issue. Simplifying the SSI or trying to solve it based on simple cause and effect reasoning should be avoided (Bosser, 2017).

(ii) *Examine issues from multiple perspectives.* For instance, individuals can adopt dissimilar but equally plausible solutions to a SSI based upon personal priorities, principles and biases (Sadler et al., 2007). SSIs that provide students with opportunities to examine multiple perspectives have been shown to promote reasoning skills and critical thinking abilities vital to informed decision-making and action in relation to SSIs (Frijters et al., 2008).

(iii) *Appreciate that SSIs are subject to ongoing inquiry*. This competency aligns with the tentative NoS and involves recognising that scientific knowledge is subject to ongoing developments and inquiries. Those with this competency are capable of identifying specific questions to support additional inquiry from both social and scientific domains.

(iv) *Exhibit scepticism when presented with potentially biased information.* This involves recognition that different stakeholders have different perspectives and interests and that evaluation of both the trustworthiness and sources of information is required (Kinslow, Sadler, & Nguyen, 2019).

In this study Sadler et al. (2007) examined 6th grade USA students' (aged 11-12; *n*=24) socioscientific reasoning competencies under the above four sub-constructs. Data indicated that the students demonstrated competencies related to each of these sub-constructs across four levels, with level four representing higher levels of mastery and level one representing low levels of same. The study concluded that future research would have to assess the perspective and scepticism aspects in different ways in order to provide useful data (Sadler et al., 2007). In addition, students' pre-intervention level of SSR was not assessed in this study. Therefore, conclusions pertaining to the impact of the intervention on students' SSR could not be reported.

In a subsequent USA study, Sadler, Klosterman and Topçu (2011) examined 14-16 year olds' SSR competencies after an intervention which encouraged students to consider the 'complexity', 'inquiry' and 'perspective' aspects of a SSI on global warming. Sadler and colleagues merged the 'scepticism' competency under the 'perspective' category. Two classes participated in the study with findings indicating that there was no statistical difference in the students' levels of SSR across the three sub-constructs from pre-intervention to post-intervention. The authors cited a number of plausible explanations for this including the short-term length of the intervention (3-weeks) and that only one SSI was used therefore students did not get an opportunity to apply their SSR skills to other contexts. Karahan and Roehrig (2017) in their study on SSR with secondary school students also found that long-term interventions were more effective than short-term at developing SSR competencies. A recent study by Cansiz (2014) suggests that an intervention length of 10-15 weeks may be necessary for students to make practical advances in their SSR competencies.

Findings from the above studies present mixed results and highlight the necessity of additional research in the field, focusing on long-term intervention (> 3 weeks) and a number of SSIs contexts (> than one context). Furthermore, current conceptualisations of SSR, for example ‘the value of ongoing inquiry’, ‘recognising the complexity of the SSI’, ‘approaching the SSI from multiple perspectives’, are likely to underrepresent the true range of activities that are associated with the negotiation of SSIs and further research exploring SSR sub-constructs is recommended (Karahan & Roehrig, 2017; Sadler et al. 2011).

2.4.6 Student-Led Citizenship

Discussion of the literature thus far has focused on the development of students’ science content knowledge, NoS understanding and inquiry skills followed by the application of this knowledge and skills to socioscientific reasoning and argumentation. Studies have found that that the development of socioscientific reasoning and argumentation enhances students’ ability to participate more actively as legitimate participants in discussions about scientific and technological innovation (Zeidler, Applebaum, & Sadler, 2011). SSIs-based curricula have also been positioned as vehicles for promoting active citizenship (Cajas, 1999; Davies, 2004; Kolstø, 2001; Zeidler et al., 2005). A large proportion of societal issues are related to science and therefore citizens require scientific literacy to participate fully in these discussions and make informed decisions concerning societal issues such as nuclear energy, climate change, genetically modified foods. According to Day and Bryce (2011) dealing with SSIs in the classroom enables students “to hold and defend informed views of social, moral, ethical, economic and environmental issues related to science” (p. 6).

Some educationalists take citizenship education in the context of SSIs a step further, beyond students developing a viewpoint on the issue; “It is almost always much easier to proclaim that one cares about an issue than to do something about it” (Hodson, 2010, p. 201). These researchers declare that the aim of science education should be the promotion of a certain type of civic action consistent with Vision III scientific literacy competencies (Aikenhead, 2006; Pedretti & Nazir, 2011; Levinson, 2010). For instance, Santos (2009) argues that we need to consider scientific literacy as a concept that should promote students' capacity and commitment to take appropriate, responsible and effective action on matters of social and environmental concern. Similarly, Hodson (1999, p. 789) asserts that:

> The ultimate purpose of science education should be to produce activists: people who will fight for what is right, good and just; people who will work to refashion society along more socially just lines; people who will work vigorously in the best interests of the biosphere.

Aikenhead (2006) agrees, considering social responsibility and students' practical actions as integral to science education. Furthermore, PISA, in its 2018 Framework for Global Competencies (OECD, 2018a) recommends that students should have opportunities to take “informed, reflective action and have actions heard” (p. 11). It is purported that through this “pedagogy of responsibility” (Martusewicz & Edmundson, 2005, p. 1), students develop a personal and community identity that enables them to actively reflect upon their lifestyles and consider their civic role and its impact on society (McInerney, Smyth, & Down, 2011; Smith & Sobel, 2014).

While the notion of promoting citizenship in science learning contexts is theoretically appealing, it remains a contentious issue. Pedretti and Nazir (2011) warn there is a fine line between indoctrination and empowerment when it comes to SSIs-based citizenship education. Bermingham and Calabrese Barton (2014) agree and claim that when students are asked to take participatory action, for example in public campaigns, the actions themselves are often mandated and little to no consideration is given to why such actions are required and how they should be carried out. Furthermore, mandating an action within a SSI may neutralise the complexity of the SSI in that it imposes particular behaviours on students; for instance, complex issues may be reduced to simple manageable solutions within a classroom context (Zafrani & Yarden, 2017). This goes against a fundamental principle of SSIs-based education whereby the issues are complex and ill-defined with multiple perspectives and multiple possible solutions (Sadler, 2011a). Others insist that SSIs-based education should focus on student development and not the promotion of pro-environmental attitudes or behaviours (Barko et al., 2011; Ling Wong, Tal, & Sadler, 2011). For example, Sadler (2011) draws a distinction between SSIs and environmental education with SSIs fostering “the development of individual learners and emergent communities of learners in terms of decision-making, participation in democratic processes, and reasoning" (p. 39); therefore, Sadler (2011) maintains that it is "… perfectly reasonable for students to participate in the unit [based on the SSI of global warming] and emerge with ideas not supportive of reductions in greenhouse gas emissions" (p. 40). Thus, while Levinson (2013) strongly maintains that 'empowerment' and 'action' be central component of SSIs, it is imperative that this action must be student-driven and not teacher imposed. The below studies illustrate how student-directed action can promote responsible civic action within community based SSIs (Barton & Tan, 2010; Roth & Lee, 2004).

Roth and Lee (2004) examined a three-year USA educational programme which involved middle-high school students (aged 12-13) learning science through participation in an environmental project on the water-related problems of one community. Parents, activists, scientists, graduate students, and other community residents participated in the programme which involved the students conducting field work, analysing data, consulting with experts and making community presentations on how the health of their local creek could be improved. The researchers found that activism on local science-related issues transformed not only the local community but also the identities of the participants themselves; many students who previously felt disenfranchised by science education actively participated in the community project (Roth & Lee, 2004). Based on their findings Roth and Lee (2004) maintain that science education should allow students to participate in legitimate ways in community life and this serves to bridge the gap between formal schooling and everyday life outside of school. Furthermore, they theorised, based on Lave and Wenger's (1991) community of practice model, that student participation in community relevant practice has the potential to set [all] people up for lifelong participation and lifelong learning in science. However, a follow-up study is required to add substance to this claim. In a similar USA study, Barton and Tan (2010) investigated the development of student agency (students aged between 10 and 14 years old) as part of a year-long programme on energy situated within their local community context. Barton and Tan (2010) found that students' participation in the activism component of the science programme deepened their desire to learn science. They argued that post-programme the students asserted themselves as Community Science Experts, who were knowledgeable about SSIs and capable of taking action based on this knowledge in their local community (Barton & Tan, 2010). This mirrors the student identity transformation in Roth and Lee's study (2004).

More recently Socio Scientific Inquiry Based Learning (SSIBL), a pedagogical framework which connects SSIs, inquiry-based learning and citizenship education, aims to support young people to make value-laden decisions which they then can enact (Amos & Christodoulou, 2018; Levinson, 2013; Levinson, 2018). As part of this project, Zafrani and Yarden (2017) investigated the development of two Israeli students' identities as activists as they participated in a high school project aimed at resolving the problem of global hunger. Zafrani and Yarden (2017) concluded that offering students' opportunities to develop their identities as science activists can support students' willingness to act responsibly through, and informed by, science. However, the findings of this study are limited by the small number of participants (two students).

Levinson (2013) argues that without an active citizenship component, SSIs-based education will remain a school simulation activity with preparation for action in the real world at the very least questionable. These studies provide some evidence that the negotiation of SSIs can therefore serve as a good learning context for the advancement of citizenship education as it encourages students to gain knowledge about current scientific dilemmas, their impacts on society, and to take a participatory and active stance toward these issues (Barton & Tan, 2010; Roth & Lee, 2004; Zafrani & Yarden, 2017). Additional studies are required to determine if the findings from these studies are relevant to different educational contexts.

2.4.7 Students' Attitudes towards School Science

Attitudes can be defined as the feelings that a person has toward an object based on his/her knowledge and beliefs about that object (Kind, Jones, & Barmby, 2007). Osborne, Simon and Collins (2003) assert that attitudes about school science can be translated to the level of enthusiasm about science, perception of school science and contribution to society. Along a similar line, Kerr and Murphy (2012, p. 627), assert that 'attitude' is multidimensional: there are emotional (such as belief about science), cognitive (which includes emotion) and action-tendency (behavioural intent or manifested interest) components. According to Blumenfeld et al. (2006) enthusiasm and motivation set the stage for cognitive engagement and leads to enhanced achievement by increasing the quality of cognitive engagement. A number of studies in the field of science education support this finding, indicating that positive attitudes towards school science correlates to students' positive commitment to science and promotes life-long interest and learning in science (George, 2006; Reid & Skryabina, 2003; Simpson & Oliver, 1990). In contrast, low levels of attitudes towards school science are likely to result in students' apathy toward the subject (Nieswandt, 2007).

Research in relation to primary school students' attitudes towards school science suggests that student attitudes decline as the students progress through primary school (Kerr & Murphy, 2012). Murphy and Beggs (2002) in their study of primary school students (*n*=1000) in Northern Ireland found that younger students (9 years old) had more positive attitudes towards science than older students (10-11 years old). Pell and Jarvis (2001) who conducted research with primary students aged 5-11 (*n*=800) in England also found that students' interest in science declined as they moved through the education system. Christidou (2011), who reviewed more than 100 studies, concluded that as students advance from primary to secondary education, students rapidly lose their interest in science and cease to see it as a viable option for their future. Tytler and Osborne (2012) suggest that student interest in science in formed by age 13. A report issued by the OECD in 2008, Encouraging Student Interest in Science and Technology Studies, identified the crucial role of positive contacts with science at an early age in the subsequent formation of attitudes towards science. Murphy et al. (2004) concur reporting that the decline in attitudes is less apparent when children are involved in practical, hands-on, science investigations/experiments. Findings pertaining to the positive impact of practical, investigative, hands-on work on students' attitudes towards science has been cited in numerous other studies (see Kerr & Murphy, 2012). In fact, Murphy et al. (2004) presented compelling evidence in their intervention study that practical and investigative work had a long-term (6 months after the intervention) positive impact on children's attitudes towards science.

From a RoI perspective, no study has been conducted which compares and analyses primary students' attitudes towards school science at the different class levels. However, studies do indicate that primary school students generally hold positive attitudes towards science (Varley et al., 2008; DES, 2012, TIMSS, 2015). It is evident from the most recent TIMSS cycle (2015) that extremely high percentages of the fourth-class children (aged 9-10 years) in Ireland who participated in TIMSS 2015 were positive about their instruction in science class (95%), reported engaging teaching in science (94%), were confident about science (82%) and liked learning science in school (89%) (Martin et al., 2016). However, in spite of this, national reports and studies are concerned that many Irish students find science irrelevant and insignificant in their lives (DES, 2016; Varley et al., 2008). For instance, in the latest TIMSS study (2015), 27% of students indicated that they did not see the relevance of school science to their everyday lives. There are also concerns that primary school children are associating science with 'cartoon' images of scientists where they perceive science as a lone pursuit where scientists often do not have any idea of the potential outcome of their investigation (Murphy et al., 2019). Kerr and Murphy (2012) also emphasised that children think about science in different ways and highlighted the importance of differentiating between out-of-school science and in-school science in attitudinal scales.

Many studies present evidence of the potential of SSIs to generate interest and enthusiasm amongst learners and enhance the relevance of science to their everyday lives (Blumenfeld et al., 2006; Dolan et al., 2009; Hong et al., 2013; Kolstø, 2001; Lindahl et al., 2011; Ottander & Ekborg, 2011; Sadler, Klosterman, & Topçu, 2011; Sadler & Dawson, 2012). However, a limited number of these are situated within a primary school context (Dolan et al., 2009; Evagorou, 2011; Hong et al., 2013). Dolan, Nichols and Zeidler (2009) investigated the use of SSIs to enhance middle school students understanding and engagement with scientific concepts in a

5th grade (aged 10-11) USA classroom. Students were asked to think critically, analyse and evaluate data, and engage in discussion and debate pertaining to controversial SSIs. Qualitative data revealed that the students displayed enthusiasm and creativity when dealing with SSIs, bolstering their learning and understanding of controversial SSIs. It is important to note that the focus of this study was one class and findings were self-reported by the classroom teacher.

Evagorou (2011) evaluated the impact of a SSI intervention (8 lessons) on primary school students' (aged 10-12; *n*=35) argumentation skills and experience of school science in Cyprus. In relation to students' experience of school science, Evagorou (2011) found that a SSI context served to engage and motivate the students throughout the intervention. The qualitative interview data indicated that various aspects of the intervention had a positive impact on the students: the use of handheld devices to gather data, working collaboratively in groups, opportunities to visit the pig farm. It is therefore unclear if it was the SSI itself 'should a pig farm be located in our local area?' or the pedagogies employed that served to enhance students' interest and motivation in this study. A USA study conducted by Sadler, Klosterman and Topçu (2011), concluded that it appeared to be the teaching methodologies (for example IBSE, opportunities for socioscientific discussion and debate), rather than the SSIs themselves that engaged the students.

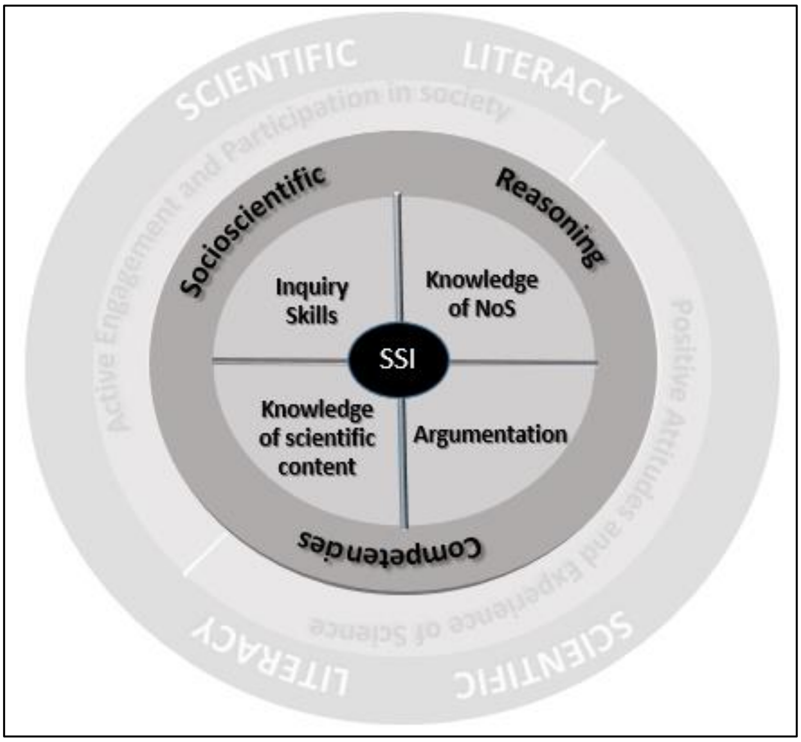
Using a similar research design as the above, Hong and colleagues (2013) investigated the impact of a 12-week SSI intervention on primary school students' argumentation skills and attitudes towards science in Taiwan. This large scale quasi-experimental study had 5th grade (aged 9-10) students (*n*=111) in an experimental group and 6th grade (aged 10-11) students (*n*=105) in a control group. Data showed that the experimental group had significantly higher attitudes towards science than the control group post-intervention. The students in the experimental group reported that they enjoyed the pedagogies employed (IBSE, hands-on science, use of internet to research the SSI, collaborative group work, discussion and debate) and stated that arguing about societal events enhanced their interest in science. However, the control group did not learn science during this intervention but instead worked on their homework or personal tasks. Therefore, it is difficult to see how the experimental group could be compared to the control group in this quasi-experimental study. Nonetheless, it appears from the limited number of studies above, that SSIs-based education has potential to connect science education to relevant real world issues, and either the issue or the pedagogical approaches underpinning SSIs has the potential to enhance students' interest in and attitudes towards school science.

2.5 Conceptual Framework

The conceptual framework underpinning this study theorises how scientific literacy can be achieved through the use of SSIs and associated pedagogies in a primary/elementary school context. It serves to unite the discrete variables examined in the literature above (Section 2.4.1-2.4.7) with the competencies of scientific literacy (Section 2.2.2) and presents an interdependent and reciprocal relationship between these variables and competencies. It conceptualises what is perceived to be a broad goal of science education into something attainable and measurable and relevant to the students' everyday lives. At the core of this framework are SSIs, see Figure 2.1.

Figure 2.1

Conceptual Framework underpinning this Study (Core Features)



The skills and knowledge depicted in the inner circle are the necessary building blocks for the development of socioscientific reasoning competencies, whilst the outer circle shows the societal aspects of scientific literacy and how an individual interacts with society. SSIs permeate the entire framework and serve as a conduit for the development of scientific literacy. Each component of the framework will now be discussed:

SSI. Central to this conceptual framework is a compelling SSI which must be both relevant to the students' everyday lives and align with the content of the Irish primary science curriculum (DES, 1999a). SSIs are complex social issues that relate to science. They are often ill-structured, open-ended problems which have multiple solutions (Dillon, 2009; Sadler, 2011a). The use of a relevant SSI has been proven to enhance student interest in, and promote positive attitudes towards, science education (Dolan et al., 2009; Evagorou, 2011; Hong et al., 2013). Furthermore, it has been found to bridge the gap between school science and science in society (Sadler & Zeidler, 2009).

Inquiry Skills. IBSE is widely accepted as an effective approach to developing science content knowledge and inquiry skills (Beernaert et al., 2015; Rocard et al., 2007). SSIs serve as authentic contexts upon which students' devise and investigate inquiry questions pertaining to a SSI. Students develop inquiry skills such as questioning, observing, predicting and communicating and the development of these skills has the potential to reciprocally enable students to evaluate and interpret data and evidence that they encounter in their everyday lives (Zeidler et al., 2009; Julien & Barker, 2009). Scientifically literate individuals need to be able to assess the validity, reliability, authenticity and legitimacy of the information or evidence provided (Vieira & Tenreiro-Vieira, 2016). Furthermore, the uncertainty and complexity of science-related issues highlights the significance of inquiry where individuals have the skills to seek evidence and knowledge pertaining to current and future SSIs (Zeidler et al., 2005).

NoS. In order to be able to engage in discussions and debates as a scientifically literate individual, a comprehensive understanding of the NoS is required (OECD, 2017). Students need to understand the tentative and subjective NoS and appreciate that science cannot provide answers to all questions. An understanding of the subjective NoS enables students to consider multiple perspectives on an issue and take into account science and non-science elements pertaining to a particular situation (Oh & Jonassent, 2007). Furthermore, scientifically literate individuals recognise the value of supporting arguments with empirical evidence (Khishfe, 2013).

Argumentation. Construction of arguments and engagement with socioscientific argumentation are key components of scientific literacy whereby scientifically literate individuals are competent at engaging with discussion and debate pertaining to SSIs that affect our everyday lives (Zeidler et al., 2005). The ability to support claims with evidence, construct counter-arguments and rebuttals is necessary to negotiate the multiple perspectives of a SSI and reach an informed-decision taking these multiple perspectives into consideration (Driver et al., 2000; Evagorou, 2011; Ratcliffe & Grace, 2003).

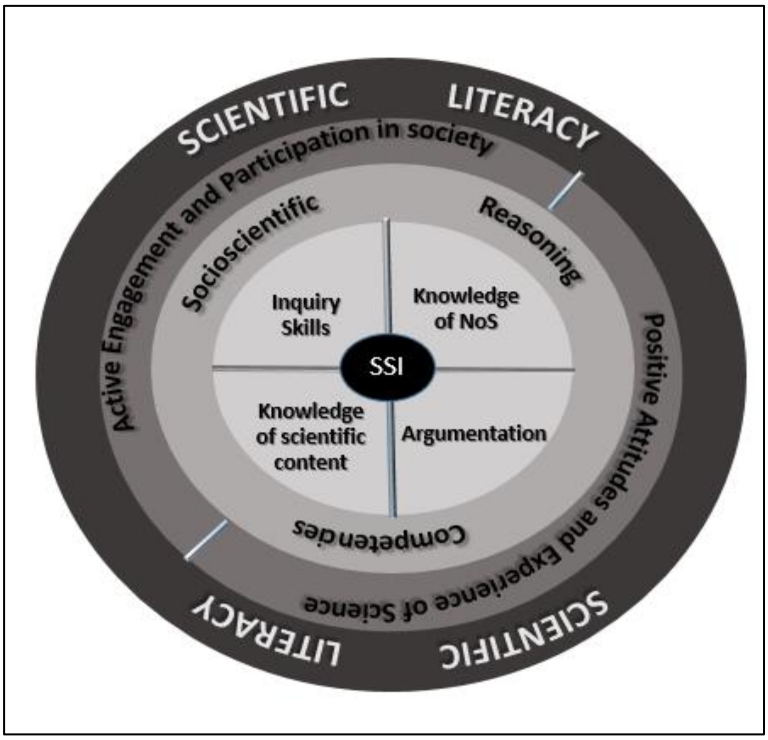
Socioscientific Reasoning. This consists of students' ability to make informed decisions pertaining to SSIs (Sadler et al., 2007; Sadler, Klosterman, & Topçu, 2011). Students apply knowledge and skills in the form of science content knowledge, NoS, argumentation and inquiry skills in order to recognise the complexity of an issue, appreciate the need for inquiry and recognise the multiple perspectives pertaining to the issue including ethical/moral/economic/environmental factors (Sadler et al, 2011). The accumulation of knowledge and skills promote the development of SSR and students' ability to make informed decisions pertaining to SSIs.

The outer circles illustrate the impact of the inner circle competencies on students' personal lives and engagement with society, see Figure 2.2:

Participation in Society. Students' experience with SSIs and associated pedagogies will prepare them for active participation in society where students are prepared to make informed decisions pertaining to issues of societal concerns such as climate change, biodiversity, social justice. Millar (1998) asserts that an individual requires a certain level of scientific knowledge and skills in order to be able to function in society. This could also encompass civic action where individuals take informed, responsible action regarding issues such as climate change (Levinson, 2018).

Figure 2.2

Conceptual Framework underpinning this Study (Societal Connections)



Positive Attitudes Towards and Experience of Science. This component is related to increasing an individual's well-being, lifelong learning and personal enjoyment of science in society. It also relates to Vision I scientific literacy where individuals could benefit through increased employment prospects. The relevant nature of SSIs has been found to enhance student interest and engagement with school science and science in their everyday lives (Sadler, 2011c). SSIs-based education will also develop students' appreciation of science and its role in everyday societal issues. Scientifically literate individuals (vision I, II and III) are not opposed to scientific and technological developments but neither are they naive or uncritically positive (OECD, 2013). They therefore evaluate media reports and participate in discussions about everyday science through a critical lens (OECD, 2015; OECD, 2018a). Scientifically literate individuals appreciate the beauty of nature and have been found to have a richer and more exciting view of science (DeBoer, 2000; Laugksch, 2000).

2.6 Learning Theories underpinning Conceptual Framework

The conceptual framework for this study was underpinned and informed by a variety of complementary science education learning theories including experiential learning and situated learning theories, and the work of constructivist educational theorists such as Dewey, Piaget, Kolb and Vygotsky.

2.6.1 Constructivism

The use of a SSI as a central component of the conceptual framework (Figure 4.2) is founded in the workings of constructivism. Many principles of learning "espoused in the [Irish] Primary Curriculum draw indirectly on aspects of constructivist learning theory…especially in science" (Loxley, Johnston, Murchan, Fitzgerald, & Quinn, 2007, p. 222). Constructivists champion a move away from the rigid approach of passive learning towards a more participatory model where children are encouraged to investigate, experiment and make their own sense of the world (Aubrey & Riley, 2016). Constructivism is based on the idea that people actively construct or make their own knowledge, and that reality is determined by your experience as a learner. John Dewey, an influential philosopher of constructivist heritage, argues that experience is critical to education. Dewey's philosophy emerged out of a concern that learning is often disconnected from everyday experience, alienating students as a result. He argued that experience can expand the understanding of concepts taught in the classroom and give 'real-world' connection and relevance to more traditional studies (Rone, 2008). Dewey saw education as a powerful force in peoples' lives and believed that learning is an active process and that tasks should be challenging and relate to real life, promoting learning through experiences and interactions. For Dewey "Anything which can be called a study, whether arithmetic, history, geography or one of the natural sciences, must be derived from materials which at the outset fall within the scope of ordinary life experiences" (Dewey, 1963, pp. 73-74).

2.6.2 Experiential Learning Theory

David Kolb's Experiential Learning Theory (ELT) is situated in Dewey's belief that education can be based on experience (Kolb, 1984; Kolb & Kolb, 2005). ELL utilises students' experiences to create new knowledge by making students face situations where their beliefs and ideas are challenged. In doing so, they are forced to examine their beliefs in order to develop more refined ideas on the topic. The resolution of the conflict between students' original beliefs and their more refined ideas is what drives learning (Kolb & Kolb, 2005). This is considered by constructivists to be key to learning with education beginning with what the student currently understands (Glasersfeld, 1995). The influence of these ideas can be seen in the primary science curriculum which describes how learners construct meanings by linking new ideas with their existing knowledge (DES, 1999). Likewise, the conceptual framework (Figure 2.2) underpinning this study aligns with Kolb's ELT, whereby students initially actively engage with the SSI through concrete experiences, are provided with opportunities to form observations and reflect on the experience. Within the framework, students discuss their ideas, opinions, empirical data and experiences with others whilst engaging in SSI argumentation. This promotes the development of the students' reasoning skills where they are encouraged to consider different perspectives and evidence related to the SSI. Thus the use of a SSI as a real-world context for science teaching and associated pedagogies align with the principles of constructivism and Kolb's ELT providing opportunities for meaningful personal growth and opportunities for the re-examination of values and worldview (Proudman, 1992).

2.6.3 Inquiry Based Science Education

Inquiry Based Science Education is a core principle of the framework underpinning this study that finds its antecedents in constructivist learning theories. It involves the use of authentic ill-defined open-ended questions or hypotheses formulated by students and teachers. Similar to relevant SSIs, scientific inquiries need to be based on student interests. Investigating a SSI using an IBSE framework, students design and conduct investigations that will provide empirical evidence to support student argumentation and reasoning. Dewey maintains that inquiry based learning begins with a "problem or obstacle to our development where we analyse the situation; we identify possible solutions; we compare the implications of the different solutions and we select the best course of action; we implement this in practice" (Dewey as quoted in Boydston, 1976, p. 15). In many ways the inquiry process, as described by Dewey, exemplifies the decision making process associated with SSIs. In addition, aligning with Vygotsky's social constructivism, learning through IBSE requires collaboration to deal with complex, multi-faceted problems. Perkins (1991) maintains that learning by cooperation or collaboration with other students becomes more efficient when the learning tasks are connected to the real world in which students are living.

2.6.4 Situated Learning Theory

Some have argued that SSIs-based learning and in particular socioscientific reasoning and argumentation aligns with Situated Learning Theory (Sadler, 2011). Situated learning as expounded by Lave and Wenger (1991) holds that learning should take place in an authentic context. In line with sociocultural learning theory and the work of Dewey, situated learning is a theoretical perspective which emphasises that learning can only be meaningful if it is embedded in a social, cultural and physical context. It should provide students with a learning environment that mirrors the culture and tools that are used in real life situations (Kozulin et al., 2003). In accordance with Situated Learning Theory, when individuals participate in environments and engage with the communities that form these environments they begin knowing and learning (Sadler, 2011). Correspondingly, community beliefs, identities, and students' lives outside the classroom affect students' interest in, attitudes toward, and motivation toward science (Lemke, 1990). Therefore, in order to participate more fully in 'communities of practice', learners must come to understand the cultural norms, rules of engagement and the standard operating procedures of that community. The term 'community of practice' describes a group who share a common interest and a desire to learn from and contribute to the community with their variety of experiences (Lave & Wenger 1991). For Lave and Wenger (1991), understanding learning in practice necessitates situating the 'person in the world' and making sense of how people become members of what they call 'socio-cultural communities' (Lave & Wenger, 1991, p. 52). This process leads to acquisition of increasingly sophisticated discourses specific to that community and corresponds to the development of identities enacted by the learner. In other words, in order for citizens to engage and make informed decisions about everyday SSIs, students must engage in capacity building. Levinson (2013), however, disagrees with this assertion claiming that SSIs that are dictated by the teacher/curriculum in a school context are unauthentic or simulation contexts and thus could not be considered situated learning in an authentic sense. Conversely, Sadler (2011) asserts that opportunities to engage in SSI discourse, debate and argumentation within an educational environment will provide students with opportunities to acquire increasingly sophisticated socioscientific reasoning capacities. Indeed, this is central to the goal of scientific literacy.

Social cultural learning theory is also a core learning theory underpinning this study. It promotes citizenship education and involves students in making informed decisions which they can then enact and contribute to a democratic society. Through this "pedagogy of responsibility" (Martusewicz & Edmundson, 2005, p. 1), students develop an ecological and community identity that enables them to actively reflect upon their lifestyles and consider their civic role and its impact to broader society (McInerney, Smyth, & Down, 2011; Smith & Sobel, 2014). This corresponds with John Dewey's (2007, p. 22) assertion in his seminal book, *Experience and Education*, that the establishment of a sound learning environment in which each student can become invested in a shared "social enterprise" is of fundamental educational importance.

2.7 Chapter Summary

This chapter provided an overview of how SSIs can be used to develop students' scientific literacy situated in a primary/elementary school context. It presented a definition that encapsulates scientific literacy and associated competencies. The current position of primary science education is outlined where Irish students were found to have positive attitudes towards science and are performing above the TIMSS (2015) centrepoint. Nonetheless there continue to be concerns over students' experience with IBSE, the disconnect between school science and the students' everyday lives, limited scientific skills development and naive understandings of NoS. These have significant implications for the development of students' scientific literacy. The emergence of SSIs and studies relating to SSIs-based education were examined especially in terms of constructs such as science content knowledge, NoS, argumentation, IBSE and SSR. The impact of SSIs on students' positive attitudes towards science and their role in fostering student-led citizenship is also discussed. The limited research available pertaining to SSIs and primary/elementary science education was highlighted. In addition, concerns regarding the suitability of SSIs-based education for a primary/elementary school context were raised. it is clear that there is a gap that this study addresses whereby the potential of SSIs and associated pedagogies to develop primary/elementary school students' scientific literacy is under-researched both nationally and internationally. In addition, much of the research available focuses on either one class, one SSI unit, over a relatively short period of time (e.g. 6-weeks). This study aims to investigate how SSIs can develop primary/elementary school students' scientific literacy competencies over a six-month period in seven primary classrooms. Findings from this study will present empirical evidence in support of the conceptual framework presented above. A detailed description of the research methods is provided in Chapter 3.

3.0 Methodology

The preceding chapters provided an overview of Irish primary science education, SSIs and its potential to develop primary school students' scientific literacy leading to the conceptual framework presented in Section 2.5. The research presented in this thesis employed a mixed-methods, multiple-site case study approach in which multiple types of data were collected. The aim of the research was to examine *to what extent do SSIs contribute to the development of children's scientific literacy within primary science education?* The potential impact of the Socioscientific Issues through the Primary Science Curriculum (SSIPSC) intervention on the development of upper primary school students' scientific literacy was operationalised in terms of the students' attitudes towards school science, their development of IBSE skills, development of science content knowledge, NoS, socioscientific argumentation and socioscientific reasoning. It was the accumulation of these constructs that were of interest in this study and how the students applied knowledge (science content knowledge, NoS), skills (IBSE, argumentation) and attitudes to engage in reasoned discourse and make informed decisions pertaining to SSIs as scientifically literate individuals. The research questions together with the research methodologies adopted in this study are presented in this chapter. Justification for a multi-site case study research approach underpinned by a mixed-methods research design is presented. Sampling procedures, qualitative and quantitative data collection methods and ethical issues pertaining to the study are discussed. Subsequently, the methods for data analysis are presented with issues of reliability and validly explored in detail. This chapter begins by providing a background to the research.

3.1 Background to Research

This study examined the impact of teaching primary science through SSIs on upper primary school students' scientific literacy in seven classes in seven different Irish primary schools. The teachers (*n*=7) who participated in the study are non-science expert teachers who taught SSIs through the Irish primary science curriculum over a six-month period from November 2018 to April 2019. These teachers had no experience of teaching primary science through SSIs prior to this study. The teachers participated in a professional learning course which consisted of a week-long (25 hours) face-to-face course in July 2018 as a Department of Education and Skills (DES) approved summer course[4]. The researcher both developed and delivered this professional learning course. During this course the teachers were introduced to SSIs, developed their understanding of SSIs and the pedagogies that support the teaching of SSIs. A number of SSIs relevant to the primary education context which aligned with the Irish primary science curriculum (DES, 1999a) were explored throughout the course. The teachers participated in inquiry based science education learning activities, engaged with explicit argumentation instruction, developed their science content knowledge and scientific inquiry skills, whilst also examining socioscientific reasoning within the context of relevant SSIs. The researcher modelled a multi-strand, cross-curricular approach to the teaching of the primary science curriculum through SSIs where consideration and negotiation of the different components of SSIs, i.e. scientific, social, economic, moral, were emphasised. Opportunities for the teachers to reflect on, and discuss their perception of the purpose of science education and previous teaching of science was a key feature of the programme of professional learning. A detailed overview of the content of the professional learning course can be found in Appendix A.

A programme was developed which aligned with the content of the professional learning summer course. The SSIPSC programme consisted of eight units, the same units examined in the professional learning course, and provided the teachers with an overview of each SSI unit: aims and objectives, resources, pedagogical support, details of science investigations and experiments and key discussion points. An overview of each SSI unit can be found in Appendix B. A typical unit from the SSIPSC programme was structured as follows: (1) Introduce a topic related to a SSI that is relevant to the students' everyday lives; (2) elicit students' prior knowledge on the SSIs; (3) small group discussion where students work collaboratively to generate inquiry questions and decide how to construct evidence-based conclusions; (4) hands-on investigations and/or research and/or field work; (5) present results; (6) justifications and debate on SSIs using evidence gathered; (7)

[4] Under rule 58 of the Rules for National Schools, teachers are entitled to Extra Personal Vacation (EPV) on foot of attending summer courses approved by the DES.

presentation of group conclusions. To provide an example, the SSIPSC unit on Bees and Biodiversity aligned with the Living Things and Environmental Awareness strands of the primary science curriculum (DES, 1999a). The students were presented with a number of headlines regarding the decline of bees in Ireland. In groups students analysed these newspaper headlines and devised inquiry questions. Typical questions posed included: Why are bees important? How do bees make honey? Why are bees in danger? Can we do anything to help? The students then engaged in a number of observations/investigations/outdoor activities to answer these inquiry questions. For example, the students observed bees pollinating in their gardens/school grounds; students devised models to represent the pollination process; students examined the food they eat daily and identified food in danger of decline should bees continue to decline; students examined different perspectives on the issue through the use of role cards and evidence. A sample unit from the SSIPSC programme can be found in Appendix C. Resources to accompany each unit were also provided in the form of PowerPoint presentations, articles for discussion, argumentation frameworks, online resources and investigation frameworks. See Appendix D for sample resources. Furthermore, a box of concrete resources was provided to each teacher to support the teaching of the unit (see Appendix E for description of these resources). It is important to note that the resources for the learning activities were differentiated for the $3^{rd}/4^{th}$ class and $5^{th}/6^{th}$ class participants. For instance, in Unit 1 where the students devised inquiry questions to investigate characteristics of kitchen paper, for example the absorbency of the kitchen paper, strength of the kitchen paper, the $3^{rd}/4^{th}$ class students investigated an inquiry question as a whole class in smaller groups whereas the 6^{th} class students devised individual inquiry questions in smaller groups. Therefore, while the $3^{rd}/4^{th}$ class investigated the absorbency/strength of the kitchen paper, the 6^{th} class looked at the effectiveness of the kitchen paper to clean different substances (e.g. oil, egg, baby food). Another 6^{th} class group investigated kitchen paper in terms of value for money. To provide another example, the evidence cards for Unit 3 Sugar Tax and the Digestive System were differentiated for the $3^{rd}/4^{th}$ class where the language of the cards was simplified and the number of evidence cards reduced. The content of the SSIPSC programme were piloted with four non-participating primary school teachers in four different schools to ensure their suitability for the primary school context. The SSIPSC professional learning course and accompanying SSIPSC programme will hereafter be referred to the SSIPSC intervention.

The teachers were provided with ongoing professional learning support for the duration of the 6-month intervention. A timeline and overview of this professional learning can be found in Appendix F. The characteristics of the SSIPSC professional learning programme aligned with 'best practice' professional learning as presented in Table 3.1. As part of the professional learning, teachers were asked to complete a reflective diary and engage in a discussion forum. These sources of data were not used by the researcher to answer the research questions but were considered to be key to supporting the teachers and promoting collaborative and reflective features of the professional learning.

In addition, a SSIPSC overview (Appendix G) and a six-month intervention schedule (Appendix H) was provided to all teachers. This provided details of each unit and key learning activities that had to be completed each month. This was intended to maximise consistency across participating schools. Such a schedule scaffolded the teachers in practically implementing the intervention and attempted to ensure instructional consistency among groups (i.e. same material was taught across all groups). This attempted to safeguard overall implementation fidelity throughout the intervention. These schedules were collected on a monthly basis by the researcher.

It is important to note that the impact of the SSIPSC intervention on the participating teachers' classroom practice, content knowledge and pedagogical knowledge are not the focus of this study. This research sought to focus on the students' learning and impact on students' scientific literacy. Notwithstanding, details of the pedagogical framework are provided in order to afford the reader contextual information for the current study.

Table 3.1

Characteristics of Best Practice Professional Learning aligned with SSIPSC Professional Learning Programme.

Characteristics of 'best practice' professional learning programme (Garet et al., 2001; Loucks-Horsley et al., 2003; Smith, 2014).	**Features in the SSIPSC professional learning programme**
Enhance teachers' content knowledge and pedagogical knowledge	The week long Professional Learning course focused on the development of teacher science content knowledge and pedagogical knowledge in term of IBSE pedagogy, argumentation and socioscientific reasoning.
Be on-going and sustained	Teachers (*n*=7*)* were supported throughout the 6-month intervention through discussion forums, regular email and telephone communication, group meetings and individual support in school. Teachers were contacted on a monthly basis.
Involve active engagement on the part of the participants	Teachers were required to actively engage in the programme through hands-on science investigations, field work, group discussions and daily reflections.
Be job-embedded	Teachers were provided with an opportunity to reflect and plan for their science class in the forthcoming school year. Teachers were provided with two in-class support sessions over the 6-month period.
Be collaborative and collegial in nature	Teachers were provided with opportunities to engage in collaborative group discussion throughout the face to face sessions. A discussion forum was set up to sustain the collaborative nature of the group over the 6-month intervention.
Encourage teachers to reflect on their learning	Teachers completed a reflective diary each day of the face to face summer course. Teachers were encouraged to continue to add to their reflective diary throughout the 6-month intervention.

3.1.2 Pedagogical Framework Underpinning this Study

Many prominent researchers in the field of SSIs and science education have developed pedagogical frameworks for SSIs instruction (Levinson et al., 2017; Presley et al., 2013; Sadler, 2011a; Sadler, Foulk, & Friedrichsen, 2017; Zeidler, Sadler, Simmons, & Howes, 2005). The pedagogical framework employed in this study synthesised key elements of previous SSI pedagogical frameworks (Levinson, 2018; Sadler et al., 2017) with the pedagogies underpinning the Irish primary science curriculum (DES, 1999a) and developed a framework for use in an Irish primary science education context and in particular this research study, see Figure 3.1. The four stages in the pedagogical framework, (i) encounter, (ii) engage, (iii) synthesis and (iv) action will now be discussed.

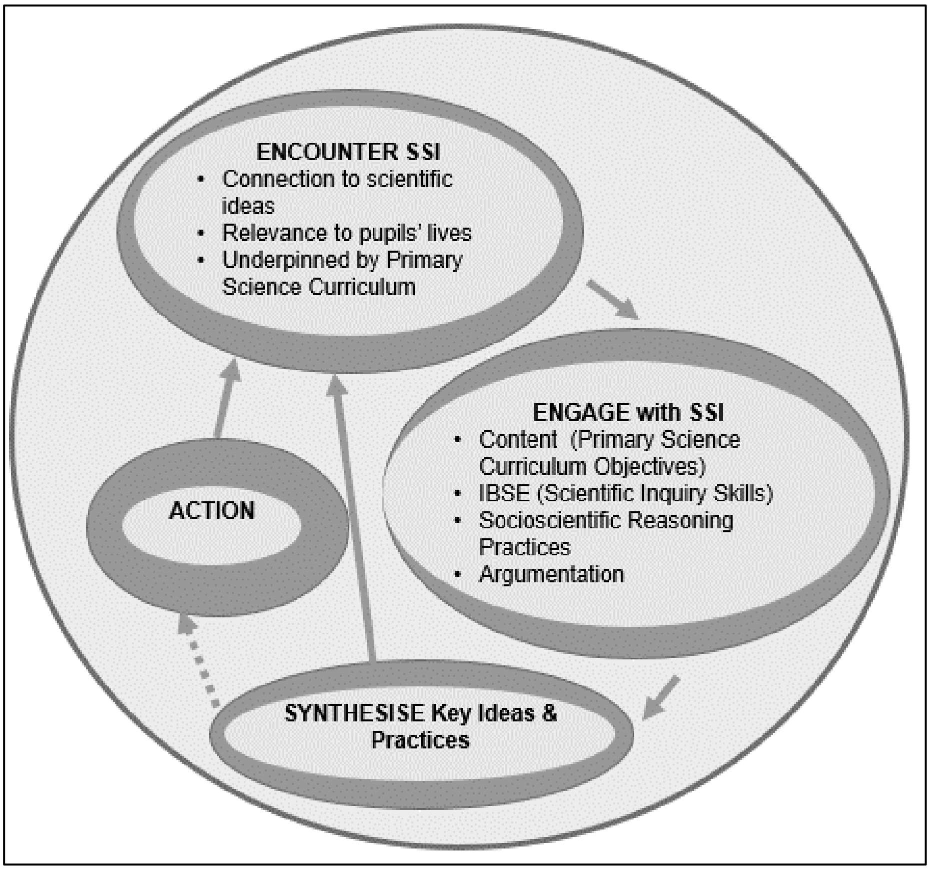
Encounter SSI. Consistent with other frameworks pertaining to SSIs (Levinson, 2018; Sadler et al., 2017) this framework began by introducing the students to a relevant SSI. Students were made aware of the scientific aspects but also social issues which permeated the issue (Sadler et al., 2017). The SSI was relevant to the students' everyday lives and complex in that there was no 'one' correct solution. Similar to Levinson's et al.'s (2019) framework the students were provided with opportunities to ask inquiry questions regarding the authentic SSI, at a personal, social and global level, which guided the teaching and learning in the next stage.

Engage with SSI. Here, the students engaged with the SSI. Students needed to gather and interpret evidence in order to make informed decisions regarding the authentic questions underpinning the SSI. As per Sadler and colleagues (2017) and Levinson et al.'s framework (2017), this phase was central to teaching and learning. The science content and pedagogical approaches at this stage were underpinned by the Irish primary science curriculum (DES, 1999a) with a key focus on the development of student content knowledge relating to the SSI, development of scientific inquiry skills through IBSE and development of understandings of the NoS. At this stage in the framework, students were provided with an opportunity to design and conduct investigations and gather and interpret empirical scientific and social evidence/data.

Synthesise Key Ideas and Practices. The third phase of this pedagogical framework corresponds with that of Sadler et al. (2017) where students were provided with an opportunity to synthesise key ideas and practices with which they have engaged throughout the unit (Sadler et al., 2017). Socioscientific reasoning and opportunities for the students to engage in argumentation were a central component of this phase. According to Zeidler and Sadler (2011), through opportunities to engage in SSI discourse, debate and argumentation, students acquire skills of reasoning and decision-making so that when they are faced with issues in the future they are equipped to take action as part of a democratic society.

Figure 3.1

Pedagogical Framework underpinning this Study (Adapted from PARISSE, Levinson et al., 2019)



Action. The final stage 'Act' empowers students to take action. This was employed in some SSIs and in some classes and is thus represented by a dashed line in this conceptual framework. This was not an original feature of the pedagogical framework but emerged retrospectively through analysis of the qualitative data, to be discussed in the findings section, Chapter 4. The 'Act' stage promoted citizenship education and involved students making informed decisions which they then enacted.

This pedagogical framework was employed by the teachers as they taught the SSIPSC programme over the 6-month intervention.

3.2 Operationalising Scientific Literacy and SSIPSC

For the purpose of this study scientific literacy is operationalised using the literature reviewed in Chapter 2 and the framework presented in Section 2.2.2. These were considered measurable constructs and suitable for a primary school context. Firstly, scientific literacy was considered in terms of science content knowledge, NoS, Inquiry skills and argumentation skills. The application of these to students' socioscientific reasoning competencies was then examined. Finally, students' level of interest in science and ability to actively engage and participate in society was considered. The accumulation of the above competencies was used to provide evidence of students' scientific literacy in this study. To operationalise SSIPSC in the research questions below, the SSIPSC refers to both the professional learning course and the SSIPSC programme which the teachers taught to their class over a six-month period. The SSIPSC intervention has been described in Section 3.1 and refers to both the SSIs and underpinning pedagogies.

3.3 Research Aims and Questions

The aim of this study was to examine to what extent teaching science through Socioscientific Issues had an impact on children's scientific literacy within the context of primary science education. More specifically the following research questions were addressed:

1. To what extent does SSIPSC contribute to developing primary school students' science content knowledge, NoS understanding, scientific inquiry skills and argumentation skills?
2. To what extent does SSIPSC contribute to developing primary school students' socioscientific reasoning?
3. To what extent does SSIPSC develop students' attitudes towards and perception of school science?
4. Did the SSIPSC intervention facilitate student-led citizenship?

It should be noted that research question 4 emerged retrospectively through thematic analysis of the qualitative data. This will be further discussed in Section 5.4.

3.4 Research Framework

3.4.1 Research Paradigms

Research is described as a systematic investigation whereby data is collected, analysed and interpreted so as to "understand, describe, predict or control an educational or psychological phenomenon or to empower individuals in such contexts" (Mertens, 2005, p. 2). A paradigm is essentially a worldview which comprises certain philosophical assumptions that set the value of research and guide and direct thinking and action (Denzin & Lincoln, 2011; Hesse-Biber & Leavy, 2008; Guba & Lincoln, 1994, 2005; Mertens, 2015; Treagust et al., 2014). Research studies generally fall into one of three paradigms; positivism, interpretivism and pragmatism (Creswell, 2008). Table 3.2 provides an overview of each paradigm along with their ontological, epistemological, axiological and data collection associations.

With reference to Table 3.2, positivism is concerned with objectively measuring social phenomena while interpretivism is based on the belief that social reality is shaped by our perceptions. From a positivist's perspective, reality is stable, can be measured using quantitative methods and then generalised to the larger population (Cohen et al., 2011). Interpretivism, on the other hand, involves studying phenomena in their natural environment in order to make sense of the phenomenon and the meanings people assign to it (Denzin & Lincoln, 2005). Interpretivists are not concerned with generalisations but with producing rich thick descriptions in order to truly understand the situation under investigation (Collis & Hussey, 2009). Therefore, positivism and interpretivism are often referred to as polar opposites whereby both are underpinned by contrasting epistemological and ontological assumptions. The period where commentators viewed qualitative and quantitative research as based on incompatible assumptions (circa 1975-1995) is referred to as the 'paradigm wars' (Creswell & Plano Clark, 2011; Hammersley, 1989; Oakley, 1999) where the dominant positivist paradigm and quantitative approaches with an emphasis on scientific objectivity (Creswell, 2014; Robson, 2011; Thomas, 2009) was pitted against the interpretivist paradigm and qualitative approaches which rejected objectivity and theory testing (Denzin & Lincoln, 1994; Guba, 1990; Tashakkori & Teddlie, 2003).

Table 3.2

Overview of Research Paradigms

Paradigm	**Positivism**	**Interpretivism**	**Pragmatism**
Ontology: the researcher's view of the nature of reality or being	External, objective and independent of social actors	Socially constructed, subjective, may change, multiple	External, multiple, view chosen to best answer research question
Epistemology: the researcher's view regarding what constitutes acceptable knowledge	Only observable data can provide creditable data. Focus on causality and law like generalisations, reducing phenomena to simplest elements (Creswell, 2007)	Subjective meanings and social phenomena. Focus upon the details of the situation and the reality behind these details (Harrison et al., 2017)	Either both observable phenomena and subjective meanings can provide acceptable knowledge dependent upon the research questions. Focus on practical, applied research, integrating different perspective to help interpret the data (Creswell, 2007)
Axiology: the researcher's view of the role of values in research	Research is undertaken in a value free way. The researcher is independent of the data and maintains an objective stance (Cohen et al., 2011)	Research is value bound. The researcher is part of what is being researched and cannot be separated and so will be subjective (Cohen et al., 2011)	Values play a large role in interpreting results. The research adopts both objective and subjective points of view (Cohen et al., 2011)
Data collection techniques associated with paradigm	Highly structured, large sample, measurement. Quantitative data collection methods (Creswell, 2007)	Small samples, in-depth investigations (Creswell, 2007)	Mixed or multiple method design with both qualitative and quantitative data collection methods (Creswell , 2007)

The author of this thesis agrees with Morgan (2007) and Duffy (2007) who question the value of engaging in the paradigm debate, considering it merely a philosophical exercise. This study therefore views qualitative and quantitative approaches as part of the same continuum (Butt, 2010; Lund, 2005; Onwuegbuzie & Leech, 2005; Tashakkori & Teddlie, 1998; 2003) and takes a pragmatic approach to research. As Cohen, Manion and Morrison (2018, p. 9) point out, to consider paradigms "as mutually exclusive is to prolong the unnecessary paradigm wars". The pragmatic paradigm focuses on 'what works', and 'what works' enables one to understand, research and solve a problem (Creswell, 2010). It rejects dogmatism which in turn affords the researcher flexibility and freedom to select the paradigm(s) most appropriate to answer the research question(s) under investigation. Pragmatism opens the door to different worldviews, and different forms of data collection and analysis (Creswell, 2007; Johnson & Onwuegbuzie, 2004). Furthermore, it legitimises the use of multiple methods to answer the research question and is not constrained by the parameters of a particular paradigm. However, a pragmatic paradigm is not without its shortcomings. It is often criticised for neglecting philosophical assumptions such as ontology and epistemology (Mertens, 2015). Therefore, the researcher's epistemological and ontological positioning is presented next in order to orientate the reader to the process of the research and provide a framework to ensure the research questions and design align with the epistemological position chosen (Creswell & Poth, 2018).

In this study, the researcher's world view aligns with interpretivism where it is acknowledged that meaning does not exist on its own but is constructed through the interactions between human beings and the interpretations that they make (Robson, 2011). For the researcher the subject of the research cannot be separated from the context with in which it is bound; this speaks to the theoretical underpinnings of SSIs where science education is seen as bound within the SSI context and the science content should not be 'extracted' from this context (Sadler, 2011a). Conversely, the rigour and systematic approach of positivist research design is highly valued and appreciated by the researcher: If findings of this study are to be used to support curriculum development as indicated in Chapter 1, then a rigorous data collection process is fundamental to support change at a systematic level. Maxcy (2003) suggests that pragmatism, "… seems to have emerged as both a method of inquiry and a device for settling of battles between research purists and more practical-minded scientists" (p. 79). Therefore, pragmatism enabled the researcher in this study to combine interpretivism and positivism, allowing one to use "… all approaches available to understand the problem", rather than relying rigidly on specific research methods (Creswell, 2009, p. 231).

3.4.2 Case Study Research Design

A case study is one of several ways of doing research whether it is social science related or socially related, because its aim is to understand human beings in a social context by interpreting their actions as a single group, community or a single event: a case (Thomas, 2011). Case study research can be described as a form of inquiry most suitable for a comprehensive, holistic and in-depth investigation of a complex issue in real contexts (Creswell, 2014; Merriam, 2009; Robson, 2011; Stake, 2006; Yin, 2014). Indeed, Cohen et al. (2011) determined that one of the strengths of case study is that they observe effects in real contexts, recognising that context is a powerful determinant of both cause and effect. Yin (2003) asserts that case study research can be useful depending on the type of research question posed, the extent of control an investigator has over actual behavioural events, and the degree of focus on contemporary events (as opposed to historical). According to Yin (2009), "the more your [research] questions seek to explain some circumstance the more that case study method will be relevant" (p. 4).

Case study was deemed suitable for this research study given the researcher's desire to examine how and why teaching science through SSIs impacted/did not impact children's scientific literacy. In addition, this research was set in a primary school context where multiple variables exist which could not be controlled and where control of such variables would have compromised the integrity of the research. This is considered one of the strengths of case study research in that the investigator "can analyse qualitatively complex events and take into account numerous variables precisely because they do not require numerous cases or those for which well-defined data sets already exist" (George, 1979, p. 39). Finally, the fundamental goal of this case study research was to conduct an in-depth analysis of the SSIPSC intervention which focused on contemporary real-life issues (Merriam, 2009; Stake, 2006; Yin, 2014). Thus case study design was considered appropriate for this study, where both outcomes of the SSIPSC intervention, (the what) and the process (how the outcomes were achieved) were of interest to the researcher.

Decisions regarding which case study design to employ was determined by the research questions. Yin (1981) presented three basic categories of case studies: exploratory, explanatory and descriptive. These were considered and deemed not suitable for this study for the reasons outlined in Table 3.3:

Table 3.3

***Categories of Case Study Research* (adapted from Brown, 2008)**

Case Study Category	Description	Suitability for this study
Exploratory	An exploratory design tends "to tackle new problems on which little or no previous research has been done" (Brown, 2006). It assists in generating new ideas for subsequent research (Yin, 2014).	Analysing the literature available on SSIs in a primary/elementary context, there is limited research available but there is research available on SSIs in a secondary and tertiary context. However, exploratory research is often intended to be a precursor for further research rather than a study in its own right. The aims of this study go beyond generating ideas for future research. **Unsuitable for this study**
Explanatory	The explanatory case study can be employed to test theories and hypotheses and set the stage for richer, more in-depth acquisition of knowledge.	This study aims to gather both quantitative data and rich, in-depth qualitative data. It is not intended to be a precursor for a qualitative study. **Unsuitable for this study**
Descriptive	Descriptive case study presents a detailed account of the phenomenon under study. For instance, a historical case study that chronicles a sequence of events (Yin, 2018).	Descriptive case study usually comes before hypothesising or theory testing. **Unsuitable for this study**

In recent years a new category of case study has emerged: evaluative case study (Mertens, 2018; Yin, 2018). Evaluative case study offers an explanation of the relationship between interventions and its outcomes within the contextual conditions of the case (INTRAC, 2017; Yin, 2018). Historically, case study is predominantly situated in the field of interpretivism and is discussed as a significant qualitative strategy or tradition (Cohen et al., 2011; Creswell, 2003; Guba & Lincoln, 1994; Mertens, 2010). In contrast, evaluative research is largely associated with strict experimental, quantitative and positivist research designs (Mertens, 2018). Combining both would therefore seem problematic from an epistemological perspective. However, according to Biesta (2010), experimental approaches are too reductionist for evaluation studies conducted in complex environments such as schools. Mertens (2018) acknowledges this and highlights concerns about the limitations of experimental research on its ability to know why certain interventions work/do not work. Thus, Yin (2018) presents evaluative case study research as an integral research method for programme evaluators, addressing the above concerns. Philosophically evaluative case study research can be orientated from a interpretivist or positivist position supporting the researcher's pragmatic worldview (Stewart, 2014; Yin, 2014).

3.4.3 Multiple-Site Case Study

A multiple-site case study was chosen for this research. The case in this context is the children (the class) and their teachers in the bounded context of their schools (Miles & Huberman, 1994). Whilst single cases are useful to confirm or challenge theories through normative case analysis, multiple-site case studies are advocated when trying to uncover cause or prevalence with an evidence base that is more compelling and robust (Herriott & Firestone, 1983; Yin, 2009; Yin, 2018). It was necessary to evaluate the SSIPSC intervention across different primary school contexts on the premise that understanding each individual case in a multiple-site case study would increase knowledge about the potential impact of the SSIPSC intervention on a larger group of cases (Stufflebeam & Coryn, 2014).

All schools in the counties of Dublin, Kildare, Meath, Wicklow and Louth were invited to participate in a face-to-face programme of professional learning in primary science education in

DCU. These counties were chosen given their proximity to DCU which was an important consideration for a face-to-face programme. The list of schools in these counties along with school email addresses are available on the Department of Education and Skills website. On 8th May 2018, an email invitation was sent to all schools in these counties inviting teachers to participate and provided an overview of the professional learning programme. Sixteen primary school teachers registered and participated in the programme of professional learning during the first week of July 2018. Upon completion of the programme of professional learning, all of the teachers (*n*=16) were invited to partake in this study. Seven of these teachers agreed to participate. This form of non-probability sampling is common in case study research where the focus is on an in-depth study of the sample rather than generalising to the population (Cohen et al., 2011; Stake, 1995; Yin, 2018). In fact, Yin (2018) contends that any application of a sampling plan to case study research would be misplaced. Cases cannot be considered sample units, thus they cannot be used to achieve a statistical generalisation (Yin, 2003). Therefore, while generalising to a population is not the aim of this study, combined analysis of the results from each case study site provided growing support for the efficacy of SSIs-based education in a primary science context. Table 3.4 illustrates participating school demographics.

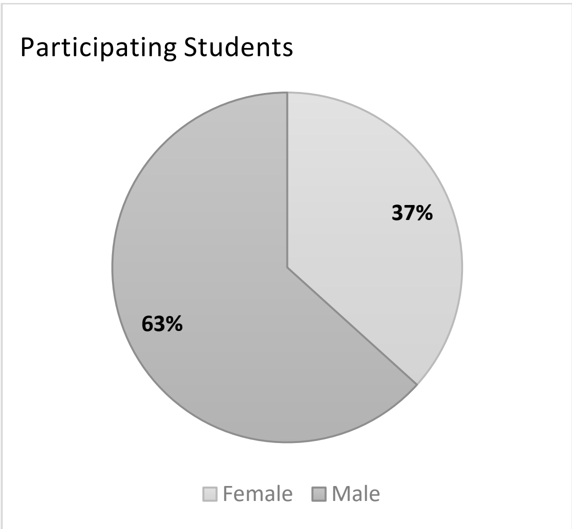
Table 3.4

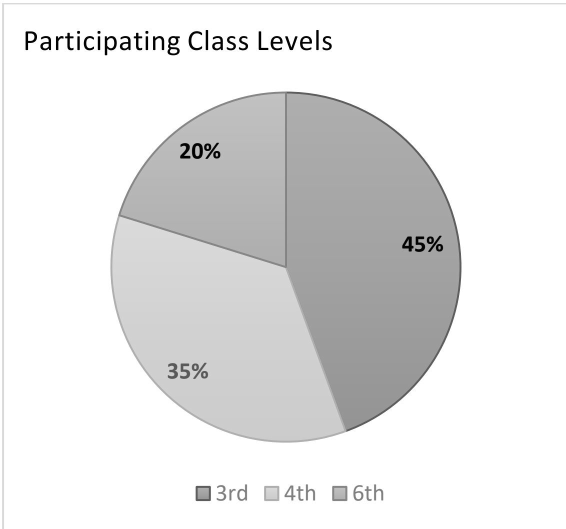
Participating School Demographics

Case	**Teacher**	**Class**	**Class Size**	**Gender**	**DEIS**
A	Teacher A	4th Class	28	Mixed	✕
B	Teacher B	3rd Class	32	All boys	✕
C	Teacher C	4th Class	28	Mixed	✕
D	Teacher D	6th Class	9	Mixed	✓
E	Teacher E	6th Class	23	Mixed	✕
F	Teacher F	3rd Class	13	Mixed	✓
G	Teacher G	3rd Class	26	Mixed	✕

The participating classes were situated across Dublin City with two schools categorised as Delivering Equality in Schools (DEIS)[5] schools. 158 students participated in this study. A higher proportion of male students participated as a result of the all-boys school. 45% were third class primary school students (8-9 years old), with 35% fourth class (9-10 years old) and 20% sixth class (11-12 years old), see Figure 3.2. In keeping with ethical guidelines, each case was provided with a pseudonym to protect their anonymity throughout the study. Hereafter, each of the of the participating classes will be referred to as a case: School A = Case A; School B=Case B; School C=Case C; School D=Case D; School E=Case E; School F=Case F; School G= Case G.

Figure 3.2 ***Overview of Student Participants*** **(*n*=158)**





3.5 Mixed Methods Research Design

Consistent with pragmatic philosophy, this research design was one that could "best frame, address, and provide tentative answers to one's research questions" (Johnson & Turner, 2003, p. 125). Accordingly, pragmatists usually begin with their research questions and from that determine their research framework (Johnson & Onwuegbuzie, 2004). This study was concerned with evaluating the impact of the SSIPSC intervention on the development of children's scientific literacy within primary science education. The nature of the constructs underpinning 'scientific literacy', concern measurements which are suited towards both quantitative and qualitative

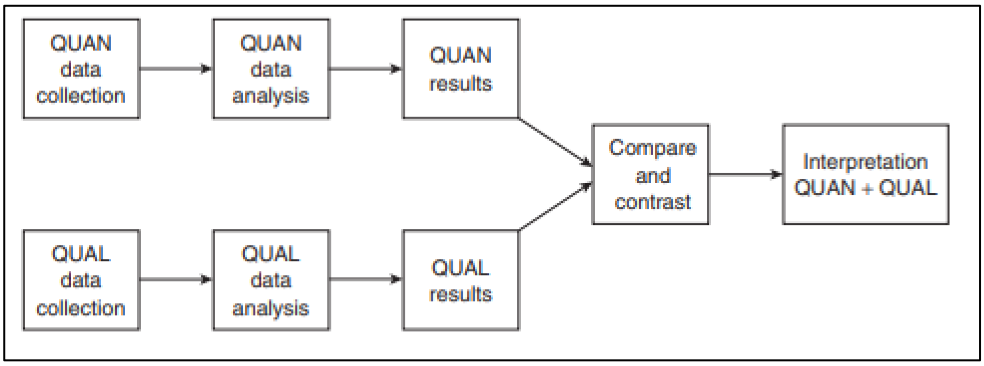
[5] The DEIS programme is aimed at addressing the educational needs of students from disadvantaged communities and includes both rural and urban schools.

methods. For instance, students' attitudes towards school science could be measured using an attitudinal measurement scale, however, qualitative data was necessary to provide a deeper understanding of the students' experiences of school science and the factors that affected their attitudes towards it. Additionally, students' science content knowledge could be measured using quantitative score data but this study is also concerned with students' ability to apply this content knowledge to SSI scenarios which is more suited towards qualitative methods. Therefore, the knowledge that was required to answer the research questions consisted of a mix of objective knowledge (measurement scales for students' attitudes towards school science, science content knowledge, conceptions of NoS, experiences of IBSE) and subjective knowledge (interpreting students' experiences of school science, their attitudes towards school science and their ability to engage in socioscientific reasoning). The use of two or more methods in a research study yielding both qualitative and quantitative data is referred to as mixed-methods (Creswell & Plano Clark, 2007; Greene, 2007; Teddlie & Tashakkori, 2006; 2009). Denscombe (2014) and Yin (2018) suggest that mixed-methods research can increase the accuracy of data, while incorporating the strengths of both approaches and simultaneously reducing the limitations of each approach; providing a more holistic picture of a phenomenon than would otherwise be possible. Mixed-methods case study design aligns with the researcher's pragmatic worldview, offering an epistemological justification for the use of a combination of quantitative and qualitative methods (Johnson & Turner, 2003).

Creswell (2012) stipulates that there are a number of factors which shape the selection of a mixed-methods research strategy: timing, weighting and mixing. In this study the qualitative and quantitative data was collected simultaneously both at the initial and exit stages of the intervention, see Figure 3.3. Thus this study is characterised as a concurrent mixed-method design, commonly referred to as a 'triangulation design' (Creswell, Plano, Clarke, Gutmann, & Hanson, 2003), where the purpose is to gather different but complementary data on the same topic (Morse, 1991). Both the quantitative and qualitative research data were given equal status and weighting in this research study as both objective and subjective data were necessary to answer the research questions (Teddlie & Tashakkori, 2006). Finally, the mixing of data in this study occurred at data analysis stage where the qualitative data was used to corroborate and add depth to the quantitative findings. Cohen et al. (2018) note that mixed-method research involves not only the mixing of data but mixing paradigms and ontologies in order to generate a more accurate picture of the phenomenon under investigation.

Figure 3.3

Triangulation Mixed-Methods Research Design



3.6 Data Collection Instruments

The quantitative and qualitative data collection methods adopted in this study included pre and post-intervention student questionnaires, student focus group interviews, student practical skill assessment and post-intervention teacher interviews. A questionnaire was chosen as the most effective method to gather data from a large population (*n*=158) where all students would be presented with the same questions. The focus group collected students' thoughts on primary science education, the SSIPSC intervention and provided the researcher with an opportunity to analyse students' argumentation and socioscientific reasoning skills. Students' performance based assessment was a practical method to assess development of students' scientific inquiry skills while the teacher post-intervention interviews were an effective means to gather the experiences and beliefs of the participating teachers. Table 3.5 presents the research questions and corresponding data collection methods.

Table 3.5

Research Questions and Corresponding Data Collection Instruments

Research Questions	Data Collection Instruments
1. To what extent does SSIPSC contribute to developing primary school students' science content knowledge, NoS understanding, scientific inquiry skills, and argumentation skills?	• Student Questionnaire (Consisting of measurement scales: attitudes towards school, attitudes towards school science, experience of IBSE, conceptions of NoS; open question). • Practical Inquiry Skill Assessment. • Student Focus Group Interview • Teacher Interview
2. To what extent does SSIPSC contribute to developing primary school students' socioscientific reasoning?	• Student Focus Group Interview • Teacher Interview
3. To what extent does SSIPSC develop students' attitudes towards and perception of school science?	• Student Questionnaire • Student Focus Group Interview • Teacher Interview
4. Did the SSIPSC intervention facilitate student-led citizenship?	• Student Focus Group Interview • Teacher Interview

3.7 Pilot Study

In order to maximise the validity and reliability of the data collection instruments a pilot study was undertaken. Oppenheim (1999) advises that piloting increases the validity and practicability of research instruments. Further discussion pertaining to issues of validly and reliability will be presented in Section 3.13. The students' questionnaire, student focus group questions, student practical skill assessment and teacher semi-structured interview questions were piloted with students and teachers who were not participating in the study as advocated by Cohen et al. (2011).

Student Questionnaire. Eighty-five primary school students in three different classes (3rd, 4th and 6th class) completed the questionnaire during the pilot phase. The researcher monitored the students completing the questionnaire and checked for clarity of questions, layout, length, commonly misunderstood or non-completed items. A small group of students (*n*=5) in each class explained their written answers to allow the researcher to check comprehensibility of content and language. This provided feedback on possible ambiguities (Mertens, 2015) and resulted in one question being deleted. Data from the pilot questionnaires were then collated and input into Statistical Package for the Social Sciences (SPSS) Version 25, with Cronbach's alpha used to determine the internal consistency or reliability of the questionnaire scales (Pallant, 2016; Tabacknick & Fidell, 2013). Cronbach's alpha determines whether or not the items in a scale consistently reflect the construct being measured (Pallant, 2016; Tabachnick, & Fidell, 2013). DeVellis (2012) and Pallant (2016) suggest that the reliability level is acceptable at 0.67 or above. A Cronbach's alpha of above 0.7/0.8 was reported for each scale indicating that the questionnaire had an appropriate level of reliability to support its use in this study.

Student Focus Group Questions (including SSIs scenarios). The focus group questions were piloted with a randomly selected group of students (*n*=5) from each of the 3rd, 4th and 6th classes who completed the pilot questionnaire. These pilot focus group interviews were recorded and transcribed. Analysis indicated that the students interpreted the questions as intended indicating a high level of construct validity. Minor adjustments were made to the SSIs scenarios to ensure that the language was accessible to all students in the sample.

Practical Skill Assessment. Preliminary versions of each skills assessment were piloted with the 3rd class (*n*=5 students) and 6th class (*n*=5 students). The scoring rubric as devised by Kilfeather et al. (2007) was used to analyse students' scientific skills. After piloting, the skill assessments were adapted to allow for a more child-led approach to scientific inquiry. For instance, the diagram used to illustrate the investigation in Kilfeather et al.'s (2007) iteration was removed as it was found to inhibit the students' creativity when it came to designing an investigation to answer the research question.

Teacher Semi-Structured Interview. The questions were piloted with a non-participating teacher and minor adjustments were made

3.8 Quantitative Research Instruments

The quantitative research instruments measured developments in the students' content knowledge, NoS understanding, experience of IBSE and attitudes towards school and school science pre and post the SSIPSC intervention. These were considered key competencies of scientific literacy and were central in the conceptual framework underpinning this study, see Figure 2.2. The qualitative research instruments, discussed in the subsequent section, were used to add depth to the quantitative findings and provided more comprehensive, holistic answers to the research questions underpinning this study.

3.8.1 Students' Questionnaire

Class teachers (*n*=7) administered the questionnaire (Appendix I) to the students (*n*=158) in the class setting. Each teacher followed detailed protocols for questionnaire administration (Appendix J). The questionnaire was administered to all students (*n*=158) on two separate occasions, pre and post/before and after the SSIPSC intervention with a time interval of six months. Each questionnaire was coded with a unique code so comparisons pre and post the SSIPSC intervention could be made. For instance, the code A 01 referred to the case (School A) and student number (01).

The questionnaire consisted of four measurement scales, each of which have been used in previous studies in primary science education in a RoI context. See Table 3.6 for reference to these studies. The Cronbach's alpha coefficient was used to assess each scale's internal consistency for this study (Pallant, 2016). For the students' questionnaire a Cronbach alpha coefficient of >0.7 was reported for each scale indicating a high level of internal consistency. Furthermore, Confirmatory Factor Analysis (CFA) was used to confirm the construct validity of each of the scales, see Appendix K. Each of these scales will now be discussed.

Attitudes towards School and School Science Scale. Kerr and Murphy (2012) emphasise the importance of using a mixture of quantitative and qualitative instruments to measure primary students' attitudes towards school science. The quantitative measurement instrument is discussed here, with the qualitative approach discussed in Section 3.9. Varley et al. (2008), in their national review of primary science in Ireland, devised an instrument which measured students' attitudes towards school and school science. More recently Smith (2014) adapted this instrument (Varley et al., 2008) to assess the impact of a programme of continuous professional development on primary school students' attitudes towards school and school science. It consisted of a four-point Likert scale questions with options ranging from strongly agree to strongly disagree. This instrument was adapted and used in this study with a high level of reliability reported (Cronbach's alpha >0.7, see Table 3.6). Furthermore, CFA was used to confirm the construct validity of the scale (Appendix K). Whilst there are other attitudinal scales available suitable for a primary school context (for example Jarvis & Pell, 2001; Murphy et al., 2004), the scale used has already been applied to a RoI context and was deemed to provide sufficient data to answer the research questions underpinning this thesis.

Table 3.6

Reliability of each Scale in the Children's Questionnaire

Scale	Cronbach's Alpha	Interpretation	Previous studies
Attitudes to school 3 item	0.798	High Reliability	Smith, 2012 Varley et al., 2008
Attitudes towards school science 4 item	0.723	High Reliability	Smith, 2012 Varley et al., 2008
Inquiry based approaches to science 9 item	0.862	High Reliability	Murphy et al., 2019
Nature of Science 6 item	0.706	High Reliability	Murphy et al., 2019 Murphy et al., 2012

Science Content Knowledge. Research in the field of SSIs recommends the use of a multi-distant approach to assess development of science content knowledge, i.e., proximal (aligned directly with the content of the programme/intervention) and distal forms of assessment (large scale national/international standardised assessment), in order to enhance the reliability and credibility of the findings (Klosterman & Sadler, 2010; Sadler et al.,2011). While this was considered for the current study, a standardised national test does not exist in an Irish primary science context. TIMSS is an international science assessment test at primary level, however this test is targeted at 4th class students which was not the only class participating in this study. Therefore, the researcher devised science content knowledge questions aligned with the content of the SSIPSC intervention and the Irish primary science curriculum (DES, 1999a). There were 10 questions in total; open ended questions, multiple choice questions and true/false questions. To ensure content validity, university lecturers in the field of science education assessed all items for correct representation of the phenomena.

Nature of Science. In 2019 Murphy and colleagues evaluated the impact of a teacher professional learning programme on primary students' NoS understanding using a NoS measurement scale adapted from Lederman et al. (2002). This scale consisted of Likert Scale statements related to 'general aspects' of NoS (namely nature of scientific knowledge, nature of scientific inquiry, science as a human activity) (Murphy et al., 2019). Murphy et al. (2019) presented findings to indicate that the scale had high levels of validity and reliability reporting a Cronbach's alpha value of greater than 0.7. An adapted version of this scale was used in the current study to assess students' conceptions of NoS prior to and post the SSIPSC intervention. A Cronbach's alpha of 0.71 was reported for the current study.

Experience of Inquiry Based Science Education. The IBSE scale has been proven a reliable scale for measuring the frequency of children's experiences of IBSE in a primary science context in the RoI (Murphy et al., 2019). This 4-point Likert frequency scale consists of 9 statements with responses ranging from 'very often' to 'never'. The scale was reported to have a Cronbach's alpha of 0.7 in Murphy and colleagues study in 2019 and a Cronbach's alpha of 0.86 for this study indicating a high level of reliability.

Argumentation. Socioscientific scenarios have been used in many studies to evaluate how students engage in argumentation within those contexts (Ratcliffe, 1996; Evagorou et al., 2012). Evagorou and colleagues (2012) devised a scenario, questions and analytical rubric to analyse primary school aged students' argumentation skills in response to a SSI in the UK: Should we kill the grey squirrels in order to save the indigenous red squirrel? The scenario (Appendix I) questions and rubric were adapted for this study. While Evagorou et al. (2012) devised the squirrel scenario for a UK context, the issue of the native red squirrel becoming extinct is also relevant to the Irish context. It was therefore, considered as relevant to the participating students in this study. The students were provided with an opportunity to respond to the above scenario in two formats both before and after the SSIPSC intervention. Firstly, the squirrel scenario was presented to the students as part of the student questionnaire. The students (*n*=158) were asked to respond to the scenario and give reasons to justify their answer. Each class teacher (*n*=7) read the scenario aloud and checked for student understanding. Students were also asked to respond to the above scenario as part of the student focus groups, to be discussed in Section 3.9.1.

3.8.2 Practical Skill Assessment: Scientific Skills

Performance-based Assessments (PA) are considered by many as an effective way for measuring students' science inquiry skills (observation, questioning, prediction, investigating, measuring, recording, communicating) (Kilfeather et al., 2006; NRC, 2012). In the literature, a PA is described as an assessment which relies on the observation and judgement of activities as they occur (Foster & Masters, 1996; Kilfeather et al., 2006). Such assessments usually have three components: a task that requires students to solve a problem or to conduct an investigation using concrete materials in a hands-on way; a response format that allows students to communicate their findings; and a scoring system that allows judgements to be made about students' ability to carry out or complete the task (Kilfeather et al., 2006). Furthermore, PAs are useful for charting progress over time since assessments tasks can be used more than once with the same student without compromising their validity (Kilfeather et al., 2006; Kruit et al., 2018).

A set of science inquiry PAs and scoring system embedded within the context of the Irish primary science curriculum was published by Kilfeather, O'Leary and Varley in 2007. Two PAs from Kilfeather et al.'s resource were used in this study. One PA was used pre the SSIPSC intervention whilst the other PA was used after the intervention. The PAs were comparable in that the students were asked to examine the relationship between two variables in both. In '*Down the Hill'* (Kilfeather et al., 2007) students had to investigate how the height of a ramp affected the distance travelled. In '*Stopping a car'* (Kilfeather et al., 2007) students had to examine how the material of a surface affected the distance the car travelled. Both PAs were equivalent in terms of scientific inquiry skills underpinning each PA. Data from the pilot study confirmed this. Furthermore, the same rubric was used to analyse students' scientific inquiry skills for both PAs. See Appendix L for sample PA.

Five students were randomly selected from each class to complete the PA. The same five students completed the pre and post practical skill assessment and the scoring rubric was used to assess the students' pre and post-intervention skill development. Analysing the students' skills in this manner provided opportunity for the researcher to score and analyse the students' work after the event had occurred. Furthermore, given that there are seven classes participating in this study, others have found that scoring based on written answers has proven to be a good alternative for real-time observation (Kruit et al., 2018; Ruiz-Primo, Baxter & Shaelcon, 1993; Solano-Flores et al., 1999).

3.9 Qualitative Research Instruments

Qualitative data was collected in the form of student pre-intervention and post-intervention focus group interviews and post-intervention teacher interviews. This data provided evidence to support the inner and outer circles of the conceptual framework presented in Section 2.5 and highlighted the intrinsic relationship between the competencies.

3.9.1 Focus Group Interviews

A focus group is "a group comprised of individuals with certain characteristics who focus discussions on a given issue or topic" (Anderson, 1990, p. 241). It consists of a small group of people, usually between six and nine in number, who are brought together by a researcher to explore attitudes and perceptions, feelings and ideas about a topic (Denscombe, 2007). Focus groups are recommended for use when interviewing children (Cohen et al., 2011) as they are deemed less intimidating for them and encourage interaction between the groups rather than a response to an adult's question (Bell, 2010; Cohen et al., 2011). The intention was that the students would interact with each other, listen to all views, and reach consensus about some aspect of the topic or to disagree about others (Bell, 2010; Watts & Ebbutt, 1987). This is especially pertinent for this study where providing students with opportunities to engage in discussion and debate pertaining to SSIs was required (Sadler, 2011a).

Focus group interviews are not without their constraints. Eder and Fingerson (2002) suggest that a power and status dynamic is heavily implicated when interviewing children; if students sense that their opinions or ideas are different to other members of the group, they are often inclined to change their views, or not speak at all (Bell & Waters, 2014). Cohen et al. (2011) refer to this as 'group think' where individuals who hold a different view are discouraged from speaking out in front of other group members. The researcher has significant experience conducting focus group interviews with children and has devised techniques of including all children in the focus group, preventing strong personalities dominating discussions and drawing silent members into the group (Bell, 2010). The researcher was also aware of the importance of establishing trust, keeping questions appropriate for the age group, asking open-ended questions, allowing wait-time and supporting the child to enjoy the experience (Cohen et al. 2011, p. 374).

The semi-structured nature of the focus group interview schedule (Appendix M) employed in this study allowed the researcher the flexibility to probe answers further and to use additional unplanned questions to address unforeseen comments that arose (Cohen et al., 2011). A group of five children from each of the participating classes were randomly selected to participate in the focus group interviews conducted by the researcher. Participating students were informed of their anonymity and their right to withdraw from the interview at any period. The same cohort of students was interviewed pre and post the SSIPSC intervention. Each interview typically lasted one hour broken into two 30 minute sections, A and B. Each focus group interview was recorded digitally and complete transcripts were produced.

Section A of the Focus Group Interview Schedule. Section A of the interviews was used to gather data on students' attitudes towards and experience of school science. Specific questions relating to attitudes towards school science were asked but students were given considerable freedom to talk about the topic and give their views in their own time (Bell, 2010). Students discussed what they liked about school science and what they did not like about school science with probing questions used to interrogate the types of science lesson the students had engaged with. Questions used in this section of the interview were based on children focus groups questions used in previous studies in a RoI primary science context (Smith, 2012; Varley et al., 2008; Murphy et al., 2019).

Section B (i): Argumentation. Each focus group (*n*=5 students) was presented with the same SSI scenario as the student questionnaire (Should we kill the grey squirrel to save the red squirrel?) (Evagorou et al., 2012). The students were asked to respond to the scenario in groups with the researcher asking probing questions where necessary. The use of this scenario in a focus group setting allowed the students to respond to each other and proffer their opinions on the scenario giving the researcher a broader insight into the students' argumentation skills and argumentation discourse. Details of scenario and prompts used can be found in Appendix M.

Section B (ii): Socioscientific Reasoning. Sadler et al. (2011) devised an SSR construct measurement tool, consisting of SSI scenarios, interview questions and analytical rubrics, which measured students' ability to demonstrate aspects of socioscientific reasoning: (i) appreciation of the complexity of the SSI, (ii) approaching the SSI from multiple perspectives, and (iii) the value of ongoing inquiry. An adapted version of the SSR construct measurement tool was used for this study. For instance, the scenarios employed in Sadler at al.'s study (2011) were devised for 6th grade students (11-12), thus the language of the scenarios was revised to ensure their suitability for the 9-12-year-old participants of this study.

Two socioscientific scenarios were used in this study to provide the students with opportunities to demonstrate socioscientific reasoning skills. Drawing on the studies of Sadler and others (Sadler & Donnelly, 2006; Sadler & Zeidler, 2005a; Sadler et al., 2007) the socioscientific scenarios comprised of written text accompanied by diagrams and pictures, followed by a series of questions (see Appendix M). The researcher read the scenario to the students and provided them with opportunity to re-read the text and examine the diagrams and pictures. When the students appeared to have a clear understanding of the scenario, the researcher posed a series of questions to elicit the group's perceptions of the SSR sub-constructs: 'appreciation of the complexity of the SSI', 'approaching the SSI from multiple perspectives', and 'the value of ongoing inquiry'. The students' responses were recorded and transcribed. The first scenario consisted of a bee keeper's problems with pesticide use. The second scenario concerned dilemmas regarding energy production and wind energy. The issues paralleled but did not replicate the SSIs students explored in Unit 4 and 5 of the SSIPSC intervention. The use of scenarios is recommended by Cohen et al. (2011) as they provide the students with opportunities to answer open-ended questions and are said to reduce the possibility of respondent bias where the children may be looking for cues as to how to respond.

3.9.2 Teacher Semi-Structured Interviews

Cannell and Kahn (1968) defined an interview as a "two-person conversation initiated by the interviewer for the specific purpose of obtaining research relevant information and focused by him on content specified by research objectives of systematic description, prediction or explanation" (p. 351). It was deemed important to get the teachers' perspective on the students' learning in primary science as a result of the SSIPSC intervention both to triangulate findings from the students' questionnaire and focus groups and to gain a deeper understanding of the answers to the research questions. Post-intervention semi-structured individual interviews were chosen because it provided opportunity for participants to make meaning of their own experiences, teaching and cognitive processes (Brenner, 2006). It was decided not to interview the teachers prior to the SSIPSC intervention as this study was focused on the process and outcomes of the

SSIPSC intervention. Furthermore, teachers were provided with opportunities to refer back to their previous experience of teaching school science in the post-intervention interviews where the participants deemed necessary.

A semi-structured interview guide (Bryman, 2016; Mertens, 2015) was created listing areas to be covered and more specific questions to be asked (see Appendix N**).** Prompts were added to each area but the main aim was to get the teachers' perspective rather than the researcher's perspective on the outcomes of the SSIPSC intervention; thus additional questions/prompts were kept to a minimum. Additionally, the semi-structured interview guide had the advantage of asking all informants the same core questions with the freedom to ask follow-up questions that built on the responses received (Brenner, 2006). The questions were delivered in order and followed a funnel approach as advocated by Wengraf (2001); that is the interview opened with general conversation style and worked towards details that were influenced by the literature and the research questions.

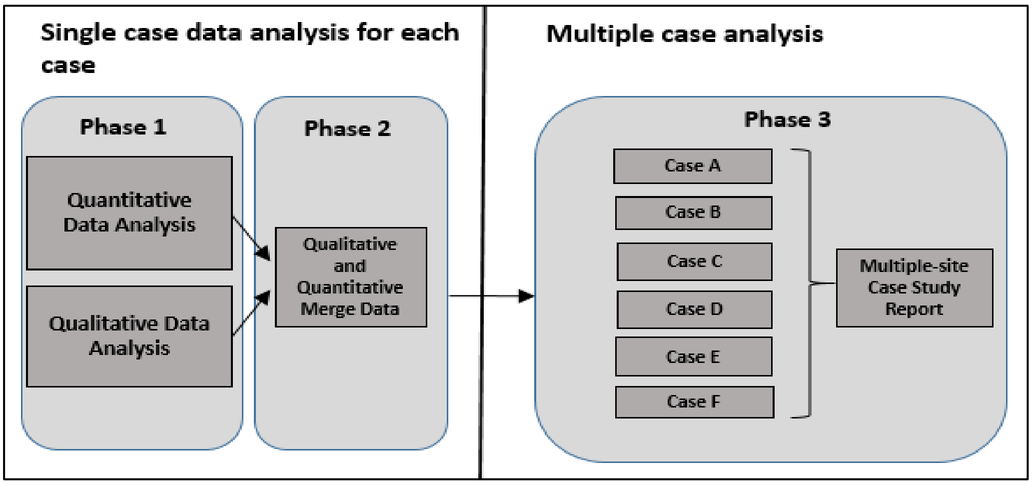
Six of the seven participating teachers agreed to participate in the semi-structured interviews which ranged from 30 minutes to one hour in duration. One teacher (Case F) declined to participate in the interview. The interviews were conducted on school grounds by the researcher. All participants were informed of their anonymity and their right to withdraw from the interview at any period. Each interview was recorded and transcribed.

3.10 Data Analysis

The data analysis process was conducted in three phases, see Figure 3.4. Phase one separately analysed the quantitative and qualitative data for each case. Phase two is where the qualitative data was embedded within quantitative data to help explain the outcomes of the SSIPSC intervention for each case (Creswell & Piano-Clarke, 2007). A sample individual case study report can be found in Appendix O. Phase three consisted of a cross-case analysis where data from each case was then analysed, compared and contrasted to the conceptual model underpinning this research study. Finally, a multiple-site case study report was devised. This multiple-site case study report is presented in Chapter 5. Phase 1 of data analysis will now be discussed.

Figure 3.4

Three Phase Data Analysis Procedure



3.10.1 Quantitative Data Analysis

Multiple sources of quantitative data were collected in this study including the measurement scales in the student questionnaire, categorisation of students' responses to the open-ended questions on argumentation and categorisation of students' responses to the socioscientific scenarios in the student focus groups. Quantitative data analysis pertaining to each of these will now be discussed.

Measurement Scales. Students' questionnaires were examined for completeness, accuracy and uniformity of questions answered (Moser & Kalton, 1977). The data generated was coded and analysed using SPSS Version 25. See Appendix P for SPSS codebook. The students' questionnaire comprised the 4 measurement scales described in Section 3.8.1. Two of these scales were attitudinal and measured students' attitudes towards school and school science prior to and after the SSIPSC intervention. Students recorded their attitudes on a 4-point Likert Scale to questions such as "I enjoy school science" and students' responses were input into SPSS with 1= strongly agree, 2= agree, 3 = disagree and 4 = strongly disagree. The NoS scale measured students' conceptions of the NoS on a 4-point Likert Scale and were input into SPSS as above. The fourth scale measured the frequency of students' experiences of IBSE pedagogies with questions such as "I plan my own investigations in science class". Students' responses to this scale were input as 1 = very often, 2=often, 3= a few times and 4 = never. The internal consistency for each scale was first measured using Cronbach's alpha (Pallant, 2016). Each scale produced a co-efficient >0.7 indicating that each scale has an appropriate level of internal consistency. The following statistical approach was then used to analyse the data across the four scales:

Raw data was input into SPSS. A total score for each scale was calculated for the pre-intervention data (Time 1) and post-intervention data (Time 2). For instance, a student's response to questions in the Attitudes towards School Scale, 'I like school', 'I find school interesting' and 'I enjoy doing school work' were totalled. Pallant (2016) suggests dividing the total scale score by the number of items in the scale for ease of interpretation, thereby calculating the mean (average) score for pre-intervention data and post-intervention data.

A histogram was used to analyse the distribution of scores across each of the scales. The data was not normally distributed thus non-parametric tests were employed in this study (Pallant, 2016).

A Wilcoxon Signed Rank test was used to check statistical significance and determine effect size between Time 1 and Time 2. A Wilcoxon Signed-Rank test was deemed appropriate for this study as it is used to compare two matched samples and assess whether their population ranks differ (i.e. it is a paired difference test) (Pallant, 2016). Using the output from the Wilcoxon Signed Rank test, the initial and post median score (the median is the value that cuts the distribution of scores in half) was recorded for each case. Since the data was not normally distributed the median score provided a more robust indicator of central tendency and was less sensitive to extreme scores (Pallant, 2016). The statistical significance of the difference between the pre and post-intervention score was also recorded; if $p<0.05$ then a statistically significant difference was reported.

The pre-intervention and post-intervention median scores were used to determine the direction of the difference. For example, in the attitudes towards school science scale, if the median score, post intervention, was closer to 1 then enhanced positive attitudes towards school science were reported.

An effect size provided a quantitative measure of the magnitude of the difference between the pre-intervention and post-intervention data (Bakker et al., 2019). The *p* value does not tell the reader how large the difference between the pre-intervention and post-intervention scores are; therefore, it has become preferred practice to report effect sizes in quantitative studies with APA Guidelines advising researchers to “always report effect sizes for primary outcomes” (p. 599). A sample of how the effect size was calculated can be found in Appendix Q. Cohen’s (1988) criteria were used to interpret effect size in this study with 0.1 - 0.29 = small effect size, 0.3 – 0.49 = medium effect size and 0.5 or more = large effect size.
The above statistical approach was repeated for the data of each scale.
See Appendix R for sample SPSS output

Analysis of the content knowledge questions in the students’ questionnaire was different to the above. There were ten questions in relation to content knowledge which included true/false, multiple choice and open questions. The questions were coded as follows: 3 for a correct multiple choice question (in multiple selection items, all items had to be correct); 3 for a correct true/false question; if the open question had two components to the answer then 1.5 was awarded for each component; if the open answer had 3 components to the answer then a score of 1 was awarded for each component. The scoring of the content knowledge questions did not allocate weighting to the different questions. Given that the questions or scoring rubric was not validated or standardised, the creation of a weighted rubric was not deemed feasible for this thesis. The purpose of the content knowledge questions was to identify a pattern in content knowledge development which was then substantiated by the qualitative student focus group interviews. Examples of content knowledge question and analysis can be found in Table 3.7. The scores for each of the ten questions were input into SPSS and a total score was calculated. A Wilcoxon Signed rank test was then used to compare Time 1 to Time 2. Statistical significance, the pre and post median score and Cohen’s effect size were used to interpret the data. Data pertaining to each case was analysed separately.

Table 3.7

Coding for Science Content Knowledge Questions.

Type of Question	Sample	Scoring Rubric
True/False	A **worker** is a male (boy) bee.	True = 3; False=0
Multiple Choice	Which of these materials can be separated using a sieve? Salt and water ◻ Sand and water ◻ Sugar and water ◻ Oil and water ◻	Sand and water = 3 Any other answer = 0
Open Question	Name 3 non-renewable sources of energy	Each correct answer= 1

Practical Skill Assessment. Each students' skill assessment was analysed using Kilfeather, O'Leary and Varley's (2007) validated skill assessment scoring rubric. A sample application of the scoring rubric to the students' skill assessment can be found in Table 3.8. Students' scores as per the rubric (Kilfeather et al., 2007) were recorded pre and post the intervention

Table 3.8

Practical Skill Assessment Scoring Rubric

Score	Working Scientifically Scoring Guide (Kilfeather et al., 2007)	Sample students' skill assessment under this category
Excellent	At least two factors for carrying out a fair test are identified (Q1) and applied during testing e.g. same size of material; car starting at same point. All measurements are made and recorded accurately. Interprets the data correctly by identifying the material that stops the car in the shortest distance (Q2).	Prediction supported "The higher the ramp the faster it will go because the gravitational pull is trying to pull the car to the ground". All fair test variables identified and controlled. Accurate measurement and interpretation of findings. Identified the material that stops the car in the shortest distance (bubble wrap). Informed follow-up questions "do thicker materials slow down the distance the car travels more?".

Table 3.8 (Continued).

Good	One factor for carrying out a fair test is identified (Q1) and applied during testing. Most measurements are made and recorded accurately. Interprets the data correctly by identifying the material that stops the car in the shortest distance (Q2).	One fair test variable identified and controlled. Some variable not identified. Prediction provided and supported. Accurate measurement, record and interpretation of results "bubble wrap slowed the car down".
Fair	One factor for carrying out a fair test is identified (Q1) but this is not applied during testing. One or two elements of the task are carried out accurately. Identifies a material, but it is not the one that stops the car in the shortest distance (Q2).	One fair test variables identified and controlled (Height of ramp). Prediction provided but not justified. Measurements not accurate (some recorded in cm some recorded in inches). Does not interpret measurements correctly.
Weak	Fair testing procedures are not identified or carried out. Measurements are not taken or recorded. Purpose of investigation is not understood. Student may identify a material in Q2, but this is not based on any data collected.	Student did not carry out a far test. Students did not identify or control variables. Measurement of distance travelled completed incorrectly. Data not interpreted correctly.

Open Ended Question: Argumentation Scenario. Students' written responses to the squirrel scenario in the open questionnaire were analysed using an adaptation of Evagorou et al. (2012)'s argumentation analytical framework. This framework was chosen as it has been proven effective for analysing primary school aged students' written argumentation responses and was built upon the principles of Toulmin's TAP framework (1958; 2003). Using Evagorou et al.'s framework students' responses were categorised according to the decision made and justification provided. Students' decisions were categorised into one of the following categories (i) Kill the grey squirrel (ii) Intermediate - Do not kill the grey but control the population and (iii) Do not kill the grey squirrel. Sample categorisation can be found in Table 3.9.

Table 3.9

Coding for Students' Decisions: Argumentation Scenario

Claim/Decision category	Quote
Kill	I think we should kill the grey squirrels and allow the red squirrels population to begin to grey
Intermediate	I don't think we should kill the grey squirrel. We should make a safe place for the red squirrels to live…a squirrel zoo.
Do not kill	I think we should let nature take its course and not interfere. It is wrong to kill one species to save another.

Students' justifications were then coded. Evagorou's et al. (2012) coding system was adapted and allowed for the students' justification to be categorised as rationalistic, emotive and no justification. Evagorou's et al. (2012) original rubric also included the following categories: 'emotive N' and 'intuitive'. 'Emotive N' or 'negative emotions' were defined by Evagorou et al. (2012) as "being consistent with the application of negative moral emotions. People that use this seem to care about their own well-being rather than that of others, or to be driven by feelings of antagonism" (p. 414). Emotive N was not a prominent feature of students' responses in this study and therefore was not included as a category. Furthermore, the 'intuitive' category defined in Evagorou et al. (2012) as "considerations based on immediate responses to the context of the scenario. It is an effective response but it is an unexplainable immediate reaction" (p. 13) was also omitted as it was difficult to ascertain from students' written responses when intuition played a role or not. See Table 3.10 for categorisation rubric used in this study. Of note, some justifications were coded into both rationalistic and emotive. The number of responses in each category were counted and compared pre and post the SSIPSC intervention.

Table 3.10

Coding for Students' Justifications: Argumentation Scenario

Code	Definition	Sample
Rationalistic	Describes reasoned calculations. These include applications of cost-benefit analysis, rational assessment and limitations of technology.	*I think they need to gather more evidence and go investigate more before they make a decision*
Emotive	Application of moral emotions such as empathy and sympathy. People that use this seem to care about well-being of others.	*No because it's not fair. The grey squirrel is cute!*
Both emotive and rationalistic	Could be categorised as both based on reasoning and on application of moral emotions	*No I like all animals and think it is wrong to kill any [emotive]. My approach to the situation is to keep the red squirrels in zoos and when they have loads of baby squirrels they can be released. It might take a while but it will be better than killing them [rationalistic].*
No justification	No reason given to support the decision	*Kill the grey squirrel*

Student Level of Argumentation. Student responses to the squirrel scenario in the focus group interviews were analysed using Erduran et al.'s (2004) analytical framework. This was deemed appropriate for the analysis of the dialogical argumentation of the student focus group discussions. Erduran et al.'s (2004) adapted version of Toulmin's Argumentation Pattern (TAP) framework was chosen for this study and was used to analyse each case's 'level of argumentation' pre-intervention and post-intervention. This analytical framework was used because it was applied by Evagorou (2011) and Osborne and Evagorou (2013) in a primary/elementary school context and thus deemed suitable for the current context where the participating students were of a similar age. Furthermore, while it may not be the most elaborate method to assess students' argumentation skills (Simon, 2008) with some such as Grimes et al. (2019) maintaining that Toulmin's framework captures some but by no means not all of the productive discourse, it was deemed sufficient for the current study where patterns in students' argumentation structures were required and the emphasis was on student output rather than an in-depth analysis of the students' argumentation skills. Furthermore, the use of levels in Erduran et al.'s (2004) framework overcomes difficulties in determining the difference between data, claim, warrant etc., a concern that has been cited by many who have used Toulmin's TAP framework (e.g. Naylor et al., 2007; Sampson & Clarke, 2008). The use of Erduran et al.'s (2004) analytical argumentation framework will now be discussed.

Five Level Argumentation Framework. Erduran et al.'s (2004) five argumentation levels were used to measure the quality of argumentation based on the theoretical principles of Toulmin's TAP framework. These argumentation levels and how they were applied to the students' focus group discussions in this study are described in Table 3.11.

Table 3.11

Coding for Students' Level of Arguments

Level	Description	Sample from Focus Group Interview
1	Arguments that are a simple claim versus counter claim or a claim versus a claim	*Pre-Intervention Case D* Student A: I think we should kill the red squirrel *[claim]* Researcher: Why do you think that? Student A: We just do. Student B: I think the same as X, shoot the grey one *[claim]*
2	Consists of claim versus claim with either data, warrants, or backings but which does not possess any rebuttals	*Post-Intervention Case A* Student B: I think we should leave it and it might sort itself out [claim]. There are other red squirrels in other parts of the world so they are not actually going extinct [warrant]. Student C: Ya I agree [claim]. If you kill the grey squirrel, they might go extinct. Nature should be left to sort it out [warrant].
3	Consists of a series of claims or counter claims with either data, warrant, or backings with the occasional weak rebuttal	*Post-Intervention Case E* Student B: I think we should kill the grey squirrel because it is carrying a disease that will kill the grey squirrel in two weeks [claim and warrant] Student C: What I disagree. There could be other reasons causing it. It's not fair to kill one animal to save another. Student B: I still think we should save our native animal. America has loads [counter claim and argument]

Table 3.11 (continued).

Level	Description	***Sample from Focus Group Interview***
4	Arguments with a claim with a clearly identifiable rebuttal. Such an argument may have several claims and counter claims	*Post-Intervention Case D* Student C: I think we should try and capture the grey squirrels and bring them to a different place like a sanctuary. That could give the red squirrels time to reproduce a bit more [claim and warrant] Student D: Well I see what you mean but the problem still isn't going away [rebuttal] Student C: I think scientists need to do an experiment about like what both species carry, what's causing it...they could try and make an antidote or something [claim and warrant]
5	An extended argument with more than one rebuttal	Students did not reach level 5 argumentation.

The following definition of components, given in Table 3.12, are required to interpret the above framework (Toulmin, 1985).

Table 3.12

Definition and Sample Application of each Element based on Erduran et al.'s framework (2004).

Element	Definition	Application
Claim	The conclusion whose merits are to be established or argument being made.	Answer to the question: For example Should the grey squirrel be culled to save the red squirrel?
Data	Evidence offered to support the claim.	Use of empirical data to include social/scientific/ economic/environmental data. Personal experience and/or generally accepted knowledge could also be included here.
Warrant	The reasoning that is used to justify the connections between the data and the claim.	Link between the data and claim. Logic used to convince that the claim is true.
Backing	Additional support, justification, reasons for backing up a claim.	Additional use of data to support the claim.

Table 3.12 (continued).

Element	Definition	Application
Qualifier	Specifies the conditions under which the claim is true and those under which it is not true. It may also include phrases that indicate the level of confidence in the claim, given the available evidence.	Critical statement for/against the claim. Should include conditions for which the claim holds.
Rebuttal	Refutation of a counter-argument.	Statement of doubt against a given claim. This should be supported with data/warrant/backing.

The students' pre and post-intervention discussions pertaining to the Squirrel Scenario were analysed based on this argumentation framework: see Appendix S for sample argumentation analysis. It is important to note that some have criticised Erduran et al.'s (2004) framework as it focuses on the structural component of the argument as a measure of argumentation quality, independent of the accuracy/relevance of the data students use to support the argument/warrant/claim (Dawson & Carson, 2020). In their review of different methods of analysis of students' socioscientific arguments, Sampson and Clarke (2008) emphasise the importance of using an analytical method which analyses both structure and content. In response to these concerns, Evagorou (2011) highlighted the necessity of analysing argumentation data based on the number of pieces of evidence used by the students to support their argument as a measure of the quality of the content of students' arguments, i.e. the greater number of pieces of evidence used to support an argument was an indicator of improvement in the content of the arguments. Evagorou (2011) felt that the use of this 'counting evidence' approach along with Erduran et al.'s (2004) framework would be a more comprehensive approach to measuring argumentation level. For this reason, the counting of evidence was used in the study in addition to Erduran et al.'s (2004) framework presented above (Tables 3.11, 3.12). The example taken from the students focus groups Case G demonstrates the necessity of this additional analytical parameter:

> "I think we should get rid of the grey one because I know the grey one doesn't realise what they're doing but they're killing the red squirrel and I think we need colourful squirrels not like natural grey ones" (Case G, pre-intervention).

> "I think we should try to protect the red squirrel because the red squirrel was in Ireland first. It's our native animal and it might become extinct. There are loads of grey squirrels in America so I think it's a bit more important to save the red squirrel" (Case G, post-intervention).

This example illustrates that pre-intervention Case G's response albeit empathetic justified removing the grey squirrel from Ireland because of a personal preference for "colourful squirrels". Post-intervention the group cited a number of pieces of evidence to support the decision to remove the squirrel including the possible extinction of the red squirrel and the necessity to protect native Irish animals. While this would have been categorised as level 2 argumentation in the pre and post-intervention analysis of the arguments, the level of evidence indicates a higher quality argument within level 2 post-intervention. The content of each groups' arguments was compared pre and post-intervention and the number of pieces of evidence used to support the argument recorded.

Socioscientific Reasoning. Sadler et al. devised an analytic rubric to analyse data pertaining to socioscientific scenarios in their 2007 study. This rubric was found to have a high inter-rater reliability, greater than 95% (Sadler et al., 2007). This rubric was revised in a 2011 study (Sadler, Klosterman, & Topçu, 2011). Sadler, Klosterman and Topçu's (2011) rubric was used in this study to analyse data pertaining to the students' socioscientific reasoning skills. Table 3.13 presents an overview of the rubric followed by a discussion on how it was applied.

In the 'approaching the SSI from multiple perspectives' category, level 1 practice represent students who were not able to examine an issue critically often providing no justification for their decision even when probed: “I think wind energy will work well [Student]. *Why do you think that?* [Researcher] Maybe the wind will blow the carbon dioxide away [Student]?”. At the highest level, level 4, students were able to assess the issue from multiple perspectives without being probed by the interviewer:

> Well then it’s still happening [climate change] even though you’re thinking ‘Oh look, I have an electric car that means I’m saving the world’ but really you need to make sure … like all the energy is coming from a solar panel or a wind turbine. But then some people can’t even afford electric cars, they’re too expensive.

Table 3.13

Coding for Socioscientific Reasoning

	Levels			
	1	2	3	4
Appreciation of the complexity of the SSI	Offers a very simplistic or illogical solution without considering multiple factors.	Considers pros and cons but ultimately frame the issue as being relatively simple with a single solution.	Construes the issues as relatively complex primarily because of a lack of information. Potential solution tends to be tentative or inquiry-based.	Perceives general complexity of the issue based on different stakeholder interests and opinions. Potential solutions are tentative or inquiry-based.
Approaching the SSI from multiple perspectives	Fails to carefully examine the issue.	Assesses the issue from a single perspective.	Can examine a unique perspective when asked to do so.	Assesses the issue from multiple perspectives.
Appreciation of the value of ongoing inquiry	Fails to recognise the need for inquiry.	Presents vague suggestions for inquiry.	Suggests a plan for inquiry focused in the collected on scientific or social data.	Suggest a plan for inquiry focused on the collection of scientific and social data.

Participants demonstrating the lowest level of inquiry did not recognise the necessity for additional information even when prompted to do so. These students asserted that they had all the necessary information to make a decision on the SSI scenarios. Examples such as “I think we have enough information” were common in this level. The highest level of practice were those students who recognised the need for scientific and social data to enable them to make an informed decision.

Sample socioscientific reasoning analysis can be found in Appendix T. The number of responses that were categorised in each level for each category were coded for each of the two SSI scenarios. The pre-intervention and post-intervention numerical data was then compared. This is considered deductive analysis where data is collected and explored in order to test a hypothesis derived from existing theory and literature in the field (Boyatzis, 1998; O’Reilly, 2009). Deductive analysis is criticised by some such as Robson (2011) for not adequately capturing how people actually think and respond to their environments in that the researcher bias may be imposed on the participants’ view of reality. However, the participants’ experience and voice was evident in the qualitative focus groups where unexpected themes emerged through the qualitative thematic analysis to be discussed in Section 3.10.2.

Quantifying Qualitative Data. There were a number of areas where the quantification of qualitative data was employed in this study. Quantification involves turning data from words or images into numerical data (Michelene, 1997; Smith, Jensen, & Wagoner, 2016). Interpretivist researchers may criticise the quantification of data suggesting that it sublimates the qualities that make qualitative data rich with narrative discussion and textual meaning however quantification in this study is used to support the thick rich descriptions and provide more information of simple frequencies and emerging patterns in the data (Cohen et al., 2018; Ward, 2010). Quantification of qualitative data under the themes of ‘children’s experiences of school science’ and ‘children’s science content knowledge’ were employed in this study. Clear descriptions of categories were provided with sample student responses under each category included to legitimise the quantification process. For instance, under the theme 'children's experience of school science' the sub- theme of 'teacher observation' emerged across a number of cases. The number of references the students made to science lessons which comprised teacher observation were then quantified adding significant information on the frequency of these types of lessons across all cases. This allowed this category to be compared pre and post-intervention using the qualitative data to substantiate the research findings.

3.10.2 Qualitative Data Analysis

Thematic analysis was employed as a means of analysing the student focus group interviews and teacher semi-structured interviews. Thematic analysis involves "identifying, analysing and reporting patterns (themes) within data. It minimally organises and describes your data set in rich detail" (Braun & Clarke, 2006, p. 6). Themes are patterns that exist in the data set and capture something important about the data in relation to the research questions (Braun & Clarke, 2006; King, Horrocks & Brooks, 2019; Robson, 2011). Braun and Clarke's (2006) six step approach to thematic analysis was employed in this study, see Table 3.14. NVivo, a qualitative data analysis research software aided data organisation and structured exploration of the data. Although each phase is presented in a linear manner, in reality the researcher moves back and forth between steps when analysing the data and reviewing findings (King et al., 2016; Nowell et al., 2017; Robson, 2011).

The qualitative data was transcribed, read and re-read. The researcher was immersed in the data, repeatedly reading the transcripts with a view to identifying patterns and taking observation notes throughout. 'Line by-line' (Bryman, 2016) analysis was conducted to ensure that the researcher did not lose contact with the participants' responses and the contextual settings. The data was then imported into NVivo 11.4. Within NVivo, each student focus group and each teacher interview was entered as a source. This enabled the researcher to input contextual information that may have impacted certain findings such as: demographic information, class level, class gender. Emergent themes in the data were then coded in a systematic fashion. Coding is an important part of analysis that enables the researcher to organise data into relevant categories (Braun & Clarke, 2006; Cohen et al., 2011; Miles & Huberman, 1994). A 'code' refers to the most basic part or element of the raw data that can be assessed in a meaningful way about the phenomenon in question (Boyatzis, 1998). A sample of the coding process for the teacher interviews and student focus groups can be found in Appendices U and V.

A tentative list of codes was developed based on this preliminary reading. This first-level coding involved labelling groups of words (Miles & Huberman, 1994). Examples of initial codes included, 'relevance to students' everyday lives', 'positive attitudes towards science', 'teacher observation'. At this stage 46 codes were identified.

Table 3.14

Braun & Clarke (2006) Six Step Approach to Qualitative Data Analysis

Phase	Description of the process
1. Familiarising yourself with your data	Transcribing data, 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 if themes work in relation to the coded extracts (Level q) and 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 definition and names for each them
6. Producing the report	The final opportunity to 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

Once the initial coding was completed, the codes were collated into potential themes: the 46 codes were coded into 9 themes. For instance, 'group work', 'student questioning' and 'design and make' were coded under the theme of 'science skills'. This is considered second-level coding (Braun & Clarke, 2006; Miles & Huberman, 1994). The themes were then reviewed and refined (Braun and Clarke, 2006). A thematic map of analysis for the entire data set was generated, see Appendix W. Then a cyclical process of coding and checking themes began. This process continued until the categories and definitions were considered acceptable and the coding decisions were found to be reliable. NVivo facilitated a thorough cross case-case analysis of themes when it came to producing the final report; NVivo enabled comparisons to be made between cases highlighting similarities, differences, variations and allowed deviant and extreme cases to emerge (Cohen et al., 2007; Gibbs, 2007)**.** This is considered inductive analysis, where the researcher works 'bottom-up' using the participants' views to build themes and generate a theory interconnecting the themes (Cohen at al., 2011). A detailed analysis of this coding process can be found in Appendix X.

3.11 Point of Integration: Qualitative and Quantitative Data

In phase two, the qualitative data analysis and quantitative data analysis for each case were brought together. Guest (2013) refers to this as the 'point of integration' and is a distinguishable feature of mixed-methods research. The point of integration can be defined as "any point in a study where two or more research components are mixed or connected in some way" (Guest, 2013, p. 56). In this study the qualitative data was used to support, expand and develop the quantitative data in each of the cases (Creswell & Piano-Clarke, 2007). The qualitative data also often provided description of the *process* that contributed to quantitative *outcomes*, a core feature of an evaluative case study. While the qualitative analysis was related to the quantitative data, it is important to note that some of the qualitative themes were not supported by quantitative data but were considered prominent themes and are presented in the findings chapter in their own right. In this mixing of the data the qualitative and quantitative data were compared, contrasted, and additional data analysis was conducted where necessary. For instance, when the students in Case D indicated in the quantitative data that they had frequent experience of IBSE but the qualitative data did not corroborate this claim, additional qualitative data analysis was conducted to find a plausible explanation for such an incongruence.

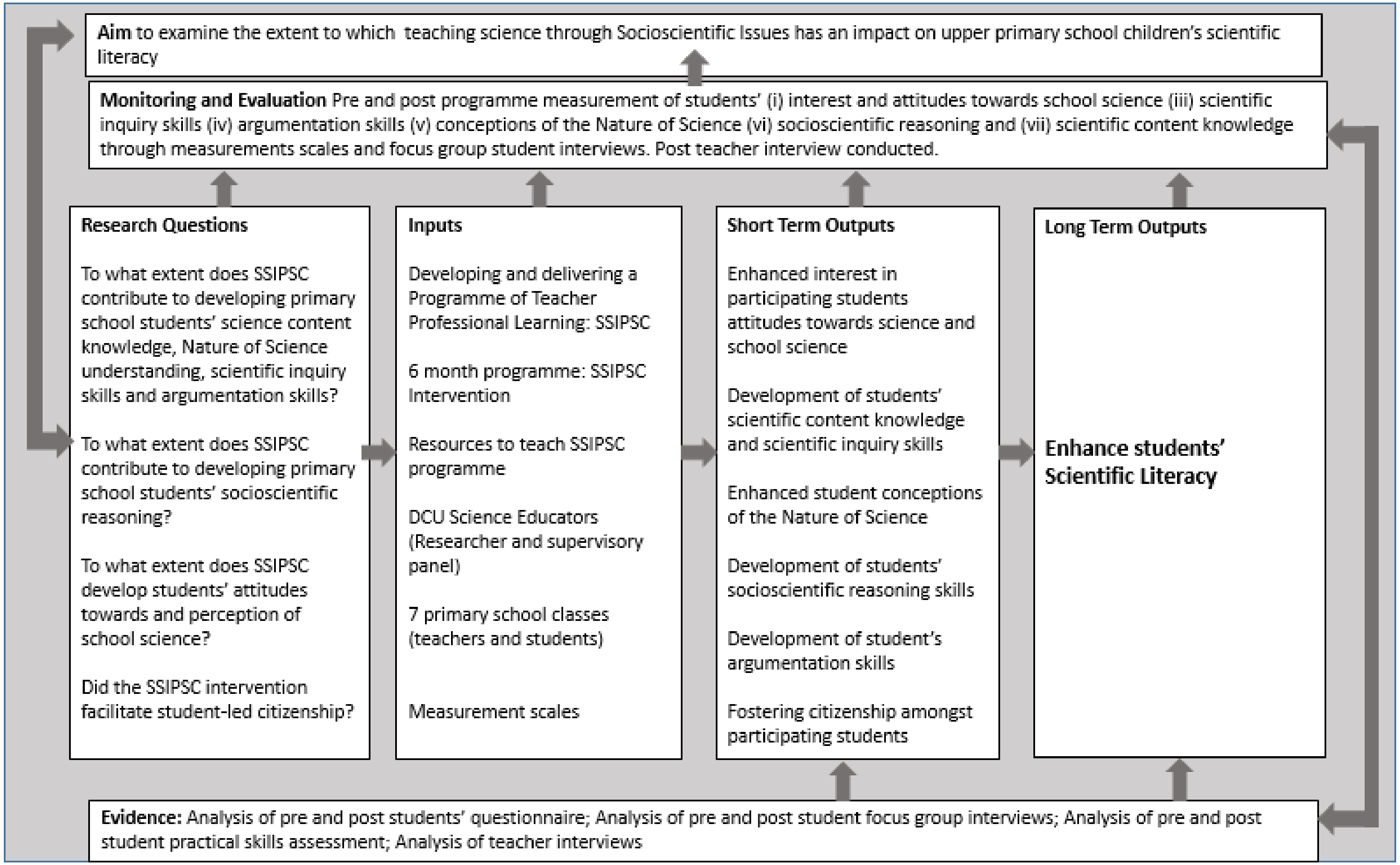
A detailed analysis of the emerging themes was presented with sufficient evidence of both quantitative and qualitative data to support a coherent account (Braun & Clarke, 2006; Nowell et al., 2017): "The key to integration is being conscientious about creating a conversation between the quantitative and qualitative data to enhance understanding" (Mertens, 2018, p. 450). This procedure was repeated for each of the seven cases. For a sample individual case analysis see Appendix O.

3.12 Cross-Case Analysis

Phase three consists of a cross-case analysis. Cross-case analysis is concerned with generating findings, lessons and conclusions across multiple cases (Yin, 2018). Each individual case study (*n*=7*)* became the subject of the whole case study where convergent evidence was sought regarding the findings and conclusions of the study. The use of a logic model assumed a key role during this phase of data analysis (Yin, 2018). Yin defines the logic model as a tool that "stipulates and operationalises a complex chain of occurrences or events over an extended period of time" (2014, p. 155). In other words, the logic model should explain how a planned intervention or ongoing initiative works (Yin, 2018, p. 270). The logic model (Figure 3.5) was matched to the qualitative and quantitative data for each case, to evaluate whether or not the SSIPSC intervention produced a certain outcome or sequence of outcomes across the seven cases (Yin, 2018). It is built upon the conceptual framework (see Section 2.5) underpinning this study. Here, the SSIPSC intervention provided students with opportunities to learn primary science through SSIs. The immediate outcome is evidence of increased understanding of science content knowledge and NoS, along with the development of students' science inquiry skills, socioscientific reasoning and argumentation skills (short-term outcomes). Eventually the intervention should lead to enhanced scientific literacy (long-term output). The logic model exceeds the capability of experimental research which focuses on the relationship between the first and last step, typically coined "black box evaluation" (Rogers, 2000, p. 213). Logic models can open the black box and explain how the intervention produced the short and long term outcomes. Each case study was compared against the logic model during phase three, where one case, Case F emerged as an outlier throughout. Plausible explanations were considered and are presented in the next chapter. This phase concluded by producing a multi-case report, drawing together the evidence from each case.

Figure 3.5

Logic Model Underpinning Study



3.13 Validity and Reliability in Mixed Methods Research

3.13.1 Validity in Mixed-Methods Research

Validity refers to the credibility of the research study (Cohen et al., 2011). It "refers to the ability of the researcher to extend the findings of a particular study beyond the specific individuals and setting in which the study occurred" (Mertens, 2015, p. 254). Qualitative validity is principally concerned with whether the accounts provided by the researcher and the participants are accurate, credible and trustworthy (Cohen et al., 2011). In qualitative research, the data collection instrument is often the researcher themselves (Brink, 1993) which immediately raises concerns of 'researcher bias' (Cohen et al., 2011). For instance, issues such as representativeness, have been raised by some in the field whereby the researcher may not always adhere to criteria of representativeness, reporting critical but unrepresentative findings (Dyer, 1995). To enhance validity of the findings in this study the researcher triangulated the qualitative data from the student focus groups and teacher semi-structured interviews with the quantitative data (Robson, 2011). Throughout the interview the researcher regularly summarised what the students/teacher had said and the researcher's interpretation of same as a form of member-checking. Lincoln and Guba (1985) describe member-checks as a crucial technique for establishing credibility in a study. Data analysis is also another area that is frequently highlighted as a 'black hole' when it comes to qualitative data analysis (Merriam, 2009; Yin, 1984). According to Merriam, "historically data analysis in qualitative research has been something like a mysterious metamorphosis. The investigator retreated with the data, applied his or her analytical powers, and emerged butterfly-like with 'findings'" (Merriam, 1998, p. 156). A transparent coding approach was employed with Braun and Clarke (2006) thematic analysis used to inform each step of the coding process. The coding process is presented in Appendix X.

The validity of data collected during the quantitative phase is concerned with the extent to which an instrument measures what is supposed to measure and performs as it is designed to perform (Cohen et al., 2011; Robson, 2011). A number of measures contributed to enhancing the validity of the quantitative results including appropriate instrumentation and appropriate statistical treatment of the data (Cohen et al., 2011). In terms of instrumentation, all scales used in this study have been used in previous studies in a RoI primary school context. For instance, the NoS measurement scale used in this study was found to have high construct validity in Murphy et al.'s 2019 study. Nonetheless, Oppenheim (1999) advises that piloting increases the validity and practicability of research instruments. Thus the questionnaire was piloted with a convenience sample of 85 primary school students in three different classes from three primary schools, see Section 3.7 (Tabacknick & Fidell, 2013).

External validity or generalisability is the extent to which the findings in the study can be applied to the wider population (Gall, Gall, & Borg, 2007). As discussed earlier, analytical statistical generalisations with references to samples and populations are not feasible given the small-scale purposive sample used in this study. In this case study, multiple cases were chosen so that if the individual case studies are found to have similar results, a literal replication can be reported. In other words, if the seven cases in this study turn out as predicted in the logic model, then there will be compelling support for the conceptual framework guiding this study. Furthermore, description of qualitative findings for each case were provided. This allows other researchers and practitioners to make judgements about the finding's applications to other contexts (Cohen et al., 2011; Merriam, 1998; Stake, 1995).

3.13.2 Reliability in Mixed-Methods Research

Reliability is the degree to which research methods produce stable and consistent results. The goal of reliability is to minimise the errors and biases in a study (Yin, 2018). In other words, if research is to be deemed reliable, similar results should be obtained if the research was carried out on a similar subject in a similar context. In terms of quantitative data, piloting provided the researcher with real data for preliminary analysis (Cohen et al., 2011). While the measurement scales in the students' questionnaire have been used in other contexts with high levels of reliability reported, the scales were used in different school contexts and thus the pilot data were subjected to statistical tests to re-establish reliability. In addition, member checking was utilised to enhance the reliability of the qualitative data. Finally, a coherent 'chain of evidence' was provided in the form of a qualitative codebook (Appendix X), so that the reader can see how conclusions pertaining to qualitative data were reached (King & Horrocks, 2010). This was necessary to clarify how the researcher arrived at the results and thus enhances the reliability of the research findings (Yin, 2009).

3.14 Ethics

Ethical issues are present in any kind of research study. Ethical approval was sought and granted from Dublin City University; REC number: DCUREC 2018_184, Appendix Y. This study was conducted in accordance with the Ethics form submitted and DCU Ethical Guidelines. Furthermore, as children participated in this study, the Ethical Guidelines published by the Department of Children and Youth Affairs (DCYA) (2012) were adhered to throughout.

Participation in this study was entirely voluntary. Initial contact was made with the potential participants, primary school teachers, through email. The participants had given their email addresses during a teacher in-service course and specified their interest in receiving information about research in the field of primary science education. The teachers who expressed interest in participating in the research study forwarded the details of their school and Principal. The Principal and Board of Management were then invited to participate in this study. Plain Language Statements (PLS) and Informed Consent Forms (ICF) were distributed (see Appendix Z). Once consent had been received, teacher consent (see Appendix AA) and subsequently parent/guardian consent (Appendix BB) were sought. The purpose and procedures of the study were outlined to all participants in the PLS. Student assent forms (Appendix CC) were distributed following a signed ICF from parents/guardians. The assent form was written in child-friendly language to ensure that their agreement to participate was fully informed (DCYA, 2012). The PLS and ICF informed participants of their right to withdraw from the research study at any point in time without any adverse consequences (Cohen et al., 2011). Participation as well as withdrawal from the study would not affect the teachers or students in any way as the SSIPSC intervention was embedded in the content of the Primary Science Curriculum (DES, 1999a). Principal/Board of

Management, teachers and parents gave consent by completing, signing and returning the ICF. Student assent was given upon signing the ICF.

Ethical issues pertaining to anonymity and confidentiality were carefully considered. On the students' questionnaire and skill assessment, no names or details that might reveal a students' identity were recorded. Each school was given a code number and the student participants were also coded. The students who participated in the focus group were randomly selected by the class teacher. The same students participated in the pre and post focus group interviews. The participating students' names were omitted on the focus group interview transcripts and students were not identified in the reporting of results. Similarly, the teachers' names were removed from the teacher interview transcripts. The students' names, teachers' names or school's name are not provided in this thesis nor are they presented in an identifiable form.

Data from the study was managed securely. Any written information, i.e. the student questionnaires, skill assessment, informed consent forms were stored in a locked storage system in the principal researcher's office for the duration of this research project and for five years after its completion. This is in accordance with the Record Retention Schedule and Data Protection Guidelines of DCU. Data will be securely destroyed after this time frame. Electronic data was stored under an encrypted code and will be deleted by the researcher from the device after five years. Data was used only for the purpose of this research and will not be shared with third parties outside the supervisors of this research project. Dissemination of research findings and feedback was offered to participants and will be provided upon request (Cohen et al., 2011).

3.15 Chapter Summary

This chapter provided an overview of the methodological approach employed in this study. The philosophical underpinnings of pragmatism guided the mixed-methods research design which was dictated by the research questions. In-depth descriptions of the quantitative and qualitative data collection instruments and analysis were provided. This concurrent mixed-methods design involved collecting and analysing the qualitative and quantitative data separately before mixing them at the data analysis stage. The chapter also outlined considerations in relation to validity, reliability and ethics. The following chapter will describe the cross-case research findings from this study.

4.0 Research Findings

The current study builds and expands upon the limited research available in the field of SSIs and primary science education. The aim of this study was to examine to what extent SSIs contribute to the development of children's scientific literacy within primary science education. The study examined upper primary school students' scientific literacy using a number of constructs: attitudes and interest towards school science, development of science content knowledge, NoS, scientific inquiry skills, argumentation capacity and ability to engage in socioscientific reasoning. It was the development, accumulation and interrelationship of these constructs that is of interest in this study and how the students applied knowledge (science content knowledge, NoS), skills (IBSE, argumentation) and attitudes to make informed decisions pertaining to SSIs (Socioscientific Reasoning) and take informed action, where appropriate; these are considered the competencies of a scientifically literate individual. Quantitative data in the form of measurement scales and coding rubrics along with practical skill assessments and qualitative student focus groups were used to gather data pertaining to the students' scientific literacy prior to and after the SSIPSC intervention. In addition, data were gathered regarding the teachers' perceptions of the impact of the intervention on the students' learning in science. This study consisted of a multiple-site evaluative case study where seven teachers and their classes participated in the 6-month SSIPSC intervention.

This chapter presents a cross-case analysis of the data gathered from each of these seven cases. Firstly, the impact of the SSIPSC intervention of the development of student science content knowledge (Section 4.1), NoS (Section 4.2), scientific inquiry skills (Section 4.3) and socioscientific argumentation (Section 4.4) is presented. Discussion pertaining to the students' socioscientific reasoning follows (Section 4.5). The emergence of student-led citizenship as a key finding will also be examined (Section 4.6). Finally, the development of students' attitudes towards, and interest in, school and school science are examined in Section 4.7. Table 4.1 presents a brief description of the characteristics of each case (*n*=7).

Table 4.1

Descriptive Overview of each Case

Case A **4th Class**	***Jack*** taught 4th class in a mixed school in Dublin. He had 34 years' experience and taught in the same school all of his teaching career. Jack completed a Bachelor of Education Degree in St. Patrick's College, Dublin. Prior to the SSIPSC intervention he had never engaged in a science related professional learning programme. There were 28 students in his class. Jack described the class as a mixed ability class who were enthusiastic about science. Prior to participation in the SSIPSC programme, Jack was dissatisfied with his approach to teaching science, using a predominantly teacher-directed approach guided by the science text-book.
Case B **3rd Class**	***Eva*** taught 3rd class in an all-boys school in Dublin. She had seven years teaching experience including a number of years teaching in Dubai and Australia. This was her second year teaching in the all-boys school. Eva completed her Bachelor of Education Degree in Marino Institute of Education, Dublin and had not participated in a science related professional learning programme prior to the SSIPSC programme. There were 32 boys in the class. They enjoyed science and were very enthusiastic about the subject. Eva was interested in science and wanted to learn some new science pedagogical approaches.
Case C **4th Class**	***Sarah*** taught in a mixed-school in Dublin. She had nine years teaching experience and completed her Bachelor of Education Degree in St. Patrick's College, Dublin. Sarah undertook a specialism in Science Education as part of her undergraduate degree and recently completed a Master's in Education specialising in Science Education. Sarah is the science coordinator in her school and is interested in continuously improving her practice in relation to the teaching of science. There were 28 students in Sarah's class. Sarah felt that the class were enthusiastic about science and school in general. Some students were engaged in science club as part of the school's after-school activities.
Case D **6th Class**	***Elaine*** taught in a mixed school on the DEIS programme. She completed the Professional Master of Education in Maynooth and had eight years teaching experience. Elaine was the Resource teacher for 6th class and taught the SSIPSC programme on a weekly basis to a group of nine higher achieving students. She had not engaged in a programme of professional learning in science education prior to the SSIPSC intervention. Elaine stated that while she had a keen interest in the teaching of science, she predominantly used the science textbook to guide her planning and teaching of the subject.

Table 4.1 (continued).

Case E **6th Class**	***David*** taught 6th class in a mixed school in Dublin. He had nine years' teaching experience and completed his Bachelor of Education Degree in St. Patrick's College Dublin. There were 23 students in his class. David completed a programme of professional learning on Outdoor Education prior to this course. He was the science coordinator in his school and was keen to introduce new science pedagogies into his teaching. He described his class as a high ability class who were enthusiastic about science and interested in everyday issues.
Case F **3rd Class**	***Ruth*** taught 3rd class in a mixed school in Dublin on the DEIS programme. It was a growing school with the 3rd class being the oldest class in the school. There were 13 students in the class. Ruth had four years teaching experience. She described her class as a mixed ability class who were interested in science and enjoyed hands-on investigations. Ruth had not engaged in a programme of professional learning in science since she graduated from her Bachelor of Education Degree in Mary Immaculate College, Limerick.
Case G **3rd Class**	***Anne*** had three years teaching experience. She graduated from St. Patrick's College with a Bachelor of Education Degree. This was her first year teaching 3rd class in a mixed school in Dublin. There were 26 students in the class. Anne described the class as a mixed-ability class who were enthusiastic about science and school in general. Similar to the other teachers in the study, Anne had not completed a programme of professional learning in science prior to the SSIPSC programme.

Quantitative and qualitative findings pertaining to each of the above cases will now be discussed under key themes.

4.1 Science Content Knowledge

This section presents quantitative and qualitative data pertaining to the development of students' science content knowledge prior to and post the SSIPSC intervention. Quantitative data from the students' questionnaire is presented followed by a discussion of students' inaccurate science conceptions that emerged during the student focus group discussions.

4.1.1 Development of Science Content Knowledge

The students answered 10 questions in relation to science content knowledge pre-intervention and post-intervention (Appendix I, Section E). Table 4.2 presents the pre and post students' questionnaire scores pertaining to the development of science content knowledge. A higher median score post-intervention indicated development of science content knowledge. For example, the median score for Case A (4th class) increased from 8.0 to 17.0 indicating that the students had more enhanced understanding of science content knowledge post-intervention. The table also presents data regarding the significance of these differences. If $p<0.05$, then a statistically significant difference between the pre-intervention and post-intervention data was reported with Cohen's (1988) criteria used to interpret the effect size of this difference. In all cases, $p<0.05$, hence the difference between the pre-intervention and post-intervention scores was considered to be statistically significant with six of the seven cases reporting a large effect size ($r>0.5$).

Table 4.2

Scale Data: Development of Scientific Content Knowledge

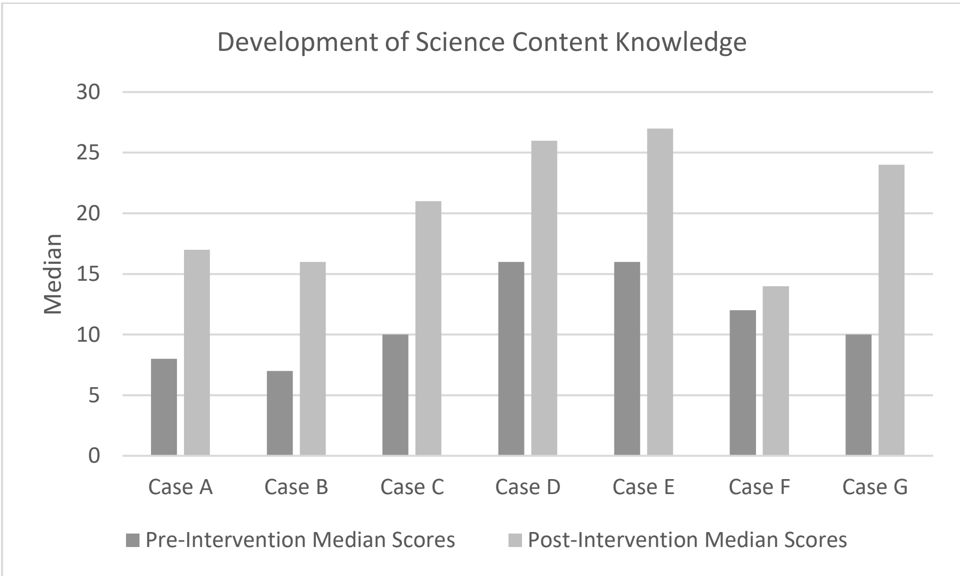
Case	Class	N/Class size	Initial Median	Exit Median	*p*	*z*	*r*	Effect Size: Cohen (1988) criteria
A	**4th**	***27/27***	**8.0**	**17.0**	**.00**	**-3.56**	**0.48**	**Medium**
B	**3rd**	***32/32***	**7.0**	**16.0**	**.00**	**-4.68**	**0.59**	**Large**
C	**4th**	***22/28***	**10.0**	**21.0**	**.00**	**-4.11**	**0.62**	**Large**
D	**6th**	***9/9***	**16.0**	**26.0**	**.01**	**-2.67**	**0.63**	**Large**
E	**6th**	***23/23***	**16.0**	**27.0**	**.00**	**-4.16**	**0.61**	**Large**
F	**3rd**	***13/13***	**12.0**	**14.0**	**.00**	**-3.08**	**0.60**	**Large**
G	**3rd**	***22/26***	**10.0**	**24.0**	**.00**	**-3.88**	**0.58**	**Large**

Figure 4.1 presents the pre and post-test median scores. All cases made similar improvement in science content knowledge from pre-intervention to post-intervention relative to their initial median score with the exception of Case F. Case D and Case E had a higher level of science content knowledge pre-intervention and they remained at the highest level post-intervention. Both Case D and E were 6th class cases and thus their position in comparison to the other cases is expected. Case C (4th class) and G (3rd class) had the same pre-intervention median scores, with

Case G presenting a higher median score than Case C (4th) post-intervention. Cases A (4th class) and B (3rd class) had similar median scores pre-intervention and demonstrated similar improvement post-intervention.

Figure 4.1

Pre-Intervention and Post-Intervention Median Scores for Development of Scientific Content Knowledge.



The development of students' science content knowledge emerged as a theme in the qualitative teacher interviews where teachers (3/6 cases: Case B - 3rd class; Case E - 6th class; Case G - 3rd class) asserted that the content of the SSIPSC intervention covered science curricular material in greater depth than previous years. They further cited that it contextualised the curriculum objectives making the content more relevant and engaging for the students. See David's response below to support this assertion:

> We found that we actually were hitting across a lot of strands and strand units of the curriculum with just one topic of the SSIPSC programme. So yes it was mapped to the curriculum really well but, I think, just in a different way and I suppose, it made me think a little bit more outside the box. I think that it was allowing them time to show their outside knowledge as well because everything was so topical. They were hearing things on the news. They were hearing their parents talking about things and that was all coming into it

at once. So they were getting a much broader, well-rounded, knowledge or opinion of science, rather than just abstract or individual topics presented in their books. I definitely think it was much more well–rounded (Case E, 6th class).

Students' content knowledge also emerged as a prominent theme throughout the student focus group interviews. In the pre-intervention focus groups many students described science lessons such as 'exploding volcanos' (4 cases), 'floating and sinking' (3 cases) and 'bouncy egg investigation' (2 cases). When recalling previous science lessons, the students described the procedure followed [i.e. what they did] but when probed most students across all cases could not discuss the science content knowledge associated with their learning. The following is illustrative of a students' response pre-intervention (Case A, 4th class):

Tell me about your favourite science lessons? [Researcher]

Making volcanoes [Student A]

When did you make volcanoes? [Researcher]

Last year…we made it with baking soda and vinegar [Student A]

Brilliant and what happened? [Researcher]

It exploded all over the place [Student A]

Why did that happen? [Researcher]

I don't know but it was fun to make [Student A]

In contrast post-intervention students in all cases, with the exception of Case F which is discussed at the end of this section, were able to discuss the science content knowledge underpinning their favourite science lessons. For instance, the students were capable of speaking in-depth about the complexities of climate change or the pollination process. When recalling the unit on sugar tax the students were able to explicitly link the topic to the digestive system and the role of fructose and glucose in the body. The following student's response illustrates this (Case D, 6th class, post-intervention):

What was the favourite thing you learned in science? [Researcher]

Probably how sugar is divided into things, glucose and fructose. And then fructose stays in the liver and glucose goes around and is converted into energy [Student B]

Brilliant, wow. And what happens then if you have too much sugar? [Researcher]

If you have too much fructose in your liver, then it clogs your liver and gives you liver problems. And then if there's too much glucose not being used as energy, then it turns into fat [Student B]

It is apparent that not only were these students able to articulate the science content knowledge underpinning their favourite science lessons but they were also able to relate it to their everyday lives. Indeed, post-intervention students in most cases (5 cases: Case B - 3rd class; Case C - 4th class; Case D - 6th class; Case E - 6th class; Case G - 3rd class) referred to the development of 'real-life' content knowledge as the reason as to why they enjoyed school science whilst also criticising previous science lessons for not developing their conceptual understanding to the same extent:

[Pre-intervention] most of the experiments were done in the class, they were always just like, baking soda and vinegar. Even when we were doing it ourselves, we never learned why they react, but every experiment always depended on baking soda and vinegar. We made papier-mâché volcanos and we put a bottle and then we put vinegar in it, and then we put a tablespoon in [baking soda] and it looked like it was erupting. But we didn't know why they reacted. And then we blew up a balloon using the same experiment but yet we still don't know why they reacted.

What is different about this year's science? [researcher]

Because we're actually learning about real-life stuff that are living. It makes sense (Case B, 3rd class, post-intervention).

4.1.2 Inaccurate Science Conceptions

Inaccurate scientific conceptions emerged as a prominent theme in the students' focus groups; these emerged when the students discussed the SSI test scenarios on 'climate change' and 'bees and biodiversity' (See Appendix M for details of scenarios). For instance, during the initial focus group interviews, a number of students in all cases referred to the role of wind turbines as being important because they blow carbon dioxide away from Ireland: "The wind [turbine] is going to take carbon dioxide away like to the Atlantic Ocean or somewhere? Yeah, just blow it into the sea where like it won't affect anything" (Case B, 3rd class). Post-intervention many of these conceptions were revised to more accurate scientific conceptions as evident in Case B (3rd class): "It [the wind turbine] makes energy without carbon dioxide… when it spins around doesn't it start some sort of generator that makes the power? … the more wind it gets; the more power it gets". Some students expressed concern about the role of greenhouses in producing carbon dioxide pre-intervention: "I don't think he should build a greenhouse [to protect the bees] because greenhouses make gases called greenhouse gases and those are very bad" (Case G, 3rd class). It is apparent that the student had a flawed understanding of greenhouse gases and how they are produced. Along a similar line, some students in all cases perceived the role of bees in society to be limited to the production of honey. Samples of common inaccurate science conceptions (pre-intervention) and more adequate science conceptions (post-intervention) can be found in Table 4.3.

Table 4.3

Samples of Students' Inaccurate Science Conceptions Presented in the SSI Test Scenarios

Description	**Exemplars (pre-intervention)**	**Exemplars (post-intervention)**
Climate change is a hole in the ozone layer *Sample from Case B (3rd class)*	Isn't global warming when there are holes in the atmosphere. It means solar rays can potentially break the atmosphere (Case B, 3rd class).	So, isn't it that every time we burn things, all the carbon dioxide goes up, and that affects earth's atmosphere, how warm it gets. So, in some… say in the North Pole and the South Pole, all the polar ice caps are melting because of global warming. And in other countries it's getting warmer and colder, and the climate is all over the place because of it (Case B, 3rd class).

Table 4.3 (Continued).

Description	Exemplars (pre-intervention)	Exemplars (post-intervention)
What causes climate change? /How can we reduce climate change? *Sample from Case C (4th class)*	*How could we reduce climate change?* We could have less tea, let's say drink less tea. Why tea? [researcher] Because it comes from the kettles, the kettles like say all the gas [carbon dioxide] comes out from kettles (Case C, 4thclass).	*How could we reduce climate change?* Well we should cut down on our fossil fuels [to reduce climate change] …make it stuff like solar panels and wind turbines (Case C, 4th class).
The function of Wind Turbines *Sample from Case A (4th class)*	Wind turbines like blow away the carbon dioxide over to England and they can have all of it and they get to keep it (Case A, 4th class).	Wind turbines make energy and doesn't make like carbon dioxide…so it's better (Case A, 4th class).
Are bees important? Why? *Sample from Case G (3rd class)*	Bees *are* important, but they're not as important as our actual food, because we barely use honey (Case G, 3rd class).	Bees they pollinate. If he doesn't have bees his vegetables won't get pollinated meaning that he will lose his crops (Case G, 3rd class).
Electricity is a 'cleaner' form of energy *Sample from Case D (6th class)*	So, if we change to electric radiators…it would be better for the environment because we're not using fuel and all. It would reduce the amount of carbon dioxide. And if most people start using it [electric radiators], then the amount of carbon dioxide would go down (Case D, 6th class).	It could still be burning fossil fuels, because it's the electric heating (Case D, 6th class).

The number of references during focus group interviews to inaccurate science conceptions across all of the cases were counted both pre and post-intervention. This data is presented in Table 4.4. It is apparent that the number of inaccurate science conceptions decreased by 75% post-intervention with 103 references pre-intervention to 24 references post-intervention. Of note while the 6th class cases, Case D and Case E, had the lowest number of references to inaccurate science conceptions at the initial stages of this study, most cases (6/7) across all class levels substantially reduced the number of references to inaccurate conceptions at the exit stage. Case F was the only exception which had 11 references to inaccurate conceptions pre-intervention and 10 references post-intervention, see Figure 4.2. The students' inaccurate conceptions had an impact on their ability to engage in socioscientific reasoning, to be discussed in Section 4.5.

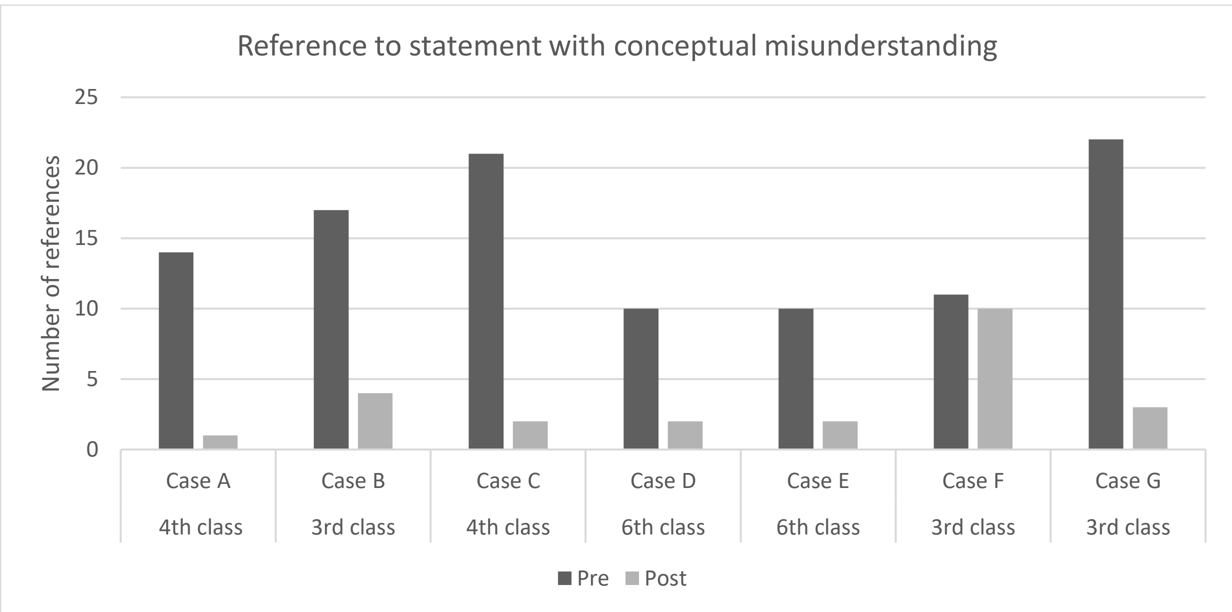
Table 4.4

Number of Inaccurate Science Conceptions across each Case

Inaccurate Science Conception:	**Case A** 4th Class		**Case B** 3rd Class		**Case C** 4th Class		**Case D** 6th Class		**Case E** 6th Class		**Case F** 3rd Class		**Case G** 3rd Class		**TOTAL**	
Theme	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Climate Change	7	0	13	4	12	1	5	1	6	1	2	2	11	2	**56**	**11**
Bee and biodiversity	4	0	4	0	8	1	3	1	3	1	7	5	11	1	**40**	**9**
Wind Energy	3	1	0	0	1	0	2	0	1	0	2	3	0	0	**9**	**4**
TOTAL	**14**	**1**	**17**	**4**	**21**	**2**	**10**	**2**	**10**	**2**	**11**	**10**	**22**	**3**	**105**	**24**

Figure 4.2

Pre-Intervention and Post-Intervention Data on Scientific Conceptual Misunderstanding for each Case



In the teacher interviews many of the teachers made reference to the inaccurate science conceptions that the students held in relation to many of the units. For instance, in relation to the unit on the digestive system, one teacher (Case B, 3rd class) asserted that pre-intervention students held many inaccurate conceptions regarding the digestive system with many students often confusing it with the respiratory system. Similarly, Sarah noted:

> I did that pre-assessment and they didn't have a clue about anything going on in their bodies. One [drew a digestive system and it] was a straight-line, or some had like a mouth and just a hole, someone else connected it to a lung. It was fascinating" (Case C, 4th class).

Another teacher commented on the inaccurate science conceptions the children had in relation to climate change even though they had participated in a local area 'climate protest':

> And like mine did the climate protest, they were all about it. And then when we were doing the climate change unit I was like oh my gosh, some of them haven't a notion [clue]! So, I think like that was an important point for me. I mean they see it in the media they understand it's important but they didn't really understand why" (Anne, Case G, 3rd class).

Quantitative and qualitative data relating to the development of students' science content knowledge is presented in this section. Quantitative data indicates that the students developed science content knowledge in line with the content of the SSIPSC intervention and the primary science curriculum. In addition, students in most cases (6/7) developed more informed understandings of science concepts pertaining to the SSI test scenarios. Case F emerged as an outlier in this section. Post-intervention the students in Case F did not make explicit reference to the units of the SSIPSC intervention when discussing their favourite science lesson instead referring to pre-intervention science lessons. Furthermore, the students in Case F were unable to articulate the science content behind their favourite science lessons instead describing the procedure followed, for example, "We added fairy liquid to the water and made bubbles [Student] *What were you investigating?* [Researcher] I'm not sure [Student]" (Case F (3rd), pre and post-intervention). The development/lack of development of science content knowledge impacted these students' ability to engage in socioscientific reasoning and make informed decisions relating to SSIs. This will be discussed in Section 4.5.

4.2 Nature of Science

Students' conceptions of NoS were measured pre and post the SSIPSC intervention using the validated NoS measurement scale (Murphy et al., 2019). Table 4.5 presents data from the Nature of Science scale. There were no statistically significant differences (p>0.05) pre and post the SSIPSC intervention.

Table 4.5

Scale Data: Conceptions of NoS

Case	**Class**	**N/Class size**	**Initial** Median	**Exit** Median	***p***	***z***	***r***	Effect Size:
A	4th	24/27	1.86	1.71	**.11**	-1.61	0.23	Small
B	3rd	28/32	1.86	1.79	**.28**	-1.21	0.16	Small
C	4th	21/28	1.78	1.57	**.11**	-1.59	0.25	Small
D	6th	9/9	1.71	1.29	**.06**	-1.87	0.44	Medium
E	6th	23/23	1.71	1.71	**.46**	-0.73	0.11	Small
F	3rd	12/13	1.86	1.86	**.36**	-0.92	0.19	Small
G	3rd	20/26	1.86	1.71	**.12**	-1.56	0.25	Small

Taking into consideration the non-significant findings in Table 4.5 above, effect size will also be reported throughout this chapter to provide insight into 'practical significance' (Fan, 2001). According to Kirk (1996) statistical significance is related to whether a research result is due to chance or sampling variability while practical significance is concerned with whether the result is useful in the real world. Fan (2001) warns that too much reliance on statistical significance testing, which is often impacted by sample size, limits understanding and applicability of educational research findings. Similarly, APA Publication Manual have emphasised the importance of reporting the effect size stating that "failure to report effect size is seen as defect in the design and reporting of the research" (APA, 2001, p. 25). McCartney and Rosenthal (2000) concur stating that it is important to report effect size in educational research regardless of whether 'significance' is obtained.

Analysing the scale data in Table 4.5, Case D (6th class) had a medium effect size ($0.3<r<0.5$) reported. The remaining cases had a small effect size ($0.1<r<0.3$) reported. Case F had the same median score pre and post-intervention with a small effect size ($0.1<r<0.3$). In all cases the pre-median and post-median values are close and always below 2. In other words, the evidence indicates the possibility of ceiling effects in this measurement, which would also explain in part the lack of statistically significant changes from the pre-intervention data to the post-intervention data.

While the quantitative scale data revealed that students had informed conceptions of NoS prior to and post-intervention, the qualitative evidence suggests that the SSIPSC provided opportunities for the students to apply their NoS understanding to real-life contexts. This was particularly true for the following 'general aspects' of NoS which were identified in the literature review (Section 2.4.2). These will now be discussed:

- Science is not a lone pursuit rather it involves collaboration
- Scientists use creativity in their work
- There is no one scientific method
- There is a tentative and developmental nature to scientific knowledge
- Scientists make observations and inferences

In the initial interview, some students in three of the cases made reference to sitting in groups during science lessons but this seemed to refer to the organisation of the class rather than collaborative group work. Two of the teachers stated that they rarely used group work in science pre-intervention citing large class sizes and a lack of equipment as inhibiting factors. In contrast post-intervention, students made frequent reference to working in groups during science in all cases; students discussed the sharing of ideas, planning of investigations and collaboratively overcoming problems they encountered during investigations or when discussing SSI test scenarios. Post-intervention, students in two cases made reference to scientists working together to collaboratively come up with possible solutions to the SSI test scenario. For instance, in response to the squirrel scenario, Student A in Case A (4th class) recommended that "scientists put all their good ideas together and think of a way to make it work". Evidently the students in these cases were developing their understanding of the collaborative NoS and beginning to the see connections between school science and how scientists work. Case G (3rd class) presented an interesting finding pertaining to the collaborative nature of SSIs in the post-intervention focus groups where they discussed the necessity of different stakeholders working together to reach a collaborative solution to the SSI test scenario, not just scientists: "We need to get the scientists to talk to the farmer and the bee keeper and see if they can work together to sort it out" (post-intervention).

Pre-intervention there was a dominance of teacher-directed science investigations which will be discussed in Section 4.3. Post-intervention students in most cases (6/7) made greater reference to child-led science inquiries referring to how they conducted science investigations and discussed how different groups came up with different ways of investigating their inquiry questions: "We got to make up our investigation, we got to decide what to do about it. It was pretty fun" (Case C, 4th class, post-intervention). Teachers (6/6) also made reference to the development of the students' inquiry skills post-intervention: "The students were like, oh, are we allowed to investigate this, or, can we do this, coming up with their own questions to investigate that they were able to design themselves" (Sarah, Case C, 4th class, post-intervention). Students in three cases discussed how scientists can come up with different ways to overcome the SSI test scenario of bees and pesticides: "Some scientists might come up with an antidote… another scientist might find medicine to help the grey squirrel" (Case B, 3rd class, post-intervention). Here these students referred to different investigations to answer the same question showing some development in this tenet of NoS, namely a more informed understanding of the scientific method.

Pre-intervention students in three of the cases (Case A - 4th class, Case B - 3rd class, Case F - 3rd class) associated creativity with mixing chemicals for an explosion. Post-intervention students referred to their creativity when designing and making a wind turbine (part of the SSIPSC intervention). These students explicitly referred to groups using their imagination to come up with different wind turbine designs. Furthermore, post-intervention the students referred to using creative ways of overcoming problems faced in the SSI test scenarios; students in the below cases present some examples of this:

> “scientists should bring pine martins into the grey squirrels territory…pine martins are squirrel natural predators” (Case B, 3rd class, post-intervention)
>
> “I think it’s cool the way scientists are making robotic bees to pollinate the fruit and vegetables” (Case E, 6th class, post-intervention)
>
> “Can scientists build a special dome for the red squirrel to protect them?” (Case G, 3rd class, post-intervention).

These students were beginning to see science as a creative endeavour and also recognised the role of scientists in devising innovative solutions to real world problems:

> I think science is about like inventing stuff and making the world better and just inventing things and …. and some people think being a scientist just means you make cool stuff, but it actually helps the world when you do it (Case G, 3rd class, post-intervention).

Evidence of students’ perceptions of the tentative NoS emerged predominantly in the post-intervention discussions on the SSI test scenarios. Students discussed how scientists are continuously trying to discover solutions to real world problems: “scientists are not 100% sure what causes climate change so they keep gathering more and more evidence” (Case E, 6th class, post-intervention). Students also made reference to how scientists sometimes get things wrong when discussing possible solutions to the squirrel scenario: “scientists can get stuff wrong, like when they were trying to figure out what happened to those dinosaurs and some said a meteor killed them and others said it was volcano…they don't know because they're not sure" (Case B, 3rd class, post-intervention). Another student in Case B concurred with this example citing that if "other people get it wrong, that means when you get it wrong … it's not bad". It appears that some students were developing more adequate perceptions of the tentative and developmental NoS and applying it to their own scientific investigations.

The importance of the subjective NoS also came to the fore post-intervention. Pre-intervention students referred to disagreements amongst scientists as 'one scientist being right and another being wrong' or that 'every scientist wants their opinion to be right'. Post-intervention students in most cases (6/7) began to discuss how people can have different opinions and perspectives on an issue because of different interests. This was crucial to enabling the students to recognise the different perspectives of a SSI test scenario. For instance, post-intervention students in some cases recognised that the farmer and bee keeper had different opinions on the SSI because of their different backgrounds and roles. The nature of SSIs as complex, multifaceted scenarios provided a useful context for developing students' understanding of the subjective NoS. This is further discussed under the socioscientific reasoning sub-construct 'approaching the SSI from multiple perspectives' in Section 4.5.2.

Students' conceptions of the role of observations and inferences emerged implicitly through the post-intervention interviews. For instance, the teacher in Case E (6th class) described how she developed students' observation and inference skills: "I spent a lot of time early on doing observation and inference activities that we had done with you and just finding the difference between what is a scientific observation and what an inference is". The teacher remarked that the students were then able to apply this skill to their investigations: "I could hear them discussing in groups, asking each other 'Well, how do you know that? while they were doing their investigation…, 'Actually no, you can't say that we don't have the evidence to support that inference". The students in Case E also made references to scientists making observations to gather evidence when discussing the SSI scenarios: "They don't have all the evidence so they can't be 100% sure (if the pesticide is killing the bee population). They need to investigate and observe what happens" (6th class, post-intervention). Reference to observations and inferences was the least referenced tenet of NoS and only emerged as a theme in Case E post-intervention.

Data from the pre-intervention and post-intervention NoS scale did not present any statistically significant (p>0.05) difference in students' NoS conceptions and a small (0.1<r<0.3) to medium (0.3<r<0.5) effect size was reported. Pre-intervention students made little reference to 'general aspects' of NoS when discussing the SSI test scenarios and their experience of school science. Post-intervention it appears that students were able to apply NoS conceptions to the SSI test scenarios. Thus it seems that the SSIPSC intervention may have served as a vehicle for enabling students to apply their NoS understanding to real-life scenarios.

4.3 Inquiry Based Science Education (IBSE) and Science Skill Development

This section presents quantitative and qualitative data used to evaluate students' experiences of scientific inquiry and development of science skills prior to and post the SSIPSC intervention. First, quantitative data from the students' questionnaire, Experiences of Inquiry Based Science Education scale, is presented. Students' experience of science pedagogies and development of science skills emerged as a prominent theme in the student focus group and teachers' post-intervention interviews; these themes will also be discussed. Finally, data related to students' ability to apply their scientific inquiry skills to a performance- based skill assessment will be presented and correlated with students' experiences of IBSE.

4.3.1 Inquiry Based Science Education Scale

Table 4.6 presents analysis of the pre and post children's questionnaire data for the Experiences of Inquiry Based Science Education scale. All questions in the questionnaire scale were coded on an ordinal scale from 1 to 4, where 1 = 'very often' and 4 = 'never' to statements such as "In school science we work in groups". Statistically significant differences emerged in four of the seven cases with p<0.01. Five cases had more frequent experience of IBSE post-intervention. Of these cases, four were found to have a statistically significant difference (Case A - 4th class, Case B - 3rd class, Case C - 4th class, Case E - 6th class), with p<0.01 and a large effect size (r>0.5). Case D (6th class) had more frequent experience of IBSE post-intervention with a medium (0.3<r<0.5) effect size but this was not statistically significant. On the contrary, Case F also did not demonstrate statistically significant differences in experience with IBSE pre- and post-intervention. Case G (3rd) presented the same median score pre and post-intervention. It should be noted that Cases D (6th), F (3rd) and G (3rd) had a low median score at the initial stages of the study representing the cases that had 'frequent' to 'very frequent' experiences of IBSE pre-intervention with median scores of between 1 and 2 reported. Post-intervention six cases had 'frequent to very frequent' experience of IBSE with one case situated between 'frequent' and 'few' experiences of IBSE, Case B (3rd); Case B (3rd) had the lowest experience of IBSE pre-intervention.

Table 4.6

Scale Data: Experience of Inquiry Based Science Education

Case	**Class**	**N/Class size**	**Initial** Median	**Exit** Median	***p***	***z***	***r****	Effect Size:
A	**4th**	***24/27***	**3.17**	**2.0**	**.00**	**-3.66**	**0.53**	**Large**
B	**3rd**	***28/*32**	**3.33**	**2.11**	**.00**	**-4.59**	**0.61**	**Large**
C	**4th**	***21/*28**	**2.61**	**1.78**	**.00**	**-4.02**	**0.62**	**Large**
D	6th	*9/*9	1.56	1.33	.11	-1.59	0.37	Medium
E	**6th**	***22/*23**	**2.11**	**1.56**	**.00**	**-3.64**	**0.55**	**Large**
F	3rd	*11/*13	1.78	1.78	.88	-0.15	0.03	-
G	3rd	*20/*26	1.89	1.89	.31	-1.02	0.16	Small

* Effect sizes will be quoted when p>0.05 based on comments under Table 4.5.

4.3.2 Students' Experience of Science Pedagogies

Data pertaining to students' experience of science pedagogies emerged inductively through the students' focus group interviews where the students described and discussed specific school science lessons they enjoyed/did not enjoy. A number of themes emerged from these descriptions. Table 4.7 provides a brief description of these five themes and examples of typical responses in each category at the initial and exit stages of the study.

Table 4.7

Experience of Inquiry Based Science Education: Quotations from Students

Theme: Category Title and Descriptor	Example of Children's Responses Initial Interviews	Example of Children's Responses Exit Interviews
Completion of worksheets/workbooks	I don't like science. We have to write down stuff [step by step procedure] in our copies and it takes ages (Case B, 3rd class).	No reference made
Teacher doing activities and the children observing	I remember just one of the experiments the teacher did, it was just called 'Tornado in a Bottle', and all she did was add water and glitter into a bottle and turn it upside and it spun around. I thought it was pointless. This really isn't going to help you (Case D, 6th class).	No reference made
Hands on activities prescribed by the teacher	Once we did science in our classroom and it was a volcano. So, we got like a big plastic container, we got soil, inside we put hot or cold water and red food colouring and when you put vinegar in it would all explode…I followed what the teacher did (= Case C, 4th class).	My favourite was when we were planting the flowers because it was really different from like what we normally do…The flowers were for the bees because if we plant flowers it helps the bees get more pollen…Bees [use it] then to make flowers and trees and honey and stuff (Case B, 3rd class).
Teacher explaining facts	I don't like when she talks about animals and stuff. It just gets boring (Case A, 4th class)	It was fun learning all the different parts of the bees, and then what type of bees we have in Ireland and how many species we have of that one type (Case G, 3rd class).
Child-led investigation	We had to investigate ...which one [bubble] was going to be the biggest, which one would last the longest, and which one was the sparkliest...I came up with that question (Case A, 4th class)	Well you see [my favourite lesson was] the experiment…we had to figure out which kitchen paper soaks up water the best. Justin came up with the question. We had to change the kitchen towels…but you see to keep it a fair test though we had to keep the water the same for every kitchen towel… we had the dropper…we had to pick up the same amount of water with the dropper and put it down on the table so then we would test which paper towel works the best (Case A, 4th class).

The number of times that students referred to science activities relating to each of the five themes (Table 4.7) in the initial and exit interviews was counted. Table 4.8 provides a breakdown of the number of references that the students made in each case during the initial and exit focus group interviews.

Table 4.8

Number of References Students made to Pedagogical Approaches in the Initial and Exit Interviews.

Theme	Case A 4th Class		Case B 3rd Class		Case C 4th Class		Case D 6th Class		Case E 6th Class		Case F 3rd Class		Case G 3rd Class		TOTAL	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Completion of worksheets/ workbooks	1	0	2	0	3	0	4	0	10	0	0	0	2	0	22	0
Teacher doing activities and the children observing	0	1	1	0	3	0	6	0	2	0	0	0	0	0	12	1
Hands on activities prescribed by the teacher	4	5	2	4	5	3	7	2	3	3	3	6	2	5	26	28
Teacher explaining facts	0	3	1	2	0	3	4	2	6	2	0	2	0	0	11	14
Child-led investigation	1	11	0	9	0	10	0	7	0	8	0	0	3	4	4	49

Evidence from Table 4.7 and 4.8 indicates that pre-intervention the students' descriptions of science lessons, in most cases, relate to more to teacher-directed methodologies. Students in all cases described science lessons where they watched teacher demonstrations, followed the teacher's step by step instructions, wrote in their science books, or listened to the teacher reading material from the book:

> It was kind of like we're going to do this experiment except I'm [the teacher] going to show you and you're going to watch it and then you're going to read about it and then you're going to write stuff down (Case E, 6th class, pre-intervention).

Some cases described ‘hands-on’ teacher-directed investigations pre-intervention:

> We did an experiment in our stations and it was like which melts butter first? Is it the wood, the steel or a plastic? We put some butter on it and watched whichever melted first. We had some paper and we put some things on it [results] (Case F, Pre-Intervention).

These lessons were directed by the teacher but provided the students with opportunities to engage in hands-on science investigations. These findings concur with the teacher interview data where teachers described previous science teaching as being predominantly teacher-led with little to no opportunities for the children to ask their own inquiry questions or lead their own investigation procedure. Jack’s comment (Case A, 4th class) is illuminating in this regard:

> Before [pre-intervention] it would have been here’s your question, here’s how you do it. I think that in most science classes, just from other colleagues that I’ve worked with here and in other schools as well, that like that the whole scientific method isn’t really adhered to or even done, it’s just a book given to the children… this is how someone else did it, try it yourself, now see if you can get the same result. Like what’s the point?

Pre-intervention, the students in Case A (4th class) provided the only example of a child-led investigation when they described a science lesson where they investigated how to make the best bubbles, see Table 4.7.

Post-intervention the students in the focus group provided examples of science lessons that were associated with child-led pedagogical approaches, see Table 4.8. The number of lessons associated with the completion of workbooks/worksheets and teacher demonstrations decreased. Data from the teachers’ interviews also highlighted that the teachers in all cases (6/6) had moved away from the science text-book:

> I think you do sometimes get into a bit of a rut where you feel like you are limited and you feel like this is what the publishers say is what you should be teaching but actually that is

such a small part. - I don't think I will be dipping in and out of the textbooks so much anymore (Anne, Case G, 3rd class).

Hands-on activities directed by the teacher remained high from pre to post-intervention but descriptions of the hands-on activities post-intervention were predominantly associated with the SSIPSC intervention. These types of hands-on activities were considered important by the students:

> The other science like, we used to do, we used to have a basin and we put water in it and we used to see if a counter would float. But this science we're learning about real important stuff (Case A, 4th class).

Responses the students gave with regard to being provided with opportunities to carry out their own investigations increased from pre-intervention to post-intervention (from 4 - 49). Post-intervention, students in most cases (6/7) frequently described how they came up with their own investigation questions and they had to 'figure out' how to complete the investigation in their groups. The following is illustrative of a post-intervention child-led investigation described by the students:

> So, we came up with one [science investigation]. It was a friction test. We rolled a car down a ramp. So, what we did was we stacked books on top of each other and then we had different materials and we would lay them at the bottom of the ramp and then we could see which material would stop the car the quickest (Case C, 4th class, post-intervention).

Discussing their investigations in the post-intervention focus groups, the students stated that they enjoyed "that you could do it [investigation] yourself, it wasn't the teacher telling you have to do it this way, you decided what way you wanted to do it" (Case D, 6th class). This was echoed by all teachers' post-intervention:

> I would have come from very prescribed science; this is what we're doing in science and this is how we're going to do it. I found it [the SSIPSC intervention] helped me to make it

> more child-led and get them more involved in inquiry-based learning… Now instead of just waiting for a teacher to tell them everything… it gave them more independence to question and find the answer themselves (Sarah, Case C, 4th class).

This allowed for greater opportunity for inquiry skill development, to be discussed in the Section 4.3.3.

Case D, sixth class students, extended the child-led inquiry approach outside of the SSIPSC intervention. The students described how they first investigated the nutritional content of their lunches and then compared this to exercise the students completed during lunch time:

> We measured out how much yard time we have. So, like, if we were to have 20 minutes of yard time and then it was like a good day and the teacher just said you can have another two minutes, we added up how much energy you'd actually burn off. And it turns out you get more sugar in the lunches than you'd be able to burn off in that few minutes that you were on yard for (Case D, post-Intervention).

The students in Case D came up with an authentic inquiry question, an investigation procedure, gathered evidence and then presented their findings at the BT Young Scientist and Technology Exhibition[6] in Dublin.

Case F is considered an outlier in this section. The quantitative data indicated the students had frequent experience of IBSE methodologies pre and post-intervention. In the qualitative data the students discussed lessons that were hands-on but teacher-directed pre-intervention; however post-intervention the students continued to describe the lessons they had described pre-intervention. Whilst the students were not asked explicitly about the SSIPSC intervention lessons, Case F was the only case in which this occurred. As stated earlier, the teacher from Case F did not engage in the post-interview thus it is difficult to ascertain how the students engaged with the programme and/or how IBSE impacted the students' learning in

[6] The BT Young Scientist and Technology Exhibition, commonly called the Young Scientist Exhibition, is an Irish annual school students' science competition that has been held in the Royal Dublin Society, Dublin, Ireland. From over 2000 entries, 500 are selected for the exhibition in Dublin.

science.

It is apparent from the qualitative data that students (6/7 cases: A, B, C, D, E, G) were engaging more frequently with child-led, inquiry-based approaches and less-frequently with more teacher-directed approaches post-intervention. Furthermore, post-intervention the lessons the students described were almost exclusively from the SSIPSC intervention (6/7 cases). It could therefore be suggested that the SSIPSC intervention provided the students in most cases with more frequent opportunities to engage with inquiry based pedagogies. It also had an impact on the development of the students' science skills discussed next.

4.3.3 Science Skill Development

The number of times the students made explicit reference to a science skill when describing school science during the focus interviews was counted in the pre-intervention and post-intervention interview data (Table 4.9). The science skills in Table 4.9 are the science skills as taken from the Irish primary science curriculum (DES, 1999a). It is apparent that students in all cases made greater reference to science skills post-intervention. Pre-intervention, no reference was made to fair test investigations. For example, a 6th class student, Student C in Case D stated in the post-intervention focus group that this was his first experience of a fair test investigation. Similarly, teachers in all cases discussed how they provided limited opportunities for the children to engage with fair test investigations prior to the programme:

> [Before the SSIPSC intervention] I thought I will read this [in science] and we will have a bit of a discussion about it…I certainly didn't have any emphasis on fair test investigations which now, that would be paramount in my lessons. Before, it wouldn't have even really come into my mind (David, Case E, 6th class).

The importance of controlling variables and testing in a fair and reliable manner was emphasised by many students' post-intervention as indicated by Student C, Case B's comment:

> Well if it wasn't fair then let's say you gave one [sheet of kitchen paper] 200 millilitres but then the other like half a litre it means that you can't exactly figure out which is better because the one that the 200 millilitres might have soaked it up quicker but the one with

500 millilitres would have had more water so you can't tell then which one would have been better (post-intervention).

Table 4.9

Number of References Students made to Scientific Skills in the Initial and Exit Interviews

Scientific Skill	Case A 4th Class		Case B 3rd Class		Case C 4th Class		Case D 6th Class		Case E 6th Class		Case F 4th Class		Case G 4th Class		TOTAL	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Questioning	1	5	0	4	0	7	0	4	0	8	1	1	0	4	2	**33**
Observing	0	2	1	1	0	1	2	2	0	2	0	0	0	0	3	**8**
Predicting	0	0	0	0	1	0	0	1	0	2	0	0	0	1	1	**4**
Investigating & experimenting	3	9	1	10	3	8	3	3	0	6	5	5	0	4	15	**45**
Estimating & Measuring	0	3	0	2	0	6	0	2	0	0	0	0	0	2	0	**15**
Analysing	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	**3**
Recording & communicating	1	1	0	1	1	4	0	2	0	2	0	2	0	0	2	**12**
Exploring	0	2	0	1	0	1	0	0	0	0	0	0	2	2	2	**6**
Planning	1	2	0	1	0	1	0	2	0	2	0	2	2	2	3	**12**
Making	1	2	0	1	0	1	0	2	0	2	0	2	2	2	3	**12**
Evaluating	1	2	0	1	0	1	0	2	0	2	0	2	2	2	3	**12**
TOTAL	**8**	**29**	**2**	**22**	**5**	**31**	**5**	**21**	**0**	**26**	**6**	**14**	**8**	**19**	**34**	**162**

Teachers in many cases further supported this skill development with Sarah’s comments illustrating the students’ learning process when it came to fair test investigations:

> Even with the paper towel [investigation], letting them make the mistake and then be like, is that really a fair test? Are you sure? And then they’re like, oh no, because this piece is bigger than the other piece, and we’re immersing the whole piece in the water…so we need to make them all the same size. It was important to give them the

> freedom maybe to go back and do it again if they made the mistake, like I suppose the problem solving. Because it was interesting with the skills assessment how many of them were not aware what a fair test was, and they would be very much aware now about what a fair test is. And that's a really good take away, I suppose that's a scientific skill, identifying a fair test, designing a fair test, conducting a fair test (Sarah, Case C, 4th class).

Opportunities to develop estimating and measuring skills were also more apparent post-intervention (from 0 reference to 15 references). Students (4/7 cases) and teachers (2/6) made reference to using thermometers and other measuring equipment post-intervention. Furthermore, prior to the SSIPSC programme students made limited reference to being provided with an opportunity to ask their own investigation questions. This was greatly enhanced post-intervention, moving from two references to 33 references (Table 4.9). This aligns with the quantitative data and discussion regarding child-led approaches in Table 4.8. Recording and communicating findings were also referenced more by the students in most cases (5/7) post-intervention. Pre-intervention, students spoke about recording results in their copy or telling the teacher their findings. During the exit interviews students discussed how they presented their findings at school assembly (Case C, 4th class), communicated information about the bees through posters displayed on the school grounds and presented their findings at RDS Young Scientist's Event: "We went to the RDS I enjoyed talking to people about our project and showing our project off" (Case D, 6th class, post-intervention). Communication to audiences outside school also emerged in the post-teacher interview:

> They would very rarely bring their parent into the classroom but they were bringing them in if we had a science display on or when we were doing sugar tax. For example, we had the scientific evidence out and parents were being dragged upstairs to come and look at it. They were really bringing the messages home (Case E, 6th class, post-intervention).

This illustrates that school science was no longer kept within the constraints of school or the students' classroom but the students began to communicate their findings to their families and wider community.

Additionally, the majority of cases (5/7: B, C, D, E, F) made no reference to the development of design and make skills pre-intervention. All cases made reference to these skills post-intervention. Students not only described the design and make process but also how they often had to revise or improve their designs to enhance their functionality: “Well it was bending [wind turbine model] so that’s why it was spinning slowly. So, we made another one out of cardboard and then it was spinning better” (Case D, 6th class, post-intervention). Some students also devised child-led investigations to evaluate their design “We had to come up with a way to test the strongest one [wind turbine]. We put a cup at the back to see how many rocks it would hold” (Case G, 3rd class, post-intervention). Other students applied their design and make skills to other units of the SSIPSC programme. For instance, Case E (6th class) designed and made solitary bee hotels for their school grounds. This is further discussed in Section 4.6 Student-led Citizenship.

4.3.4 Performance-based Skill Assessment

Sections 4.3.1 to 4.3.3 discussed students’ experience of IBSE and development of science skill through the analysis of quantitative and qualitative data. The PA skill assessment provided evidence of students’ ability to apply scientific inquiry skills and experience of IBSE to an investigation. Depending on the class size, a number of students from each case were randomly selected to conduct a practical investigation both prior to and after the SSIPSC intervention. Kilfeather, O’Leary and Varley (2007) devised the skill assessment for an Irish primary science context and their rubric was used to analyse and categorise students’ skills as ‘weak’, ‘fair’, ‘good’ or ‘excellent’ both at the initial and exit stages of the intervention. See Figure 4.3 below for students’ skill categorisations in each case pre and post-intervention.

The practical skill assessment data indicated that five out of the seven cases demonstrated enhancements in science skill categorisation from pre-intervention to post-intervention. Four cases (Case A - 4th class, Case B - 3rd class, Case C - 4th class, Case D - 6th class) correlated with the quantitative data and qualitative focus group data where findings indicated that the students had greater experience of IBSE post-intervention and this aligned with students' practical skill assessment where the students were able to demonstrate enhanced level of science skills

Figure 4.3

Data pertaining to Practical Skill Assessment

in the practical science investigation post-intervention. For instance, Case B (3rd class) reported limited opportunities to engage in IBSE pedagogies pre-intervention which is reflected in their science skills categorisation of 'fair' (3 students) and 'weak' (4 students). Post-intervention questionnaire data indicated that students had more experience of IBSE pedagogies with the difference being statistically significant (p<0.05) demonstrating a large effect size (r>0.5). Again this aligns with the practical skill assessment data where five students were classified as having 'good' science skills and two students as having 'excellent' science skills at the exit stage. Two of the cases (Case E - 6thclass, Case F - 3rd class) did not fully align with the quantitative data; For Case E (6th class) the scale data indicated a large significant (p<0.05) effect size (r>0.5) where the students had more frequent experience of IBSE post-intervention. The qualitative focus group interview data also indicated that the students had greater experience of child-led IBSE post-intervention. However, in the practical skill assessment, the students were categorised as having ‘excellent’ science skills both pre and post-intervention. In addition, Case F reported frequent experience of most IBSE methodologies in the pre-questionnaire data. However, the qualitative data indicated that the students had limited experience of child-led IBSE both pre and post-intervention. Thus, their score of ‘good’ in the skill assessment aligns somewhat with the quantitative scale data but seems high when compared to the qualitative findings.

It is apparent from the data that students in all cases, with the exception of Case F, were engaging more frequently with child-led inquiry-based approaches and less-frequently with teacher-led approaches post-intervention. Furthermore, post-intervention the lessons the students described were almost exclusively from the SSIPSC intervention (6/7 cases: A, B, C, D, E, G). It could therefore be suggested that the SSIPSC provided the students in most cases with more frequent opportunities to engage with inquiry-based pedagogies which had a positive impact on the development of the students’ science skills and their ability to apply them to practical science investigations. The significance of this is examined in socioscientific reasoning Section 4.5 where the students’ ability to apply these inquiry skills to a SSI is discussed.

4.4 Socioscientific Argumentation

Students (*n*=158) were asked to respond to the SSI Squirrel Scenario (see Appendix I for details of the scenario) in the open-ended question in the students’ questionnaire. These written arguments were analysed using Evagorou et al.’s (2012) analytical rubric. Students’ level of argumentation pertaining to the same scenario were assessed using the focus group interview data with Erduran et al.’s (2004) framework used to analyse students’ dialogic arguments. Results pertaining to students’ written argumentation and dialogic argumentation will be discussed here.

4.4.1 Student Written Argumentation

Students’ written argumentation responses provided data pertaining to students’ use of justifications to support decisions and the type of justifications used. Students were asked to make a decision pertaining to the SSI Squirrel Scenario and provide a justification for their decision in the pre and post-questionnaires. The students’ responses to the scenario were firstly categorised as kill [kill the grey squirrel], intermediate [do not kill the grey squirrel but control the population] and do not kill [do not kill the grey squirrel]. The justifications provided by the students were then analysed and categorised as (i) Rationalistic (ii) Emotive and (iii) No justification. Finally changes in students' justifications pre and post-intervention are discussed. Table 4.10 presents the total number and percentage of student decisions which were categorised as 'kill', 'intermediate' and 'do not kill' pre and post the SSIPSC intervention.

Table 4.10

Percentage of Student Reponses Categorised as 'Kill', 'Intermediate' and 'Do Not Kill'

CASE	**Kill** *No. of claims* (%)		**Intermediate** *No. of claims* (%)		**Do not kill** *No. of claims* (%)	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**
Case A (4th class)	15 (57.5%)	6 (23%)	3 (11.5%)	3 (11.5%)	8 (31%)	17 (65%)
Case B (3rd class)	23 (79%)	10 (33%)	4 (14%)	5 (17%)	2 (7%)	15 (50%)
Case C (4th class)	13 (50%)	7 (28%)	2 (8%)	3 (12%)	11 (42%)	15 (60%)
Case D (6th class)	2 (22%)	1 (12.5%)	3 (33%)	1 (12.5%)	4 (44%)	6 (75%)
Case E (6th class)	7 (33%)	4 (18%)	4 (19%)	1 (5%)	10 (47%)	17 (77%)
Case F (3rd class)	9 (69%)	5 (38%)	2 (15%)	3 (23%)	2 (15%)	5 (38%)
Case G (3rd class)	12 (52%)	3 (13%)	2 (9%)	1 (4%)	9 (39%)	19 (83%)
TOTAL	**81 (55%)**	**36 (24%)**	**20 (14%)**	**17 (12%)**	**46 (31%)**	**94 (64%)**

The data from Table 4.10 show that 55% of students decided to kill the grey squirrel pre-intervention. Post-intervention this was reduced to 24% of students. Case D and Case E, both 6th class cases, had the lowest percentage of students who decided to 'kill the grey squirrel' pre and post-intervention. Post-intervention the number of students who decided to kill the grey squirrel was reduced by about half in all cases; this corresponded with an increase in the number of students who decided not to kill the grey squirrel post-intervention. The intermediate section, categorised as those who do not wish to kill the grey squirrel but control the population, was the least popular category both pre and post-intervention. Thus the data in Table 4.10 presents a similar pattern of decisions across all cases where there was a decrease in 'kill the grey squirrel' category and an increase in 'do not kill the grey squirrel' category, post-intervention.

Students in all cases were asked to provide written justification for their decision. Figure 4.4 presents an overview of the number of students who provided a justification at the initial and exit stages of the study. Pre-intervention 43% of students did not provide a justification to support their decision. These students' responses include ones such as 'Kill the grey squirrel', 'We shouldn't kill it', 'Die grey squirrel die' and 'Yes shoot, trap or poison the grey squirrel because he is bad, so kill the grey squirrel'. Post-intervention 86% of students provided a range of justifications for instance: 'No. Try and solve the problem, Carry out tests on the grey squirrel. When you find something that works give it to all the grey squirrels through the acorns' or 'Kill it because it is not native to Ireland and they carry diseases'.

Figure 4.4

Students who provided Justification for the SSI Scenario

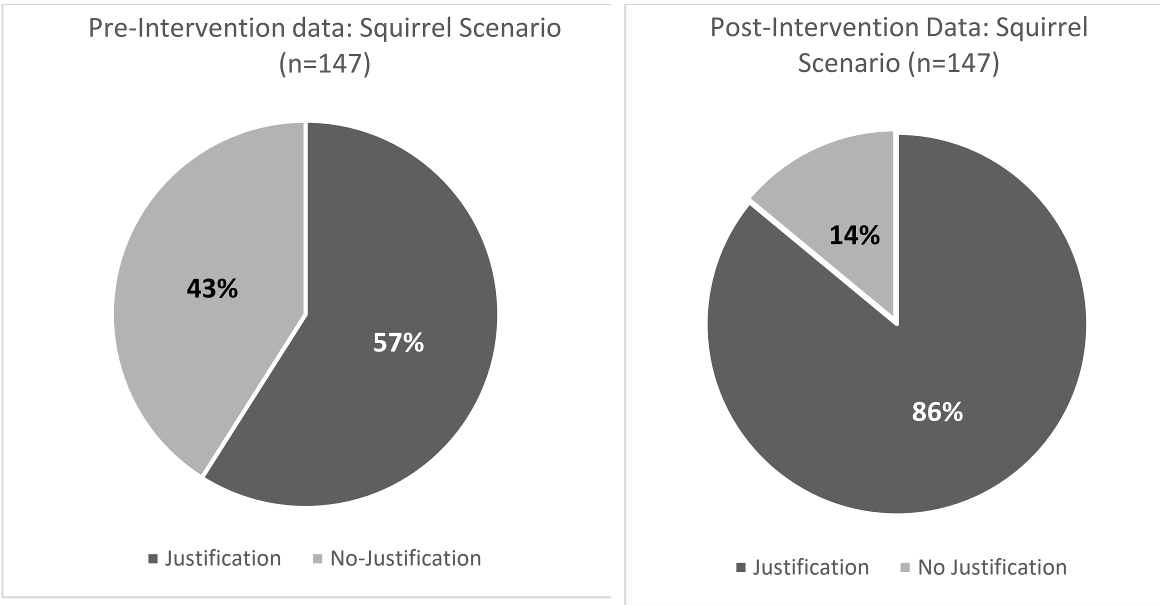


Table 4.11 presents data pertaining to the number of justifications per case pre and post-intervention. In most cases (6/7) the number of students who provided justifications increased post-intervention. Case D is the only exception where all students in the 6th class provided justifications pre and post-intervention.

Table 4.11

Number of Students who provided Justifications according to each Case

Case	**Pre-Intervention Justification** *No. of students (percentage) who provided a justification*	**Post-Intervention Justification** *No. of students (percentage) who provided a justification*	**Difference** *+ more* *- less*
A (4th class)	20 students (77%)	24 students (92%)	+15%
B (3rd class)	11 students (39%)	28 students (93%)	+54%
C (4th class)	15 students (58%)	23 students (92%)	+34%
D (6th class)	9 students (100%)	8 students (100%)	-
E (6th class)	18 students (82%)	21 students (95%)	+13%
F (3rd class)	0 students (0%)	7 students (54%)	+54%
G (3rd class)	11 students (47%)	16 students (70%)	+23%

A general pattern can be seen above, where the cases with the least number of justifications pre-intervention made the largest increase in justifications post-intervention and the cases with the highest number of justifications pre-intervention made the lowest percentage increases post-intervention. It could also be said that a greater percentage of students in the older classes (i.e. 6th class) provided justifications both pre and post-intervention.

Students' justifications in each case were then categorised into 'emotive', 'rationalistic' or 'emotive and rationalistic', see Table 4.12. This data indicates that not only did more students provide justifications in most cases at the exit stage of the study, there was also a larger cohort of students who provided rationalistic justifications post-intervention.

Pre-intervention, three cases provided more emotive than rationalistic justifications (Case A - 4th class, Case B - 3rd class, Case C - 4th class), post-intervention all cases provided more rationalistic than emotive justifications with the exception of Case F. Thus it could be said that the

Table 4.12

Categorisation of Students' Justifications as Emotive or Rationalistic

Case	**Pre-Intervention Justification** *No. (%) of emotive and rationalistic justification*		**Post-Intervention Justification** *No. (%) of emotive and rationalistic justification*	
A (4th class)	20 students (77%)		24 students (92%)	
	Emotive	*Rationalistic*	*Emotive*	*Rationalistic*
	16 students (62%)*	5 students (19%)*	8 students (31%)*	19 students (73%)*
B (3rd class)	11 students (39%)		28 students (93%)	
	Emotive	*Rationalistic*	*Emotive*	*Rationalistic*
	7 students (25%)	4 students (14%)	5 students (17%)*	25 students (83%)*
C (4th class)	15 students (58%)		23 students (92%)	
	Emotive	*Rationalistic*	*Emotive*	*Rationalistic*
	13 students (50%)*	3 students (12%)*	7 students (28%)*	17 students (68%)*
D (6th class)	9 students (100%)		8 students (100%)	
	Emotive	*Rationalistic*	*Emotive*	*Rationalistic*
	4 students (44%)*	6 students (67%)*	1 student (12.5%)	7 students (87.5%)
E (6th class)	18 students (86%)		21 students (95%)	
	Emotive	*Rationalistic*	*Emotive*	*Rationalistic*
	8 students (38%)*	12 students (57%)*	4 students (18%)*	21 students (95%)*
F (3rd class)	0 students (0%)		7 students (54%)	
	Emotive	*Rationalistic*	*Emotive*	*Rationalistic*
	-	-	5 students (38%)	2 students (15%)
G (3rd class)	11 students (48%)		16 students (70%)	
	Emotive	*Rationalistic*	*Emotive*	*Rationalistic*
	4 students (17%)	7 students (30%)	1 students (4%)	15 students (65%.5)
Total	57% of students provided justification (*n*=146)		86% of students provided justifications (*n*=147)	
	Emotive	*Rationalistic*	*Emotive*	*Rationalistic*
	52 students (35%)*	37 students (25%)*	31 students (21%)*	106 students (72%)*

* If a student's response was categorised as both emotive and rationalistic it was put into two categorisations. Thus the total percentage may be over the total % of students who provided justifications.

majority of students (57%) who provided justifications pre-intervention were doing so based on an emotive justification whereas post-intervention, students' justifications became more rationalistic (72%) where many began to consider the role of evidence (social, economic, scientific) to help them make a decision and/or the role of scientists in coming up with alternative solutions to the SSIs. The following are some examples of changes in students' justifications from pre to post-intervention to illustrate this movement:

Table 4.13

Examples of Student Socioscientific Arguments from Pre-Intervention to Post-Intervention

No Justification (pre)
"Kill the grey squirrel" (pre). **Student B31**

Rationalistic (post)
"Yes kill the grey squirrel. The red squirrel is native. The grey squirrel in not. The red squirrel is going extinct and there are plenty of grey squirrels in other countries. The grey squirrel is native to America" (post). **Student B31**

Emotive (pre)
"Yes because red squirrels are nice and the grey ones are not; they are trying to kill the red ones" (pre) **Student A3**

Rationalistic and Emotive (post)
"I don't think the grey means to kill the red squirrel. We should trap the grey squirrel and test them to find out what disease they have. Scientists and doctors should make medicines or a vaccination" (post) **Student A3**

Emotive (pre)
"No we should not kill the grey squirrel because both are nice on the inside" (pre) **Student C9**

Rationalistic (post)
"No. we need to plant more trees so that there are more acorns. We should make something that we will keep the acorns away from the grey squirrel until they are ripe" (post) **Student C9**

Emotive (pre)
"No because they [grey squirrel] don't know what they're doing and they don't mean to" (pre). **Student E4**

Rationalistic (post)
"No the words highlighted above are the words [the students highlighted text in the scenario] that mean maybe ('may be' and 'that can' highlighted). They [scientists] don't know fully. Something else could be causing it" (post). **Student E4**

In summary, pre-intervention over 40% of students did not provide a justification but made a decision regarding the Squirrel SSI. Furthermore, out of those who provided justifications pre-intervention, the majority of students provided emotive justifications (for example sympathy or empathy towards the grey squirrel). Post-intervention responses indicated that a larger cohort of students (64%) decided not to kill the grey squirrel, a larger cohort of students provided justifications (86%) and the larger majority of these justifications were categorised as rationalistic justifications (71%) (i.e. reasoned-based decision). Thus it could be said that, as students devised more rationalistic justifications, this could have had an impact on students' decision as to whether or not to kill the grey squirrel with the majority of students (64%) deciding the latter, post-intervention.

4.4.2 Student Dialogic Argumentation

The qualitative data from the student focus group SSI scenario discussions was analysed in terms the structure and quality of the students' dialogic argumentation. Erduran et al.'s (2004) analytical framework was used to analyse the students' arguments based on the principles of Toulmin's (1958) TAP framework. Table 4.14 presents students' level of argument for each case both pre and post-intervention.

Table 4.14

Case Level of Argumentation Pre and Post-Intervention

Case	Pre-Intervention Level	Post-Intervention Level
A (*n*=27, 4th class)	2	2
B (*n*=32, 3rd class)	2	2
C (*n*=28, 4th class)	2	2
D (*n*=9, 6th class)	2	3
E (*n*=23, 6th class)	3	4
F (*n*=13, 3rd class)	2	2
G (*n*=26, 3rd class)	2	2

Evidently all cases engaged in argumentation during the pre-intervention focus group discussion. As shown in Table 4.14, pre-intervention most cases were categorised at a level 2 where students were able to make claims supported by a piece of evidence: "I'd say just leave it [leave both the red squirrels and grey squirrels] because there'll still be other squirrels all over the world [no student responds to this justification (researcher note)] (Case A, 4th class, pre-intervention)". One case, Case E (6th class), was categorised as a level 3 where the students provided a claim, warrant and backing when discussing the SSI test scenario:

> Well then I think if you find any grey squirrels maybe capture them and bring them to a different place like a squirrel sanctuary to stop the spread of the disease [claim and warrant] (Student D, Case E)
>
> That's not fair. The grey squirrel doesn't know what it's doing [counter claim and warrant] (Student C, Case E)
>
> I get what you're saying but the red squirrels are close to extinction and it would give them time to reproduce [counterclaim and backing] (Student D, Case E).

Post-intervention, only two of the cases, Case D and E, both 6th classes, improved their level of argumentation. Thus it seems that the students in all cases had reached the claim and warrant stage of Erduran et al.'s (2004) framework but most cases were not yet fully competent at counter-arguments or rebuttals.

Applying Evagorou's (2011) 'counting evidence' analysis it became evident that even though there were no improvements in the level of argumentation, in most cases (5/7), there was an improvement in the content of their arguments. The following is an example of an argument constructed by Case C (4th class) pre-intervention followed by an argument constructed by Case C post-intervention which illustrates this change in the content of students' arguments:

> I think if the grey squirrel gets killed then it will be better for the red squirrel to live, as the red squirrel was the one that was found in Ireland (Case C, 4th class, pre-intervention).

> I think we should kill the grey squirrel because the red squirrel is our native animal. There are plenty of squirrels in other countries. They have them in America. I think that we should like say get nuts in forests and like people could trap them and then they should kill them (Case C, 4th class, post-intervention).

Pre-intervention, the student in Case C (4th) provided one piece of evidence to support their decision to kill the grey squirrel. Post-intervention the student cited additional pieces of evidence to support the decision to remove the grey squirrel including stating that the squirrel is Ireland's native animal and that there are grey squirrels in other countries. So while this would have been categorised as level 2 argumentation using Erduran et al.'s (2004) framework, the number or pieces of evidence referred to adds depth to the analysis of the students' argumentation. Table 4.15 presents the number of pieces of evidence each case made reference to in the pre and post-intervention focus groups.

Table 4.15

No. of Pieces of Evidence used by each Case to Support Argument Pre and Post-Intervention

CASE	Pre-Intervention		Post-Intervention	
	Level	**Evidence***	**Level**	**Evidence***
A (*n*=27, 4th class)	2	1	2	3
B (*n*=32, 3rd class)	2	2	2	2
C (*n*=28, 4th class)	2	2	2	3
D (*n*=9, 6th class)	2	2	3	4
E (*n*=23, 6th class)	3	2	4	4
F (*n*=13, 3rd class)	2	1	2	2
G (*n*=26, 3rd class)	2	2	2	3

* The argument that used the most pieces of evidence was selected from each focus group discussion pre and post-intervention.

Therefore, even though Case D (6th class) and E (6th class) were the only groups that improved in terms of level of argumentation, the majority of groups (6/7: A, B, C, D, E, F, G) included students who increased the number of pieces of evidence they used to support their justifications post-intervention. Case B, a 3rd class case, was the only case that remained the same pre and post-intervention.

In the teacher and student interviews, both commented on discussion/debate as an important and enjoyable feature of the SSIPSC intervention. The teachers (6/6) indicated that discussion and debate was something they had not incorporated into their science lessons prior to this study and was therefore a new pedagogical approach for teaching science. Eva highlighted that because 'discussion' is not an explicit skill in the primary science curriculum it was often something she never considered including in her science lessons: "Definitely not. I think because it wasn't in the curriculum and because it wasn't in the book" (Case B, 3rd class). Other teachers (2/6) indicated that persuasive writing was taught as part of the literacy curriculum but that the SSIs underpinning the SSIPSC intervention added a real-life context to discussion and debates:

> I suppose, it [SSIPSC intervention] kind of gave them more of a meaning behind the discussion, as opposed to just saying, okay, you're for or against this motion, go and write me a debate…whereas this, they were able to discuss and then kind of like argue or debate against each other about the same issue... And that was good because it's not just black and white. Whereas, sometimes when you're just teaching persuasive writing it's very like, you're either yes or no, or, today we're going to write for and tomorrow we're writing against. And this is how you write it and this is how you lay it out. Whereas, that gave them an opportunity to see it in a real context (Sarah, Case C, 4th class).

Furthermore, many students stated that they had no experience of discussion/debates in science prior to the SSIPSC intervention: "No. We did a walking debate in English, so it would be like, 'I agree' 'I disagree' 'I'm not sure'. So, you got to get up and walk and then speak about it" (Case E, 6th class, post-intervention). The third class teachers in Case B and G confirmed that the students in their classes had limited experience of discussion/debates and highlighted that this lack of experience was challenging in that it took additional time to develop the students' skills and scaffold their ability to support their arguments with evidence instead of the students' opinion:

> Yeah, that was kind of the harder bit I think for the third classes. Just because they didn't do anything like this before, it was hard for them to keep the evidence behind whatever they were saying instead of just their opinion (Anne, Case G, 3rd class).

Students in Case F (3rd class) did not make reference to the discussion or debate component of the SSIPSC intervention.

Quantitative analysis of the students' socioscientific argumentation indicated that only two cases enhanced their level of argumentation from pre-intervention to post-intervention with many remaining at the 'claim and warrant' level. In spite of this, students in most cases (6/7) became more competent using evidence when justifying decisions, making reference to more pieces of evidence to support their argument at the exit stage of the study. Discussion and debate as part of primary science was a new pedagogical approach for teachers and one which provided the students with opportunities to engage in socioscientific argumentation pertaining to the SSIs.

4.5 Socioscientific Reasoning

Students were asked to discuss two SSI test scenarios 'Bee Scenario' and 'Energy Scenario' in their focus groups pre and post-intervention. Details of the scenarios can be found in Appendix M. Note the 'SSI scenarios' referred to throughout this section were part of the qualitative focus group questions and these SSI scenarios, while authentic and relevant to the students' lives, were not an explicit feature of the SSIPSC intervention. Findings pertaining to socioscientific reasoning are discussed under: 'appreciation of the complexity of the SSI', 'approaching the SSI from multiple perspectives', and 'the value of ongoing inquiry'. Each of these sub-constructs of socioscientific reasoning were analysed using a rubric devised by Sadler et al. (2011). Four performance levels were utilised for each construct with each level identified numerically (1-4); a higher number represented more sophisticated practice. Each construct will now be discussed.

4.5.1 Appreciation of the Complexity of the SSI

Sample categorisation of the students' responses according to each level of 'appreciation of the complexity of the SSI' can be found in Table 4.16. Recognising the inherent complexities of a SSI involves recognising that an issue has different scientific and social components (Sadler et al., 2007).

Table 4.16

Sample Classification of Student Responses in terms of Appreciation of the Complexity of the SSI.

Levels	1	2	3	4
	Offers a very simplistic or illogical solution without considering multiple factors.	Considers pros and cons but ultimately frame the issue as being relatively simple with a single solution.	Construes the issues as relatively complex primarily because of a lack of information. Potential solution tends to be tentative or inquiry-based.	Perceives general complexity of the issue based on different stakeholder interests and opinions. Potential solutions are tentative or inquiry-based.
Bee Scenario: Exemplar quote	*You should make a big wall, like the wall of China, and try and separate…the pesticides or the bees, so the wall would probably need to be super high so the bees don't fly over.*	*I think they should not ban them [pesticides], because say they ban them and insects just kept like eating our food, vegetables and everything? Then we wouldn't have anything to eat. And by the way Tom's bees are going to die anyway in the winter, so it doesn't really matter if they die early.*	*Well I'll say I don't know because I say we need bees –bees make our vegetables but then we need to get the vegetables to eat so that we stay alive so I'd say it's kind of both we need because we need like say to keep insects off so we can get our food*	*it'll be even worse for the vegetable farmer if he goes around killing the bees. Because then the bees cannot pollinate the tree or perhaps the flower to produce the fruit or veg and then he definitely won't be able to sell the fruit or vegetables.*
Energy Scenario: Exemplar quote	*Wind turbines could blow the carbon dioxide away.*	*Wind turbines are better for the energy.* Why? *Because it's reusing renewable energy because we can use that over and over and over. It's not making carbon dioxide.*	*It is difficult because we don't know for sure if the wind farm is causing noise pollution for the people living beside them.*	*Some people think that it's not going to affect them. Like, they keep driving around in a car that burns off loads of fossil fuels and they're like, it doesn't affect me, I'll be dead by the time it actually gets bad. People make decisions so fast when they're not investigating it more. They just make the decision.*

The number of times the students made a statement that aligned with a level on the scale (Table 4.16) was quantified to allow a comparative analysis of the 'appreciation of the complexity of the SSI' sub-construct from pre-intervention to post-intervention (Table 4.17).

Table 4.17

Quantification and Percentage of Student Responses according to level of Appreciation of the Complexity of the SSI in each Case Pre and Post-Intervention.

CASE	Level 1		Level 2		Level 3		Level 4		Total	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
A *n*=5/27, 4th class	5 (38%)	1 (11%)	8 (61%)	2 (22%)	0 (0%)	4 (44%)	0 (0%)	2 (22%)	13	9
B *n*=5/32, 3rd class	10 (83%)	3 (27%)	1 (8%)	4 (36%)	1 (8%)	3 (27%)	0 (0%)	1 (9%)	12	11
C *n*=5/28, 4th class	8 (73%)	1 (11%)	2 (18%)	4 (44%)	1 (9%)	3 (33%)	0 (0%)	1 (11%)	11	9
D *n*=5/9, 6th class	4 (36%)	0 (0%)	4 (36%)	3 (27%)	3 (27%)	4 (36%)	0 (0%)	4 (36%)	11	11
E *n*=5/23, 6th class	3 (27%)	0 (0%)	4 (36%)	2 (17%)	4 (36%)	5 (42%)	0 (0%)	5 (42%)	11	12
F *n*=5/13, 3rd class	12 (92%)	7 (64%)	1 (8%)	4 (36%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	13	11
G *n*=5/26, 3rd class	7 (47%)	3 (25%)	4 (27%)	5 (42%)	4 (27%)	2 (17%)	0 (0%)	2 (17%)	15	12
Total	**49 (57%)**	**15 (20%)**	**24 (28%)**	**24 (32%)**	**13 (15%)**	**21 (28%)**	**0 (0%)**	**15 (20%)**	86	75

Looking at the data above, all cases present evidence of movement towards higher levels of 'appreciation of the complexity of the SSI' post-intervention. Pre-intervention, over 50% of statements align with level 1 where students offered simplistic solutions of a cause and effect nature without recognising the inherent complexity of the issues presented in the SSI scenarios. No level 4 responses were identified in the pre-intervention data. Post-intervention, 20% of responses were categorised as level 1 with a corresponding increase (+33%) in the number of responses categorised in the level 3 and 4 categories. Furthermore, the sixth class cases (Case D and E) had the highest proportion of level 3 and 4 categories at the exit stage of the study. The 'transferability' of students' content knowledge emerged as a theme in the students' focus group responses to the SSI test scenarios. To take one example from the students' focus group interviews, pre-intervention the 6th class students in Case E put forward the proposal of separating the bees from the vegetables to prevent the bees being affected by the pesticides that the farmer was spraying on his vegetables. Possible solutions included building a high wall, moving the bees to a new location or building a bee hive for the bees to stay in. These solutions demonstrate a lack of conceptual understanding of the importance and function of bees in society and more specifically their role in the pollination of the farmers' vegetables in the first instance. This was further supported by students' comments which indicated that while they felt bees were important for the generation of honey, bees were of little importance in comparison to the farmer's vegetables. Post-intervention students demonstrated enhanced understanding of bees and their role in pollinating the plants. This immediately affected the students' responses to this SSI test scenario as they understood the need for the bees to pollinate the farmers' vegetables. For the students, their enhanced level of science content knowledge resulted in the SSI becoming more complex and they presented alternative solutions and inquiries. The 6th class discussion in Table 4.18 is another example of this. Case F was the only case which remained at level 1 and 2 post-intervention; triangulating this data with science content knowledge development (Section 4.1) the students in this case presented a high number of inaccurate science conceptions post-intervention which may have had a subsequent impact on their interpretation of the complexity of the SSI.

Students' ability to apply their content knowledge to SSI discussions also emerged as a theme in four of the teacher interviews. Jack's comment is representative of the teachers' responses:

> They structured their debates on the things that they had found out as part of the experiments…especially like with the paper cups… I can really see now they were using the knowledge they'd found in that investigation to prop up the debate, like…this is what

we know and this is how we know (Case A, 4th class).

Table 4.18

Extract from Case D Discussion pertaining to Appreciation of the Complexity of the SSI Pre and Post-Intervention

Pre-Intervention	**Post-Intervention**
I think that they should ban the spray because we need to care about the animals because God make them and because they're like humans and it's not really nice to kill them because…the animals don't kill us or do nothing to us [Student]. *Okay, so what do you think [Researcher]?* Well personally I think they should ban it but I mean you could also just like move his vegetables inside maybe…so the bees can't get in [Student]. *Okay. RJ what do you think [Researcher]?* Well I think that bees are very important because they make honey and it's actually good for you if you have a cough. They also get pollen but I'm not exactly sure what it helps with but I know that it helps [Student]. (Case D Pre-Intervention)	Well I'm not too sure but I would stop using it and then just try to find other ways of stopping the insects from getting in. Like the bees pollinate…if he doesn't have bees, his vegetables won't get pollinated, meaning that he will still lose his crops [Student]. *And what do you think? Should John continue to spray his fruit and vegetables [Researcher]?* I'm just like in my head like bee, vegetables, bee, vegetables. I don't know because I say we need bees –bees make our vegetables but then we need to get the vegetables to eat so that we stay alive so I'd say it's kind of both we need because we need like say to keep insects off so we can get our food. We should get a spray like that does not kill any bees [Student]. (Case D, Post-Intervention).

Evidently the students were using the evidence gathered to make informed arguments when discussing a SSI scenario as part of the SSIPSC intervention. This is further supported by developments in the students' use of evidence to support their arguments post-intervention, as discussed under Socioscientific Argumentation in Section 4.4. Additionally, all teachers reported that they did not include discussion or debates in science lessons prior to the intervention. Thus, it seems that the SSIPSC intervention was providing the students with opportunities to apply their science content knowledge to the discussion of SSIs relevant to the students' everyday lives.

4.5.2 ***Approaching the SSI from Multiple Perspectives***

The 'approaching the SSI from multiple perspectives' sub-construct of socioscientific reasoning reflects how participants are able to examine an issue from multiple perspectives. See

Table 4.19 for examples of each level across both SSI test scenarios.

Table 4.19

Sample Classification of Student Responses in terms of Approaching the SSI from Multiple Perspectives

Levels	**1**	**2**	**3**	**4**
	Fails to carefully examine the issue.	Assess the issue from a single perspective.	Can examine a unique perspective when asked to do so.	Assesses the issue from multiple perspectives.
Bee Scenario: Exemplar quote	*I think they should not ban that [the pesticides].* Why do you think that? *I'm not sure.*	*Think they shouldn't ban the insect spray because we need to eat vegetables to be healthy.*	Why might someone disagree with your solution? *Well the farmer, he won't have any food to sell and then he might run out of money and also, he won't have enough food to feed himself.*	*Well I'll say I don't know because I say we need bees –bees make our vegetables but then we need to get the vegetables to eat so that we stay alive so I'd say it's kind of both we need because we need to keep insects off so we can get our food in the first place.*
Energy Scenario: Exemplar quote	*I think wind energy will work well* Why do you think that? Maybe the wind will blow the carbon dioxide away?	*People don't want to spend so much money on [electric cars]. They don't want to put the effort into like… building more wind turbines to like do stuff like that and they're just not bothered.*	Why might someone disagree with your solution? *If they live near a city it [wind turbines] would cause noise pollution meaning some people won't work as well and it will be harder for people to get to sleep. I didn't want to say that.*	*Well then it's still happening even though you're thinking 'Oh look, I have an electric car. That means I'm saving the world' but really you need to make sure you're buying it off, like all the energy is coming from a solar panel or a wind turbine. But then some people can't even afford electric cars, they're too expensive.*

The number of times the students made a statement that aligned with a level on the scale above was quantified pre-intervention and post-intervention data (Table 4.20). This data indicates that there was an enhanced level of 'perspective' across the seven cases to varying degrees post-intervention. Pre-intervention, over 80% of responses were categorised as level 1 and level 2 'approaching the SSI from multiple perspectives' which indicates that students were predominantly looking at an issue from a single perspective or failing to examine the issue carefully. Post-intervention, over 70% of responses were categorised as being capable of examining the issue from multiple perspectives (level 3 (with probing) and level 4 (without probing)). Case F was the only case that remained predominantly at level 1 and 2 with only one statement being categorised as level 3 post-intervention.

Table 4.20

Quantification and Percentage of Student Responses according to level of Approaching the SSI from Multiple Perspectives in each Case Pre and Post-Intervention.

CASE	Level 1		Level 2		Level 3		Level 4		Total	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
A *n*=5/27, 4th class	2 (50%)	0 (0%)	1 (25%)	0 (0%)	1 (25%)	5 (83%)	0 (0%)	1 (17%)	4	6
B *n*=5/32, 3rd class	4 (50%)	0 (0%)	2 (25%)	1 (11%)	2 (25%)	4 (44%)	0 (0%)	4 (44%)	8	9
C *n*=5/28, 4th class	5 (83%)	0 (0%)	1 (17%)	2 (29%)	0 (0%)	2 (29%)	0 (0%)	3 (43%)	6	7
D *n*=5/9, 6th class	9 (69%)	0 (0%)	3 (23%)	0 (0%)	1 (8%)	3 (33%)	0 (0%)	6 (67%)	13	9
E *n*=5/23, 6th class	0 (0%)	0 (0%)	2 (40%)	0 (0%)	1 (20%)	4 (36%)	2 (40%)	7 (64%)	5	11
F *n*=5/13, 3rd class	5 (83%)	5 (63%)	1 (17%)	2 (25%)	0 (0%)	1 (13%)	0 (0%)	0 (0%)	6	8
G *n*=5/26, 3rd class	1 (14%)	0 (0%)	4 (57%)	4 (36%)	2 (29%)	5 (45%)	0 (0%)	2 (18%)	7	11
Total	26 (53%)	5 (8%)	14 (29%)	9 (15%)	7 (14%)	24 (39%)	2 (4%)	23 (38%)	49	61

Through analysis of the qualitative data, it became apparent that the students were beginning to examine the SSIs from multiple perspectives post-intervention; they reasoned using a number of different perspectives namely, environmental, economic, social and scientific perspectives. The following excerpt from Case E (6th class) is an example of this:

I get what the farmer is trying to do. He is trying to make sure that the food is fit for human consumption [Student A].

But it'll be even worse for him if he goes around killing the bees. Because then the bees cannot pollinate the tree or perhaps the flower to produce the fruit or veg and then he *will* run out of money [Student B].

You know it's more expensive to [produce] organic [Student A].

The reason they're expensive is because they have to make sure nothing gets to it without using anything that is like a killer [Student B].

Here the students were examining the SSI from the farmer's, environmental and economic perspectives. Also evident are the students' considerations of the implications and consequences of decisions-made whereby the students attempted to weigh up different options. Furthermore, it seems that providing the students with opportunities to engage in discourse pertaining to SSIs allowed the students to hear and respond to different perspectives on the SSI. Examining SSIs from multiple perspectives was an explicit feature of the SSIPSC programme and it seems that the students were able to transfer this skill to the SSI test scenarios. One teacher supported this assertion stating that the SSISPC intervention provided opportunities to see issues from the perspectives of different stakeholders which added to the complexity of making decisions pertaining to SSIs.

[Post-intervention] they [the students] were able to discuss and then argue or debate against each other about the same issue, but from different perspectives. And that came from the roles, for example in the wind farm unit, they all had the different roles, and then they were like, well I don't know if this person is for or against…And that was good because…that gave them an opportunity to see how complex issues are actually discussed.

4.5.3 ***The Value of Ongoing Inquiry***

Table 4.21 provides descriptions and interview excerpts to support 'the value of ongoing inquiry' categorisations across the two scenarios.

Table 4.21

Sample Classification of Student Responses in terms of the Value of Ongoing Inquiry

Levels	**1**	**2**	**3**	**4**
	Fails to recognise the need for inquiry.	Presents vague suggestions for inquiry.	Suggests a plan for inquiry focused in the collected on scientific or social data.	Suggest a plan for inquiry focused on the collection of scientific and social data.
Bee Scenario: Exemplar quote	*Yeah.* *We probably should [continue to use pesticides], because honey isn't actually that very good for you, but your fruit is.* *Honey is only good if you have like a bad cough and you eat honey*	*Well because first of all you don't know if it is [pesticides] killing the bees. It could be, could not and it depends… so, we need to know that.*	*They could get…like some antidotes and then they could test it. They could get a few bees and test it on them and other insects and then they could see 'Does this kill insects, but not kill bees?' So, they're not quite sure now, but if they did that they would.*	*No exemplar*
Energy Scenario: Exemplar quote	Do you think we need more information before we make a decision? *No I think I have enough information.*	*Scientists need to investigate the issue more. They're not doing enough.*	*I would agree that we should [have renewable forms of energy] but like we need to find out the right type; the solar panels need sunlight and in Ireland we don't get a lot of sunlight so if they built a wind turbine they could generate electricity easier.*	*No exemplar*

The number of times the students made a statement that aligned with a level on 'the value of ongoing inquiry' scale above was quantified (Table 4.22). More advanced levels of the 'value of ongoing inquiry' were evident across six of the seven cases post-intervention. A similar pattern to the 'appreciation of the complexity of the SSI' and 'approaching the SSI from multiple perspectives' scales emerged, where the number of level 1 responses decreased from pre-intervention to post-intervention. Case F was an exception in this scale also where responses to the scenarios were recorded as level 1 both at the initial and exit stages of the intervention. Of note there were no level 4 responses categorised either pre or post-intervention in that there was evidence of plans of inquiry for scientific data but plans of inquiry for social data did not emerge across any of the cases.

Table 4.22

Quantification and Percentage of Student Responses According to level of the Value of Ongoing Inquiry in each Case Pre and Post-Intervention.

CASE	Level 1		Level 2		Level 3		Level 4		Total	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
A *n*=5/27, 4th class	1 (20%)	0 (0%)	4 (80%)	3 (38%)	0 (0%)	5 (63%)	0 (0%)	0 (0%)	5	8
B *n*=5/32, 3rd class	1 (17%)	1 (11%)	2 (33%)	5 (56%)	3 (50%)	3 (33%)	0 (0%)	0 (0%)	6	9
C *n*=5/28, 4th class	7 (70%)	2 (13%)	3 (30%)	8 (50%)	0 (0%)	6 (38%)	0 (0%)	0 (0%)	10	16
D *n*=5/9, 6th class	9 (75%)	0 (0%)	3 (25%)	7 (44%)	0 (0%)	9 (56%)	0 (0%)	0 (0%)	12	16
E *n*=5/23, 6th class	0 (0%)	0 (0%)	9 (60%)	7 (44%)	6 (40%)	9 (56%)	0 (0%)	0 (0%)	15	16
F *n*=5/13, 3rd class	4 (100%)	4 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	4	4
G *n*=5/26, 3rd class	2 (14%)	2 (13%)	8 (57%)	5 (33%)	4 (28%)	8 (53%)	0 (0%)	0 (0%)	14	15
Total	24 (36%)	9 (11%)	29 (44%)	35 (42%)	13 (20%)	40 (48%)	0 (0%)	0 (0%)	66	84

The qualitative focus group data provided further evidence to support a movement from vague suggestions of inquiry (level 1) to the presentation of plans recognising the importance of ongoing inquiry that focused on the collection of data (level 3). Student responses became more in-depth when describing inquiries at the exit stage of the intervention, as shown in the following example from the same student in Case E (6th class): "Can they make a spray that won't affect the bees?" (pre-intervention) to:

> We would need evidence to say that it [pesticides] definitely does harm the bees. They could get like some pesticide and then they could test it, they could get a few bees and test it on them and other insects and then they could see 'Does this kill insects, but not kill

bees?' at the moment they're not 100 % sure, but if they did that they would be (post-intervention).

This illustrates a more focused plan of inquiry post-intervention. Furthermore, it also demonstrates students' recognition for the need of additional data before making a decision on the issue. The necessity for data also emerged as a theme in the squirrel scenario (see the argumentation Section 4.4). Even through the squirrel scenario was not analysed using the socioscientific reasoning scale, students in five out of the seven cases requested further information/further investigations before they were willing to make a decision on the squirrel SSI post-intervention:

> I think the next step should be to see the amount of grey squirrels and the amount of red squirrels. We need to see what difference has been made between red squirrels being extinct and the grey squirrels being extinct. Then if it gets worse… I think they should bring them into a lab and get the medicine or an antidote and try and fix them (Case G, 3rd class).

This demonstrates that students in some cases were able to transfer their inquiry skills to other SSIs contexts. Case F remained at level 2 inquiry pre and post-intervention. Referring to the qualitative data in Section 4.3, the students in Case F did not refer to any of the inquiries as part of the SSIPSC programme when discussing their science lessons. Their possible lack of engagement with the SSIPSC intervention may have inhibited the development of, and subsequent transfer of inquiry skills to the SSI scenarios.

In relation to SSR, the quantified data indicated that the students in most cases had more informed understanding of 'the appreciation of the complexity of the SSI', 'approaching the issue from multiple perspectives', and 'the value of ongoing inquiry' post-intervention; this varied to different degrees across the different cases. The qualitative data from the students' focus groups indicated that there is a possible correlation between the development of science content knowledge and the level of 'appreciation of the complexity of the SSI'; in that it seems that when students had a high level of science content knowledge they had a more informed understanding of the complexity of the SSI. Many students were also capable of examining an issue from multiple perspectives post-intervention demonstrating cognisance of social, economic and environmental perspectives of a SSI. The necessity for scientific inquiry also came to the fore especially when some students requested further information prior to making a decision on a SSI. Finally, teachers in all cases also saw the value of discussion and debate in science, something which was not a feature of teachers' pedagogical approach to school science prior to the intervention.

4.6 Student-Led Citizenship

Student-led citizenship emerged as a prominent theme in the student focus groups and teacher interviews. It was not an explicit feature of the SSIPSC intervention. However, this theme emerged from the qualitative data thematic analysis. For instance, students in Case B and G, both 3rd class cases, felt compelled to provide a suitable habitat for the bees and communicate their findings regarding bees' importance to society, to their family and wider school community. They initiated a campaign to highlight how their school and family contribute to the decline of bee populations and took a series of actions to tackle this SSI: "Well yeah. I planted, my family planted flowers outside our house, lavender and other stuff and in the back garden so that they can get more flowers, meaning that they can pollinate more" (Case B, post-intervention). Students in Case D (6th class) described how they felt empowered when they contacted their local lunch company and were successful at convincing them to change the single-use plastic packaging used on their lunches. Similarly, other students highlighted the importance of taking action to reduce energy consumption in school: turning off lights and walking to school where possible (Case G, 3rd class, post-intervention). At a personal level, some students made lifestyle changes in terms of their consumption of fizzy drinks (Case B, 3rd class). It became apparent that the students were not only learning about SSIs but also taking action in response to the issues explored at a local level: "All the science that we're learning, it's been interesting. It's very good for our brains to like develop these solutions because it could really help us when we're older" (Case G, 3rd class, post-intervention). Taking action about these real world issues also influenced the students' positive attitudes towards school science in many of the cases (Case B - 3rd class, Case C - 4th class, Case G - 3rd class). Students in these cases indicated that they preferred science lessons where they were provided with opportunity to discuss and tackle issues like climate change: “It’s way better now [science lessons] because we get to learn about like problems in the world, you get to share your opinion on how it can be changed, whereas looking in the book isn’t going to do anything” (Case E, 6th class, post-intervention).

The teachers’ post-interview responses were also illuminating in this regard. Many teachers (3/6) spoke at depth about how the children were applying their science content knowledge to their everyday lives; planting bee gardens at home, implementing whole school plans to reduce recycling, reducing their intake of sugary drinks. Other students were enthusiastic about sharing their learning with their parents/guardians in an effort to challenge some of the issues they had investigated with their teachers (2/6 cases) stating that the students were continuously coming to school with newspaper articles regarding SSIs for whole class discussions. Teachers stated (3/6) that the students were getting their parents/guardians involved not only in terms of communicating their learning but also encouraging them to take civic action. Eva spoke about how:

> Parents are coming into me telling me they are being driven mad about recycling at home and they know all about the bees and the parents are planting stuff at home, doing a lot of things that we wouldn’t have done in school without the SSIPSC programme (Case B, 3rd class).

Jack further reported that the SSIPSC intervention was enabling and inspiring students to make informed decisions pertaining to SSIs but also empowered them to take action in response to SSIs that affected their everyday lives:

> I think they were shocked by how relevant it [SSIPSC programme] actually was, that there was an awful lot of it that they’d know a small bit about the topics but a lot of things that they were actually shocked about. They felt compelled to take action no matter how small

(Jack, Case A, 4th class).

4.7 Attitudes towards School and School Science

Thus far developments of students' science content knowledge, science inquiry skills and experiences of IBSE have been discussed. Students' engagement with argumentation and socioscientific reasoning have also been examined along with student-led citizenship. The SSIPSC intervention also had an impact on students' attitudes towards school science which will now be discussed. Students' attitudes towards school were firstly examined to set a baseline for the discussion pertaining to attitudes towards school science.

4.7.1 Attitudes towards School

Table 4.23 presents quantitative analysis of the pre and post student questionnaire data for the 'attitudes towards school' scale. As stated in Section 3.8.1, all questions for this scale were coded on an ordinal scale from 1 to 4, where 1 = strongly agree and 4 = strongly disagree to statements such as "I like school".

Table 4.23

Scale Data: Attitudes towards School.

Case	**Class**	**N/ Class size**	**Initial** Median	**Exit** Median	***p***	***z***	***r****	**Effect Size**
A	4th	*25*/27	2.0	2.0	.51	-0.65	0.09	Small
B	3rd	*32*/32	2.33	2.0	.13	-1.51	0.19	Small
C	4th	*22*/28	1.67	2.0	.51	-0.68	0.1	Small
D	6th	*9*/9	1.67	1.67	.71	-0.38	0.09	Small
E	6th	*23*/23	2.0	2.0	.91	-0.11	0.02	-
F	**3rd**	***13*/13**	**2.33**	**2.0**	**.02**	**-2.29**	**0.45**	**Medium**
G	3rd	*20*/26	2.0	2.0	.77	-0.29	0.04	-

* Effect sizes will be quoted when p>0.05 based on comments under Table 4.5.

A Wilcoxon Signed rank test was used to determine the difference between the pre-intervention and post-intervention scale data with Cohen's (1988) criteria used to interpret the effect size. Analysing the median scores, two of the seven cases had more positive attitudes towards school post the SSIPSC intervention (Case B - 3rd class and Case F - 3rd class). Only Case F had a statistically significant difference ($p<0.05$), with a median of (2.33) pre-intervention and (2.0) post-intervention. Using Cohen's (1988) criteria this is considered to be of medium significance where the students in Case F reported more positive attitudes towards school post-intervention. Case C (4th class) had a decrease in attitudes towards school post-intervention. However, this decrease is not statistically significant ($p=0.505$) with a small effect size reported (Cohen, 1988). All other cases, Case A (4th class), Case D (6th class) and Case G (3rd class) had the same median score prior to and post the SSIPSC intervention with $p>0.05$. Cross-analysing the data (Table 4.23), the majority of cases (5/7) had a pre median score of less than or equal to 2. This indicates that students in these cases had positive attitudes towards school pre-intervention. Post-intervention, all cases presented positive attitudes towards school with a median of less than or equal to 2 reported for all cases.

Analysing the qualitative student focus group data, over 80% of students in all cases had positive attitudes towards school pre-intervention. Most students in all cases stated that they enjoy learning in school and playing with their friends: "I like school, because we need to learn and you need to learn to be able to do things. You can make friends in school and on yard" (Case A, 4th class, pre-intervention). Students in four of the cases (Case B - 3rd class, Case D - 6th class, Case F - 3rd class, Case G - 3rd class) spoke about the connection between school and future careers with one of these students stating that "You need school so that when you're a grown-up you can be able to get a job and have money" (Case D, 6th class, pre-intervention). Most (>80%) students in all cases agreed that school is fun and interesting. Post-intervention, all students maintained their positive attitudes towards school. The qualitative focus group data did not provide any insight into why Case F had a statistically significant increase in positive attitudes towards school in the questionnaire data post-intervention. Thus, triangulating the quantitative and qualitative case data, it is clear that most students in all cases had positive attitudes towards school at the initial and exit stages of this study.

4.7.2 Attitudes towards School Science

Table 4.24 presents the pre and post student questionnaire data for the Attitudes towards School Science scale. Similar to the above Attitudes towards School Scale all questions were coded on an ordinal scale from 1 to 4, where 1 = strongly agree and 4 = strongly disagree to statements such as "School science is interesting"'.

Table 4.24

Scale Data: Attitudes towards School Science

Case	**Class**	**N/Class Size**	**Initial** Median	**Exit** Median	***P***	***z***	***r****	Effect Size
A	4th	*23/*27	1.6	1.6	**.31**	-1.02	0.15	Small
B	3rd	*32/*32	2.1	2.0	**.28**	-1.07	0.13	Small
C	4th	*22/*28	1.2	1.4	**.07**	-1.82	0.27	Medium
D	6th	*8/*9	1.4	2.2	**.22**	-1.23	0.31	Medium
E	6th	*23/*23	1.8	1.8	**.81**	-0.24	0.04	-
F	3rd	*12/*13	1.7	1.8	**.42**	-0.81	0.17	Small
G	3rd	*18/*26	1.6	1.6	**.87**	-0.17	0.03	-

* Effect sizes will be quoted when p>0.05 based on comments under Table 4.5.

Statistically significant differences did not emerge across any of the cases but a small to medium effect size was reported in five out of the seven cases. Case B (3rd class) had more positive attitudes towards school science post-intervention with a small effect size (0.1<*r*<0.3) reported. Three cases, Case A (4th class), Case E (6th class) and Case G (3rd class) had the same median score pre and post-intervention. The remaining three cases reported a decline in attitudes towards school science post-intervention, Case C (4th class), Case D (6th class) and Case F (3rd class), with a small to medium effect size presented (0.1<*r*<0.5). Pre-intervention the majority of cases (6/7) had a pre median score of less than or equal to 2. This indicates that the students in these cases had positive attitudes towards school science pre-intervention. Post-intervention the same number of cases (6/7) presented positive attitudes towards school science with six cases reporting a post-median of less than or equal to 2.

The student focus group interviews for each case provided qualitative findings regarding students' attitudes towards school science prior to and after the SSIPSC intervention. In corroboration with the quantitative findings, all cases presented predominately positive attitudes towards school science at the initial stage of this study. Students in all cases indicated that they enjoyed science investigations and experiments and found them fun and interesting. For instance, the 6th class students in Case D who had recently participated in a 'science fair' where the students demonstrated different experiments to the whole school, referred to this as a thoroughly enjoyable experience. This was a 'once a year' activity. It was apparent that when the students had experience of 'hands-on science' they enjoyed these lessons: "Yeah I like school science, because we do like loads of cool kind of project stuff and I feel like a scientist when I'm doing it" (Case G, 3rd class, pre-intervention). All teachers who participated in the interview supported these findings indicating that the students enjoyed school science pre-intervention.

Even though the students stated they enjoyed school science, students in most cases (Case A - 4th class, Case B - 3rd class, Case C - 4th class, Case D - 6th class, Case F - 3rd class) indicated that they had little experience of it. One 6th class student in Case E stated "It's fun because we don't really do much [science] so then it's like kind of a treat for us" (Case E, Pre-Intervention). Another student in Case C (4th) further described that science was often deprioritised compared to other subjects:

> Yeah, because like on one day we'd only do like Maths, English and Irish and then like there would be a certain day that we do science but then all the teachers would sometimes forget or like some other things would come up so we don't get to do science often (Case C, 4th class, pre-intervention).

One teacher further supported this, stating that science was often relegated to 'science week' with little school science being taught outside of this: "science was just blitzed kind of in science week; it was a fun science thing to do for like two weeks." (David, Case E, 6th class). This limited experience could be the reason why some students found it difficult to expand on the types of science lessons they enjoyed, even when probed (Case A - 4th class, Case B - 3rd class, Case F - 3rd class). Furthermore, students in many cases (Case B - 3rd class, Case E - 6th class, Case F - 3rd class, Case G - 3rd) often confused school science with science they had done at home, at a science club, or something they would like to do when describing school science:

> My favourite science lesson was the volcano thing where you put salt and everything in it and then it comes out (Student A, Case B, 3rd class)
>
> So, did you actually make one of those volcano things (Students B, Case B, 3rd class)
>
> I done one with my Dad (Student A, Case B, 3rd class).

The theme of 'explosions and potions' emerged across most cases (Case A - 4th class, Case B - 3rd class, Case E - 6th class, Case F - 3rd class) where the students across the different class levels often associated science with the mixing of chemicals and explosions, "Science is like explosions and blowing things up" (Case F, Pre-Intervention). Once prompted these students stated that they had never made an explosion or potion in school: "we don't really do any like real science [in school]. Like we don't really like put potions together or stuff like that" (Case B, 3rd class, pre-intervention). Some of the teachers (Case B - 3rd class, Case D - 6th class, Case G - 3rd class) also indicated that pre-intervention the students often associated science with 'explosions'. Eva's response is illustrative in this regard "Even at the start when I said we were doing science, they were saying, 'Do we get to blow stuff up?' and that is what they relate science to" (Case B, 3rd class).

Students also discussed school science they did not enjoy during the focus group interviews, referring specifically to the pedagogical approaches employed and science lesson content to illustrate this. Students in Case D (6th) and G (3rd) indicated that they did not enjoy teacher demonstrations and often felt frustrated with them: "I remember one experiment we did, we all just crowded around a table and Miss Kelly [pseudonym] just did the experiment and we were just all, 'yeah'…it was so annoying, science wasn't enjoyable" (Case E, 6th class, pre-intervention). Students in three cases (Case B - 3rd class, Case C - 4th class, Case D - 6th class) indicated that science was too easy and that content was often repeated from class level to class level with two cases specifically recalling a ‘floating and sinking’ science investigation illustrative of a junior and senior infants lesson as an example of this. Furthermore, students from Case E (6th class) indicated that school science content was often not relevant to their daily lives and that they wanted to learn more “about things that would actually be useful in our life” (Case E, 6th class, pre-intervention).

Students in all cases seemed critical of text-book science pre-intervention, describing it as boring and repetitive. The following are representative of the students’ responses: “Yeah, like we often have to write [in science] and it would literally be the thing that we just talked about and then we’re just repeating it in writing” (Case E, 6th class, pre-intervention) and “Like when the teacher keeps reading and reading and reading, I feel bored” (Case A, 4th class, pre-intervention). Correspondingly, ‘text-book’ science emerged as a prominent theme across all of the teacher interviews. Science text-books were in use in all of the cases but were part of a school book rental scheme and thus the teachers were not obliged to use the book as a result. However, many of the teachers co-planned with other teachers with the same class level and felt this inhibited their ability to teach ‘outside the book’. Others stated (two cases) that they lacked confidence and were often overwhelmed at having to conduct experiments/investigations and thus focused on discussing the content of the text-book with little emphasis on hands-on investigations. Indeed, this lack of confidence was why some of the teachers (3/6) enrolled in the SSIPSC science course to begin with:

> The main reason I did the course was because I felt there was something lacking. I wasn’t happy with the way my science lessons were going last year. I wasn’t proud to stand over them. But the way that I would have done science last year was I would have picked a particular theme that I wanted to cover like electricity and I would usually start it off with the class of KWL [K: what you know W: What you want to know and L: what you have learned] with 'what do you know about electricity?'. Then I would have asked them what did they want to learn? Then I would usually show them a PowerPoint or YouTube video

that I had researched…but I was never brave enough to set up the whole class doing investigations (Elaine, Case D, 6th class).

These findings regarding text-book dominated and teacher-directed nature of some science lessons corroborate the students' responses in the focus groups above. Whilst students reported predominantly positive feelings towards science in the pre-intervention questionnaire data, students experience of school science as revealed in the qualitative data appears narrow and possibly limited. In spite of this, it is evident that pre-intervention students had positive attitudes towards science lessons when they consisted of investigations and experiments and provided opportunities for the students to engage in hands-on science.

Post-intervention student focus group interview data and teacher interviews indicated that all cases presented positive attitudes towards school science at the exit stages of the study; the students considered school science to be engaging, relevant and enjoyed the child-led pedagogies employed. The students still considered science to be fun and interesting however all students in all cases were able to illustrate 'fun and interesting' lessons providing examples from school science to justify their responses. Students' interpretation of school science and what it entails changed from pre to post-intervention but yet the students were still eager and enthusiastic about school science. Students in three of the cases (Case A - 4th class, Case B - 3rd class, Case E - 6th class) indicated that they enjoy science more post-intervention. The comment by Student C, Case E (6th class) is illuminating in this regard:

> Yeah like with the science before it was just like…really boring. She'd say, 'Okay, we're going to do science', and everybody would be like, 'I hate science'. Like, I used to hate science, I used to think I hate science so much. You'd see science written up and you'd go…'Oh my God' and now when you see science, you're like, yes, it's my favourite subject.

This finding was echoed in the teacher interview data where all teachers stated that they felt that most of the students in their class enjoyed science more post-intervention. Teacher's A response is indicative of this:

> There is a buzz about science. I put up a timetable the day what they are going to do and when they see science on it, they are kind of excited and dying to see what will happen. I think they see themselves able to work scientifically and they are kind of proud of that (Elaine, Case D, 6th class).

Some teachers (3/6) in the post-interviews also reported that these positive attitudes had a positive impact on the students' attitudes towards secondary school science and in one case a student's future career in science:

> They have had such a positive experience of science. Like, there's a girl in my class like, 'I definitely want to be an entomologist now, that's definitely it, that's what I want to do'. She loved the programme…and she's really like gung-ho about it now and she's serious, she's not just like, I want to be a scientist when I grow up, she's like, I want to be an entomologist. So, I think that … you need to get them young to get that positive experience with it and the world (Sarah, Case C, 4th class).

The importance of learning 'real-world' science came to the fore as a prominent theme in the qualitative data where the relevant nature of the SSIPSC intervention had a positive impact on the students' attitudes towards science. Students in most cases (6/7) considered school science to be important in their everyday lives, something that did not emerge in the pre-intervention data:

> It's different from the other times that we've done [science] because…it was kind of like hard. It was kind of silly stuff before but now it's fairly important stuff…like bees and climate change and all the things that really matter (Case D, 6th class, post-intervention).

This also emerged as a strong theme in all of teacher interviews with many teachers (5/7) citing it as one of the main reasons that they felt the children found the SSIPSC programme so engaging:

> I think it is just because they were learning about what is going on in their life…it is their legacy and it is what they are growing up with. I think it made them way more interested in it because even when we brought them out on trips and stuff, they were able to spot things that we had talked about in class, so they were able to relate it back to the real world. They were able to talk to their parents about it (Eva, Case B, 3rd class).

Of note, all teachers stated that the connection of school science to SSIs was something new to them with most (5/6) teaching school science without contextualisation prior to the programme:

> I think sometimes there's a tendency to kind of like, oh, pick these great experiments off Primary Science or whatever. But there's no contextualisation for it. So, they do the experiment, they learn something on that day, but that's it, it's not kind of brought forward in any meaningful way (Sarah, Case C, 4th class).

Post-intervention, some students (3 cases) stated that they found the science topics as part of the SSIPSC programme more challenging. However, these students emphasised the importance of learning about these issues and stated that they enjoyed engaging in discussions and having opinions on challenging issues such as climate change, "People actually need to start knowing more about how they can help and stuff" (Case E, 6th class, post-intervention). Many teachers (4 cases) concurred with this, stating that the SSIPSC programme was challenging but that it was challenging in a positive manner in that:

> The children enjoyed the topics because it was challenging for them and I found that [before the SSIPSC intervention] …they would be doing experiments before they got that wow factor…but because they were actually researching something from scratch and doing the work themselves, that when they got to the end product and what they learned, it was their learning that they enjoyed and it was relevant to them (Jack Case A, 4th class).

The challenging science content could be in response to students' experience of science lessons prior to the SSIPSC intervention where some students in these cases stated that they felt the science content was too easy or repetitive.

Greater experience of hands-on science and child-led investigations was also evident in most cases and impacted students' positive attitudes towards school science (Case A - 4th class, Case B - 3rd class, Case C - 4th class, Case D - 6th class). The 6th class students in Case D enjoyed that they had to "figure out" investigations for themselves and that they were now "trusted to conduct investigations" (Case D, post-Intervention). Teachers in three of the cases concurred that students were provided with greater autonomy to devise and conduct investigations for themselves, something the teachers were nervous about doing prior to the study. Science post-intervention was therefore presented as being more interesting for some students as for example Student A, Case D described "it wasn't just writing into a copy and taking it from a book, it was actually experimenting and learning". Other students (2/7 cases) described science as problem-solving and inquiry-based. This was in contrast to their previous experience of science where "all you did was get a book, read a huge bit of writing and then have like 12 questions on it" (Case D, 6th class, post-intervention). Even Student B who stated she always loved science reflected on the change in teaching approaches post-intervention "It [science] was way more boring like before, like get out your textbooks, read this page, then we'll talk about it, the subject now it's not just the same teaching method, it's a different method." All of the teachers in each of the cases stated that the change from teacher-directed, often text-book orientated teaching to child-led inquiry based teaching methodologies was one which had a great impact on their teaching of primary science and resultant positive impact on children's engagement with science. Many felt that they underestimated the children's ability and were now more confident to hand 'control' over to the children in terms of devising investigation questions and investigation methods:

> It was a tricky thing. I am very much like - be independent, think about it yourself and figure it out, but I think I didn't give them enough credit in science. I think they are able to do a lot more than I let them. Letting them have a go and allowing them to discuss and investigate for themselves it made a big difference (Eva, Case B, 3rd class).

Qualitative findings from both the student focus groups and teacher interviews indicated that the students had positive attitudes towards science pre-intervention. This is consistent with the quantitative data. However, qualitative evidence indicated that students in many cases may have had little experience of school science and/or inaccurate conceptions of what school science entails at the initial stages of the study. Post-intervention many new themes associated with the students' positive attitudes towards school science emerged: relevant science, child-led investigations, more frequent experience of hands-on investigations. Students in many cases (5/7) also indicated that they had more frequent experience of school science post-intervention. Case F (3rd class) was the only exception where the students referred to science lessons that they had engaged with prior to the SSIPSC intervention at the post-intervention stage and did not demonstrate any developments in terms of understanding of science and/or more/less positive experiences of science at the exit stage. Thus, while students in Case F (3rd class) displayed positive attitudes towards science, both prior to and at the exit stage of the study, it is difficult to ascertain their level of engagement with or enjoyment of the SSIPSC intervention.

4.8 Chapter Summary

This chapter provides quantitative and qualitative evidence pertaining to the impact of the SSIPSC intervention on students' scientific literacy competencies. Quantitative scale data indicated that the students in all cases had positive attitudes towards school and school science prior to and post the SSIPSC intervention. The qualitative student focus group data and teacher interviews substantiated these claims but raised concerns regarding students' limited experience of school science and dominance of teacher-directed pedagogical approaches pre-intervention. Post-intervention themes of enhanced relevance of school science, more frequent student engagement with child-led pedagogies and heightened student experience of hands-on science were found to have had a positive impact on students' attitudes towards school science. Quantitative scale data and qualitative interview data presented findings regarding students' improved science content knowledge and science inquiry skills post-intervention. Furthermore, students were provided with opportunities to engage in socioscientific argumentation where students' demonstrated enhanced ability to make evidence-based arguments post-intervention. Quantitative and qualitative data provided evidence of students' socioscientific reasoning skills. Here findings indicated that the students applied their content knowledge, inquiry and argumentation skills to enable them to engage in reasoned discourse pertaining to SSIs and make informed decisions. While the quantitative scale data indicated that the students in all cases had informed conceptions of NoS pre and post-intervention, qualitative data indicated that the students applied their NoS understanding to SSI scenarios post-intervention. Finally, many cases demonstrated evidence of student-led active citizenship as a result of their engagement with SSIs at the exit stage of this study. The following discussion chapter will explore these findings in relation to the literature and current policy in the field.

5.0 Discussion of Findings

This mixed-methods study examined the impact of teaching primary science through SSIs on the development of upper primary school students' scientific literacy across seven cases. The focus of this chapter is on reviewing and synthesizing the quantitative and qualitative data presented in Chapter 4 with recent literature in the field of science education. Quantitative and qualitative findings pertaining to the development of students' science content knowledge, conceptions of the NoS, science inquiry skills and socioscientific argumentation are presented. This is followed by a discussion of the relationship between these constructs and the development of students' socioscientific reasoning competencies. Primary students' ability to engage in reasoned discourse, make informed decisions and in some cases take informed action in response to SSIs will be examined.

It is important to note that Case F (3rd class) emerged as an outlier in this study. The class teacher participated in the 25 hour face-to-face professional learning programme in July 2018 but became disengaged with the professional learning mid-way through the SSIPSC intervention. This did not occur in any of the other cases. Furthermore, the students in Case F (3rd class) did not refer to the content of the SSIPSC intervention in the post-intervention focus group interviews and their responses to the SSI test scenarios at the exit stage of the study were similar to the students' responses prior to the intervention. This also did not occur in any of the other cases. Therefore, findings pertaining to Case F (3rd class) will not be included in the discussion from 5.1 to 5.4 but will instead be discussed in Section 5.5. Discussion of findings relative to the class levels will also be presented at the end of this chapter, Section 5.6. The cross-case findings will be discussed under each research question underpinning this study.

5.1 To what extent does SSIPSC contribute to developing Primary School Students' Science Content Knowledge, NoS Understanding, Scientific Inquiry Skills and Argumentation Skills?

5.1.1 Development of and Application of Science Content Knowledge

Several science education researchers have argued that SSIs-based instruction can support development of science content knowledge and should be used as contexts for learning science (Sadler & Dawson, 2012; Sadler, Klosterman & Topçu, 2011; Von Aufschnaitor et al., 2008; Yager et al., 2006). Quantitative findings from this study indicate that the primary school students enhanced their science content knowledge post-intervention with statistically significant findings ($p<0.05$) reported in all cases and all class levels (Section 4.1). Using Cohen's (1988) effect size criteria to interpret findings, five cases (B, C, D, E, G) reported a large effect size ($r>0.5$) and one case (A) a medium effect size ($0.3<r<0.5$). Similar to other studies which have investigated content knowledge gains following a SSI intervention in a primary/elementary context (Wongsri & Nuangchalerm, 2010; Yager et al., 2006), the quantitative assessment instrument used in this current study aligned directly with the SSIPSC intervention; thus the quantitative learning gains, discussed above, are expected and not surprising. However, these findings do provide empirical evidence that the science content of the Irish primary science curriculum (DES, 1999a) can be successfully anchored within SSIs (Brotman, Dawson, & Moore Mensah 2011; Zeidler, Applebaum, & Sadler, 2011). In fact, two teachers specifically cited that it was a more efficient means of achieving the primary science curriculum objectives as the SSIs units facilitated a 'multi-strand' approach where the units covered content aligned with a number of strands/strand units of the primary science curriculum.

The qualitative data added depth to the quantitative findings providing evidence of the development of students' science content knowledge and students' ability to transfer this knowledge from the SSIPSC intervention to the SSI scenarios. Post-intervention students in all cases (6/6 cases) were capable of engaging in an in-depth discussion of the science content knowledge underpinning their favourite science lesson, illustrating the depth of their knowledge development; this was not evident in the pre-intervention focus groups. Furthermore, students in all cases were able to apply science content knowledge to the SSI test scenarios a number of months after they had covered the content in class. Similar to Yager et al. (2006), this study provided qualitative evidence that the students were able to apply their science learning to new situations in terms of the SSI scenarios and the students' own lives. A number of teachers substantiated this finding highlighting that the contextualisation of the primary science objectives through SSIs made the science content more relevant and engaging for the students. Furthermore, these qualitative findings alleviate concerns expressed by Pouliot (2008) and others (Hughes, 2000; Orpwood, 2001) that SSIs-based teaching may dilute students' exposure to basic scientific ideas and principles. Evidence from this study strongly suggests that connecting science to the students' everyday lives through SSIs promoted cognitive engagement, deeper understanding of science concepts and promoted the application of science content knowledge to real-life contexts. This finding is supported by a number of studies in the field of SSIs (Dawson & Carson, 2020; Von Aufschnaiter et al., 2008; Zeidler, Applebaum, & Sadler, 2011; Zohar & Nemet, 2002). In an Irish context, this is particularly pertinent as past studies have found that Irish students have difficulty seeing the relevance of school science to their everyday lives (Matthews, 2007; TIMSS, 2015; Varley et al., 2008).

Students' naive conceptions of some science concepts emerged as a prominent theme in both the students' focus groups (6/6 cases) and teacher interviews (3/6 cases). These inaccurate science conceptions emerged when the students were exploring the SSIs test scenarios of 'bees' and 'energy' and had a significant impact on students' discussion of these scenarios and the decisions they made regarding them. Inaccurate science conceptions are common at primary level (Allen, 2010; Gilbert, Osborne & Fensham, 1982; Harlen & Qualter, 2018; Maharaj-Sharma, 2009) with similar inaccurate conceptions emerging in the 3rd class cases, 4th class cases and 6th class cases. Post-intervention there was a 75% reduction in the number of inadequate conceptions in all cases and the students demonstrated more accurate conceptions of science underpinning everyday issues, for example, bees and their role in pollination, the complexities of climate change, and the digestive system. These findings concur with other studies stating that SSIs are a suitable means to firstly identify and then challenge students' inaccurate science conceptions through a relevant context that the students can relate to (Zeidler & Nichols, 2009; Zeidler & Sadler, 2008). According to Osborne et al. (2013), as scientific concepts are evaluated and judged in comparison with various alternatives through SSIs discourse, the shortcomings of various held beliefs are modified in light of available evidence. This is an important finding given that others have reported that student inaccurate science conceptions can often be difficult to rectify (Harlen & Qualter, 2018).

Furthermore, similar to other studies (for example Lewis & Leach, 2006), misunderstanding of basic science content can result in flawed lines of reasoning and un-informed decision-making when discussing SSIs. A basic level of content knowledge was required in order for the students to interpret, analyse and critically evaluate science-related issues (Siarova et al., 2019). From a pedagogical perspective, this is referred to as knowledge transfer and has been observed in other SSIs intervention studies (Lederman et al., 2014; Klosterman & Sadler, 2010; Sadler, Romine & Topçu, 2016). According to Haskell (2001)

> The aim of all education … is to apply what we learn in different contexts, and to recognize and extend that learning to completely new situations. Collectively this is called *transfer of learning*…meaningful transfer of learning is among the most—if not the most—fundamental issue in all of education. (Haskell 2001, pp. 3–4)

This transfer of knowledge to the SSI test scenarios will be discussed in more detail in Section 5.2. It is apparent that the students in this study developed content knowledge aligned with the primary science curriculum (DES, 1999a) and they were able to apply this content knowledge to real-world contexts and the students' everyday lives. Furthermore, many of the students' inaccurate science conceptions were addressed. Romine et al. (2017) assert that SSI-based instruction does not come into its own until we move the focus toward evaluating how students use their understanding of science content to negotiate the complex interactions between the various human viewpoints around important and pressing issues. Thus it could be said that not only were Vision I and II scientific literacy aims being achieved, but a relationship between the development of science content knowledge and the students' ability to negotiate complex SSIs was developed. In some cases, the students used their science content knowledge to take informed action in responses to the SSI (Vision III), however, this will be discussed in more detail in Section 5.4, Student-led Citizenship.

5.1.2 Development of Nature of Science Understanding

Research asserts that an important component of scientific literacy is an understanding of the NoS, in that sophisticated understanding of NoS has been found to enhance the quality of decisions made regarding scientific issues we encounter in our everyday lives (Sadler, 2011a; Yacoubian & BouJaoude, 2010; Zeidler et al., 2005). Equally, experience of SSIs can help students to understand aspects of NoS that influence decisions about such issues (Bell & Linn, 2000; Karisan & Zeidler, 2017; Khishfe, 2013). NoS was a feature of the SSIPSC intervention in that many of the tenets of NoS were addressed through the inquiry, argumentation and reasoning features of the SSIPSC intervention but NoS instruction was not planned for. The results presented in this thesis provide an authentic insight into the potential of SSIs to develop Irish primary students' understanding of NoS and provide empirical evidence on primary school aged students' ability to transfer this NoS understanding to SSI scenarios.

Data pertaining to students' NoS conceptions were gathered through a quantitative instrument. Analysing the pre and post-intervention median score, all cases were found to have 'informed' to 'very informed' understanding of NoS at the initial and exit stage of the study. Quantitative scale data indicated that all cases (6/6) reported more informed understanding of NoS post-intervention, however, this finding is not considered to be statistically significant ($p>0.05$) with a small (5 cases) to medium (1 case) effect size reported for all cases. Despite the theoretical expectation and empirical evidence from other studies (Bell & Linn, 2000; Khishfe, 2013; Soysal, 2015) which have declared that the inherent nature of SSIs-based education, for example socioscientific argumentation, IBSE, the open-ended, socially-connected characteristics of SSIs, can develop primary/elementary students' conceptions of NoS to a certain level, this finding was not corroborated by this research.

There is little evidence that mere recall of the tenets of NOS, as measured by the NoS quantitative scale, is sufficient to ensure they are applied effectively in context (Allchin 2011). Indeed, findings from this study support the opposite whereby reference to informed conceptions of NoS did not occur in the pre-intervention focus group discussions on SSIs despite the quantitative findings indicating that students had informed to very informed conceptions of NoS. Others have criticised the 'tenets of NoS' approach, for developing declarative rather than functional NoS understandings and advise that students need opportunities to apply NoS to context rich scenarios in order for NoS learning to be meaningful (Erduran & Dagher, 2014; Matthews, 2012; Osborne, 2014). According to Allchin (2011) "short lists of NOS features should be recognized as inherently incomplete and insufficient for functional scientific literacy" (p. 524). From this perspective, decontextualized teaching of NoS could be seen to be promoting Vision I scientific literacy competencies to the neglect of Vision II.

Post-intervention, the students in most cases made reference to many tenets of NoS when discussing the SSI scenarios. For example, students referred to working collaboratively in groups and the necessity for different stakeholders to work together to solve complex SSIs. They also made references to different methods of solving SSI scenarios emphasising that scientists use their creativity in their work and that there are a number of ways to respond to SSIs. Tentative NoS came to the fore as students referred to technological and scientific information continuously changing and developing. It seems that the SSIPSC intervention offered a learning environment for the students to practise their use of NOS knowledge in everyday socioscientific contexts (Eastwood et al., 2012; Khishfe & Lederman, 2006; Simonneaux, 2007). Furthermore, similar to Khishfe (2013), the students in this study were able to transfer their NoS understanding from familiar (SSIPSC units) to unfamiliar contexts (SSI scenarios) post-intervention. Khishfe (2013) infers that this type of 'distributed model of NoS' instruction whereby NoS is distributed across different contexts for an extended period of time provides multiple opportunities for students to reflect on, examine, and apply NoS to relevant contexts. Therefore, while teaching NoS was not an explicit goal in this study, it was naturally embedded in the SSIPSC classroom instruction, discussion and questioning.

Policy documents and research, both nationally and internationally, continuously highlight concerns that primary school students generally do not hold contemporary conceptions of NoS (Rocard et al., 2007; Murphy et al., 2007; Murphy et al., 2019; Varley et al., 2008) and call for its explicit inclusion in curricula documentation. As discussed earlier, NoS is not an explicit feature of Irish primary science curriculum but it is a feature of the 2017 Junior Cycle Curriculum (lower secondary school science curriculum) where NoS is identified as a curriculum strand and SSIs are presented in the assessment criteria; however, they are presented as separate entities rather than interconnected constructs. The quantitative findings in this study suggest that the upper primary students had relatively high levels of NoS understanding pre-intervention; however pre-intervention they were not able to apply this understanding to the SSI test scenarios. Given the research that supports the relationship between NoS and informed decision making (Khishfe, 2013; Sadler, 2011a) and the evidence from this study where students applied informed conceptions of NoS to SSI scenarios post-intervention; this study declares that SSIs embedded in the Irish primary science curriculum provide a suitable context to develop students' NoS conceptions and provide explicit opportunities for students to apply this understanding to real life contexts. Thus, instead of NoS being taught as a discrete topic/strand in the delivery of curriculum, this study asserts that when students are experiencing the social, tentative, subjective, moral and ethical nature of SSIs, teachers can readily engage students in explicit contextualised discourse that touches on many tenets of NoS. This approach has the potential to enhance scientific literacy whilst also allowing teachers to use their instructional time more efficiently (Yacoubian & Khishfe, 2018).

5.1.3 Experience of Inquiry Based Science Education

IBSE has been considered highly effective in supporting the development of science content knowledge and skills and for motivating children in science class both at an international and national level (Artique et al. 2012; Harlen 2010; Murphy et al., 2012; Rocard et al. 2007). A number of pedagogical frameworks have emphasised the importance of IBSE underpinning SSIs education (Levinson, 2018; Sadler, 2011a); however, no study has examined the relationship between SSIs and IBSE in an Irish primary science context. Here, findings pertaining to students' experiences of IBSE pedagogies and development of scientific inquiry skills within SSIs are discussed. The acquisition of scientific inquiry skills is deemed essential for responsible citizenship and understanding SSIs that confront modern societies (Beernaert et al., 2015; Rocard et al., 2007). Application of scientific inquiry skills to students' socioscientific reasoning competencies will be presented in Section 5.2.3.

Quantitative data in Section 4.3.1 indicated that students in most cases (5/6) had more frequent experience of IBSE pedagogy post-intervention with four of these cases having statistically significant ($p<0.5$) more frequent experience of IBSE at the exit stage of this study with a large effect size reported ($r>0.5$). The other case presented more frequent experience of IBSE with a small effect size ($0.1<r<0.3$). From students' descriptions of their experience of school science in the qualitative focus groups, evidence suggests that the students had had limited experiences of IBSE in most cases and extensive experience of teacher demonstrations, completion of worksheets and teacher prescribed hands-on activities at the pre-intervention stage. Teacher qualitative interview data (6/6 cases) supported this finding. Other large scale Irish studies and reports (DES, 2012; Varley et al., 2008; Murphy et al., 2019; Smith, 2014) over the past decade have found that primary students are being provided with limited opportunities to engage with IBSE pedagogy with traditional teacher-directed approaches continuing to dominate classroom practice. Similar concerns regarding the scarcity of such IBSE teaching methods persist at an international level (Beernaert et al., 2015; Rocard et al., 2007). Post-intervention the use of IBSE emerged as a prominent theme in both the students' focus group and teacher interviews with students in most cases (6/7) describing their favourite science lessons as ones that were categorised as child-led inquiry-based lessons. Teachers revealed heightened level of confidence with using an inquiry-based approach and the students in all focus groups highlighted their enjoyment of IBSE approaches; asking their own inquiry questions, devising scientific investigations, working collaboratively, discussing conclusions and presenting findings. The results support other studies that have found that inquiry based pedagogies enhance student interest in science (Gibson, 1998; Jiang & McComas, 2015; Rocard et al., 2007; Smith, 2012, 2014; Murphy et al., 2019). This thesis is the only Irish study that has examined primary students' experiences of IBSE through a SSI intervention and whilst it cannot be said that SSIs is superior/inferior approach for facilitating IBSE, it does provide evidence that SSIs are a suitable context for IBSE in an Irish primary school context.

The ability to connect inquiry to relevant everyday societal issues is a distinctive feature of the SSI inquiry pedagogical approach (Outlon et al., 2004; Levinson, 2006; Amos & Levinson, 2019), merging Vision I and Vision II scientific literacy aims. For example, the 6th class students (Case D) developed an authentic inquiry which examined (i) the nutritional content of their school lunches and (ii) the role of exercise in maintaining a healthy lifestyle. Here the students devised investigations, gathered evidence and presented their findings at a national science event. In the process, they interpreted, analysed, and critiqued evidence from a variety of sources. It could be argued that these students had the knowledge, skills and attitudes to make an informed decision about a SSI that affects their everyday lives, exemplifying the key competencies of a scientifically literate individual. Many students (5/6 cases) and teachers (6/6) made positive references to authentic student-led science inquiries related to real world issues in the focus groups post-intervention. The SSI inquiry pedagogical approach emerged as a key factor underpinning students' (6/6) engagement with the SSIPSC intervention. According to Constantinou and colleagues (2018), inquiry based learning provides opportunities for students to develop positive attitudes towards science by connecting their classroom activities with their personal experience. Thus the findings from this study add evidence to support this and further supports Lederman and colleagues' assertions that SSIs offer a platform for the development of scientific inquiry in an authentic real world context (Lederman, Antink & Bartos, 2014), something which has not been empirically investigated prior to this study. The findings also add further question marks over the negative correlation between PISA scientific literacy scores and students' experiences of IBSE (Oliver et al., 2019; Sjoberg, 2018). SSIs are constantly changing and developing and students need to develop the inquiry skills, interest and positive attitudes necessary to gather, interpret, analyse and evaluate evidence from a variety of sources in order to make informed decisions about current SSIs and future unknown SSIs (Zeidler et al., 2009). It is difficult to see how this can be achieved through a predominant teacher-directed approach, an approach that has a positive correlation with high scientific literacy scores according to PISA (2015).

5.1.4 Development of Scientific Inquiry Skills

Quantitative scale data indicated that students in most cases had more frequent experience of IBSE pedagogies at the exit stage of the study. Similarly, the qualitative data indicated that the students made more frequent reference to scientific skills as presented in the Irish primary science curriculum (DES, 1999a) post the SSIPSC intervention. Students across all cases (6/6) made greater reference to conducting fair test investigations and highlighted the importance of testing and controlling variables in a fair and reliable manner. Greater opportunities to develop other skills such as measuring, recording, communicating and designing and making also emerged. Additionally, students referred to enhanced opportunities to ask questions to guide science inquiries post-intervention. This correlates with findings pertaining to students' experience of IBSE discussed in Section 5.1.3 above. The practical skill assessment provided evidence of the students' ability to apply scientific inquiry skills to a practical investigation. While a study has been published on the development and validation of the practical skill assessment resources in an Irish context (Kilfeather et al., 2007), no study has examined students' practical investigation skill development from a SSI intervention perspective. In this study most cases (5/6) demonstrated an improvement in skill development from pre-intervention to post-intervention. It therefore seems that the SSIPSC intervention provided students with greater opportunities to develop and apply the science skills underpinning the primary science curriculum especially when compared to the pre-intervention analysis. This is a significant finding given that previous studies have highlighted concerns regarding the limited development of Irish students' scientific inquiry skills especially in regard to estimating, raising their own questions and communicating (DES, 2012; Varley et al., 2008). Furthermore, Varley et al. (2008) in their national review of the implementation of the primary science curriculum concluded that there was a lack of development of students' scientific skills as they progressed from the junior to the senior classes. It seems that the SSIPSC intervention provided the students with opportunities to develop and apply scientific skills as envisioned by the Irish primary science curriculum. The students' ability to apply these inquiry and science skills to SSI contexts, referred to as transfer capability (Zoller & Levi Nahum, 2011), will be discussed in Section 5.2.3.

5.1.5 Development of Argumentation

This study explored argumentation using the context of the 'red squirrel V grey squirrel' SSI scenario. Engaging students in practices of argumentation has been cited as central to achieving the goal of scientific literacy (Driver et al., 2000; Duschl, 2008; Kuhn, 1993). Even though there are a number of studies on argumentation in science education (Albe, 2007; Evagorou, 2011; Hong et al., 2013), little is known about primary students' argumentation skills in an Irish context. Indeed, many of the studies that exist in an international field focus on small scale studies, using one SSI context, over a short period of time. Thus this study is significant given the characteristics of the SSIPSC intervention.

Students provided written responses to the squirrel scenario in the pre and post-intervention student questionnaire which were analysed in terms of justifications and decisions made. Pre-intervention, over half the students decided to kill the grey squirrel. Over 40% provided no justification to support their decisions and out of those that did provide a justification, the majority (62%) provided emotional justifications in the form of personal opinions or based on an emotional response without considering the evidence presented or questioning the necessity of additional evidence (e.g. 'I don't like grey squirrels, kill them' or 'Grey squirrels are cute, do not kill them'). According to the International Council for Science (2011), without explicit argumentation instruction, students and adults are likely to make decisions and choices with implications for themselves and others that are based on opinion, experience, personal interest, or the beliefs of others (ICSU, 2011). Thus, the ability to weigh evidence in an effort to regulate emotional responses to situations is critical if individuals are to make decisions on contentious everyday issues (Newton & Zeidler, 2020).

Post-intervention the majority of students (64%) decided not to kill the grey squirrel. 86% of students provided justifications to support their decision. Out of the justifications, 71% of students provided rationalistic reason-based arguments to support their decision where the students used the evidence presented, considered alternative solutions and/or sought additional information before making a decision in response to the SSI squirrel scenario (e.g. ‘Kill the grey squirrel because the red squirrel is our native animal. The grey squirrel is not. The red squirrel is going extinct and there are plenty of grey squirrels in other countries’). Therefore, findings from this study indicate that primary students can improve the quality of their arguments through explicit argumentation instruction in the context of SSIs. This echoes findings of other studies which have found SSIs interventions as effective in developing students’ ability to provide logical and coherent arguments supported by evidence (Atabey & Topçu, 2017; Berland & Reiser, 2010; Evagorou, 2011; Khishfe, 2013; Ryu & Sandoval, 2012; Zohar & Nemet, 2002). Furthermore, even though quantitative findings present a relationship between students’ justifications and class level, whereby the highest class level provided the highest number of justifications pre and post-intervention, the younger classes (3rd class, 8-9 years old) were also capable of providing justifications to support their claims at the exit stage. Naylor and colleagues (2007) also concluded that young students (7-9 year olds) are capable of forming rational arguments in their UK study.

The students’ use of scientific evidence to support their arguments post-intervention is in contrast to Evagorou’s study (2011) where she found that primary students (11-12 years old) ignored scientific evidence if it was not in accordance with their own claims irrespective of class level, teacher, or cultural background. Evagorou’s finding is supported by previous studies in socioscientific argumentation where students were found to allow ideas that align with core beliefs to become part of their knowledge base while dismissing or ignoring evidence to the contrary (Evagorou et al., 2012; Lewis & Leach, 2006; Newton & Zeidler, 2020; Sadler et al., 2007; Zeidler, 2003). In the current study, the students did not seem to hold ‘strong’ initial beliefs pertaining to the SSI test scenario; more so there was a lack of conceptual understanding of the SSI corresponding with a lack of understanding of the importance of a claim and justification approach. Thus it may have been easier for the students to renounce previous conceptions and change their decision from emotive to rationalistic post-intervention. Furthermore, many assert that students need opportunities to work collaboratively in groups, challenge each other's point of view, and engage in socioscientific discourse to enable them to consider all available evidence as part of the construction of an argument (Khishfe, 2013; McNeill, 2011; Naylor et al., 2007); the SSIPSC intervention provided explicit opportunity for the students in this study to do so. This pedagogical approach is supported by others who have indicated that students need time and explicit instruction on how to form arguments (Christenson & Rundgren, 2015; Driver et al., 2000; Hong et al., 2013; Khishfe, 2013; McNeill, 2011; Zohar & Nemet, 2002). Hofstein, Eilks and Bybee (2011) further argue that providing students with opportunities to engage with and discuss SSIs develops skills that are important for student participation in societal debates concerning the development of their future as scientifically literate citizens.

While the content of students' written arguments may have improved from pre-intervention to post-intervention, the qualitative data indicated that the students' level of argumentation remained consistent in 4/6 cases as measured by Erduran et al.'s (2004) argumentation analytical framework. However, the number of pieces of evidence the students made reference to in their arguments increased in most cases (5/6) post-intervention, illustrating developments in the quality of students' arguments within the argumentation level. Chang and Chiu (2008) and Xia and Sandoval, (2017) agree with this assertion, stating that the more the number of descriptions, elaborations/examples to support a claim, the stronger the argument will be. Evagorou reported similar findings in her 2011 study whereby the students' level of argumentation, as analysed by Erduran et al.'s (2004) framework, did not improve post-intervention but the number of pieces of evidence the students referred to did. A number of studies reported that individuals struggle with constructing a rebuttal even after repeated interventions and specially designed instruction (Osborne, Erduran, & Simon, 2004; Chang & Chiu, 2008; Jimenez-Aleixandre & Pereira Muñoz, 2002; Simonneaux & Simonneaux, 2009; Ryu & Sandoval, 2012; Foong & Daniel, 2013). This has resulted in some researchers questioning the suitability of Erduran et al.'s (2004) framework as a means of assessing students' argumentation level whereby structural elements of an argument are counted and the presence of rebuttals is deemed to be indicative of high quality argumentation (Dawson & Carson, 2020; Sampson & Clarke, 2008; Simon, 2008). This concern is compounded by the fact that Erduran et al.'s (2004) framework does not analyse the quality of an argument; for instance, inaccurate evidence or data could be used to support an argument and it would still be considered as a high quality argument according to Erduran et al.'s (2004) analytical framework. Indeed, Grimes et al. (2019) conclude that Toulmin's framework, which underpins Erduran et al.'s (2004) framework, measures some but not all components of productive argumentation discourse. As a result, Grimes et al. (2019) extended the TAP framework to include sense-making and transactivity in order to incorporate holistic aspects of discourse into an argumentation analytical framework. Future studies on argumentation and SSIs in an Irish primary context should consider the use of such an analytical framework that will assess the structure, content, and validity of students' argumentation practices in order to provide a more comprehensive understanding of this complex construct.

In addition, most SSI argumentation studies do not highlight the potential impact of the researcher/teacher on students' discourse (Evagorou, 2011; Evagorou et al., 2012). Naylor et al. (2007) in their study on argumentation and primary science highlighted the impact of the teacher on group dynamics whereby the group often reverted to their whole class behaviour of sitting quietly and waiting for the teacher to decide who can speak and when, having a consequential negative effect on naturally occurring discourse. Duschl and Osborne (2002) argue that such teacher/student power relations do not encourage classroom discourse and dialogic interaction. Similarly, Bosser and Lindahl (2017) highlighted that teacher interactions with students either provide or inhibit student empowerment in the context of SSIs-based education. In this study, the 'position' of the researcher may have inhibited natural argumentation within the focus groups. Therefore, it is perhaps not surprising that the level of argumentation did not increase as the researcher cannot simultaneously hold power and direct the focus group and then expect the students to participate in group discussions as equals. A methodological approach where students are recorded during a class discussion on a SSI may have provided a more natural context to assess students' level of argumentation especially in terms of counter-arguments and rebuttals. This will be further discussed in the Limitations Section 6.4.

Despite the above methodological and analytical issues, this study adds to the growing body of research on primary school aged children's capacities to engage in sophisticated socioscientific argumentation and the difficulties that arise when attempting to measure these developments. Findings from this research indicate that the content of students' arguments was enhanced from pre-intervention to post-intervention after explicit engagement with the SSIPSC intervention. This was not a pedagogy the teachers used prior to this intervention; it was one which the students in most cases (5/6) thoroughly enjoyed. In spite of this, research indicates that discussion, debate and arguments are not common features of the primary science classroom in Ireland (DES, 2012; Varley et al., 2008). This is perhaps not surprising given that argumentation is not an explicit feature of the primary science curriculum (DES, 1999a). If we want students to engage in discussion pertaining to SSIs as scientifically literate individuals then students must be provided with explicit opportunities to do so (Maloney & Simon, 2006; Newton, Driver & Osborne, 1999; Osborne & Dillon, 2008). This study advances findings that SSIs are suitable contexts for the development of students' argumentation skills and should have a central position in primary/elementary science curricula and classroom practice (Duschl & Osborne, 2002; Simon et al., 2006).

5.2 To what extent does SSIPSC contribute to developing Primary School Students' Socioscientific Reasoning?

Socioscientific Reasoning (SSR) is an epistemological resource, consistent with Vision II scientific literacy (Kinslow et al., 2019). It was developed to directly examine the complex learning outcomes SSIs instruction is intended to promote (Sadler, Barab, and Scott 2007; Sadler & Zeidler 2009) and has been used in previous studies as a measure of scientific literacy (Sadler et al., 2007; Sadler & Zeidler 2009; Sadler, Klosterman, & Topçu, 2011; Karahan & Roehrig 2017; Romine et al., 2017). SSR is considered to consist of a set of interrelated sub-constructs: 'appreciation of the complexity of the SSI', 'approaching the SSI from multiple perspectives', and 'the value of ongoing inquiry' (Sadler et al., 2007; Sadler et al., 2011). SSR is a relatively under-researched area in a primary school context with few studies published to date (Sadler et al., 2007; Sadler, Klosterman, & Topçu, 2011). These studies have found that SSIs interventions have minimal impact on the development of students' SSR competencies concluding that the short-term length of the intervention and limited number of SSI contexts may have been inhibiting factors to SSR development (Sadler et al., 2007; Sadler, Klosterman, & Topçu, 2011). Other researchers such as Koslowski (2012) have questioned whether primary school aged children are developmentally capable of the thinking and reasoning skills associated with SSR. This study presented rich data to support the potential of SSIs to develop students' SSR in an Irish primary school context and advances a relationship between the constructs examined in Section 5.1 and SSR. Furthermore, the use of SSR as a measure of scientific literacy and the complex learning outcomes of SSIs-based education is considered.

5.2.1 Appreciation of the Complexity of the SSI

The 'appreciation of the complexity of the SSI' relates to a student's ability to recognise that a SSI is complex from a social and scientific perspective (Sadler et al., 2007). Students in all cases presented higher levels of 'appreciation of the complexity of the SSI' post-intervention. Pre-intervention, over 60% of students' responses were more likely to align with level 1 and level 2 where the students/cases offered a simplistic solution and did not appreciate the need to include evidence and/or diverse perspectives in their arguments. Furthermore, they did not seek additional evidence prior to making a decision pertaining to the SSI. Post-intervention, the students demonstrated growth in the 'appreciation of the complexity of the SSI' sub-construct where all cases reduced the number of level 1 responses and increased the number of level 2, 3 and 4 responses. Some students in all cases reached level 4 where they began to evaluate complex and often conflicting perspectives pertaining to the scientific and social component of the SSI test scenario.

The qualitative data revealed a possible relationship between student development of content knowledge and more accurate science conceptions and their ability to appreciate the complexity of the SSI. The data appears to indicate that students who demonstrated enhanced content knowledge also showed enhanced levels of recognising the complexity of the issue whereby informed science content knowledge about the SSI may have impacted students' understanding of the complexity of the SSI from both a scientific and social perspective. The quantitative method of gauging students' content knowledge development, in this case a 10-item content knowledge scale, limited the extent to which relationships between science content knowledge and SSR could be confirmed. Nonetheless the qualitative data provided rich insight and this relationship is worthy of further exploration in future studies.

In addition, much evidence amassed over the last decade in the area of SSIs suggests that SSI decision-making processes are primarily guided by socio-moral factors and that students are likely to ignore scientific evidence if it does not align with their personal opinion when making decisions pertaining to a SSI (Evagorou, 2011; Levinson, 2006; Patronis et al., 1999; Sadler & Zeidler, 2004). This study presents findings to indicate that the development of students' science content knowledge seems to have informed most students' justification and defence of their decision post-intervention. The use of scientific evidence to support arguments was modelled for the students by the teachers throughout the SSIPSC intervention with a similar pattern of rationalistic justifications emerging in the argumentation data, Section 5.1.5. Similarly, when students' science misunderstandings were addressed through the SSIPSC intervention, the students also demonstrated more informed decisions. Thus, it seems that the students had limited scientific understanding pertaining to the SSI pre-intervention and therefore could not use it to support their decisions. In support of this assertion, Barab and colleague's study (2007) concluded that flawed reasoning as a result of science misunderstandings is a fundamental inhibiting factor to the development of primary school students' socioscientific reasoning skills. Furthermore, other studies have found that students are able to start identifying issues of relevance and engage in some form of reasoned discussion when they have a strong content knowledge base and common science misunderstandings are addressed (Barab et al., 2007; Faize, Husain, & Nisar, 2007; Lewis & Leach, 2006; Patronis et al., 1999). Thus it could be said that the

SSIPSC intervention was effective at developing primary students' science content knowledge and students in most cases were able to apply this knowledge to the SSI test scenarios. It is not possible to ascertain how students were weighing up evidence or indeed ignoring evidence (scientific, social, financial) prior to making a decision on a SSI as the researcher did not interrupt the students to question them on their reasoning process. This is worthy of examination in future studies.

5.2.2 Approaching the SSI from Multiple Perspectives

A number of studies have identified perspective-taking as a crucial component for the development of scientific literacy (Chung et al., 2016; Kahn & Zeidler, 2019; Ratcliffe & Grace, 2003; Sadler et al., 2007; Zeidler, Herman & Sadler, 2019). Student examination of multiple perspectives has been shown to promote reasoning skills and critical thinking abilities vital to informed decision-making in relation to SSIs (Frijters et al., 2008). Similar to Section 5.2.1, students in most cases demonstrated higher levels of 'approaching the SSI from multiple perspectives' post-intervention. Pre-intervention, over 70% of students' responses in all cases (6/6) were categorised as level 1 or 2 where students failed to examine an issue critically or assessed the issue from a single perspective. At the exit stage, 70% of students' responses in all cases (6/6) were categorised as level 3 and 4 where the students were often able to consider the issue from multiple perspectives without being probed.

Examining an issue from multiple perspectives was an explicit feature of the SSIPSC intervention. Throughout the SSIPSC units, teachers provided students with opportunities to take on roles via role-play, representing different perspectives on a SSI and promoting the analysis of the SSI and potential solutions from diverse viewpoints. This often challenged the students' own perspective and/or inaccurate science conceptions on the issue. Therefore, as alluded to in other studies (Chung et al., 2016; Patronis et al., 1999; Sadler & Zeidler, 2005a), findings from this study suggest that discourse and debate scaffolded by the teacher allowed students to articulate and clarify values and perspectives on a SSI. Furthermore, it seems that the students in most cases were able to transfer 'perspective taking' from the SSIPSC intervention to the SSI scenarios where many students began to examine the SSIs from social, economic, environmental and scientific perspectives post-intervention. Students' ability to recognise an issue from multiple perspectives also emerged in the NoS findings where students developed their understanding of the subjective NoS. Being cognisant of and considering different perspectives is essential for making informed judgements about SSIs (Kahn & Zeidler 2019; Ratcliffe & Grace 2003; Sadler et al. 2007).

5.2.3 The Value of Ongoing Inquiry

'The value of ongoing inquiry' was the third sub-construct examined within SSR. Here the 'value of ongoing inquiry' referred to student ability to recognise the need for both scientific and social inquiry in order to make a more informed decision regarding a SSI (Sadler et al., 2007). More advanced levels of 'the value of ongoing inquiry' were evident across all cases post-intervention. However, students did not reach level 4 either pre-intervention or post-intervention. Furthermore, students demonstrated that they were able to critique the evidence underpinning the SSI scenarios with students in five cases making reference to the necessity of gathering additional evidence/conducting additional research prior to making a decision pertaining to the SSI scenarios. This supports Sadler and colleagues' (2005) assertion that in order for students to make informed decisions about SSIs they must recognise the need for an inquiry approach to uncover science knowledge for themselves (Sadler et al., 2005). This is in accordance with Lewis and Leach (2006) who assert that developing students' inquiry skills ensures that additional information can be accessed when required to ensure decisions are evidence-based and informed.

The students did not recognise the necessity of 'social' inquiry (level 4) prior to making a decision either pre or post-intervention. Whilst scientific reasoning should play an important role when making decisions regarding SSIs (Xia & Sandoval, 2017), studies revealed that scientific reasoning alone cannot resolve ill-structured problems (Barko et al., 2011; Kuhn, 1991; Sadler, Barab & Scott, 2007; Yang & Tsai, 2009; Zimmerman, 2000) and may lead to a partial or limited understanding of SSIs (Morris, 2014; Sadler, 2011a). It could be inferred that the teachers in the SSIPSC intervention prioritised scientific inquiry and scientific data to ensure that the curricular objectives of the Irish primary science curriculum were being achieved. Further research is warranted to explore student use of different forms of evidence, for example financial, social, scientific, and students' perceived need for scientific and/or social inquiry.

The most obvious implication of these findings is that primary school children are capable of engaging in sophisticated SSR, as measured using the SSR sub-constructs of 'appreciation of the complexity of the SSI', 'approaching the SSI from multiple perspectives', and 'the value of ongoing inquiry', adding to a limited body of literature in the field (Barab et al., 2007; Patronis et al., 1999). When comparing the findings of this study to previous SSI intervention studies that reported minimal impact on students' SSR reasoning development (e.g. Sadler et al., 2007; Sadler, Klosterman & Topçu, 2011), it seems that the long-term nature of the SSIPSC intervention where the students were provided with opportunities to develop and apply their SSR competencies across six different SSI units over a six-month period may have had a positive impact on the students' SSR competencies. This is supported by Romine et al. (2017) who argue that learning experiences that target SSR growth need to be extended beyond single units, if the instructional goal of student development of SSR is to be achieved. However, this is an inference and measurement of SSR competencies at different time periods in future interventions, for example after one SSI unit, three SSI units, would provide empirical evidence to support this claim.

Furthermore, the findings in this section highlight a possible connection between SSR and other tenets and the interdependent relationship between them; for example, content knowledge and 'appreciation of the complexity of the SSI', IBSE and 'the value of ongoing inquiry', NoS and 'approaching the SSI from multiple perspectives'. Teasing out these relationships in future studies would be productive. Sadler et al. (2011) proposed that additional constructs may need to be added to SSR in order to more validly capture practices associated with the negotiation of SSIs. Some researchers in the field have considered the possibility of including 'content knowledge' as a SSR sub-construct (e.g. Sadler et al., 2007); others have considered the addition of SSR constructs such as 'making cost and benefit analysis for the evaluation of claims' (Karahan & Roehrig, 2017). The findings from this study assert that the appropriate use of science content knowledge is a very important aspect of SSR which has a significant impact on students' reasoning and decision making ability (Sadler & Donnelly, 2006; Sadler et al., 2007; Zohar & Nemet, 2002).

This study also suggests that to use SSR as a measure of scientific literacy and/or a measure to capture the complexity of SSIs learning outcomes is limiting. This study demonstrates the holistic impact that teaching science through SSIs has on student learning in science, attitude towards science and perception of science. Furthermore, the SSIPSC inspired and motivated the students to engage in student-led citizenship. Thus it could be argued that SSR is not a comprehensive measure of scientific literacy and should not be used as such but rather a central competency of scientific literacy which has the power to enable students to make reason-based decisions pertaining to SSIs and also inspire them to take action.

5.3 To what extent does SSIPSC develop Students' Attitudes towards and perception of School Science?

5.3.1 Attitudes towards School and School Science

According to Bybee and McCrae (2011) attitudes play a significant role in an individual's interest, attention, and response to science in general and to issues that affect them in particular. Other researchers have indicated that positive attitudes towards science promote positive commitment to science and lifelong interest and learning in science (Blumenfeld et al., 2006; Reid & Skryabina, 2003). Such commitment and interest in science is required if young people are to pursue careers in scientific and technological areas (Osborne et al., 2003). Moreover, irrespective of this, positive attitudes are necessary to develop public interest, appreciation and engagement with science (Osborne et al., 2003). Many researchers have found that students' career aspirations and interest in science are largely formed by age 13 (see Tytler & Osborne, 2012). Similarly, Hong et al. (2013) purport that it is imperative to focus on promoting school students' attitudes toward science early with interventions in primary/elementary school in order to inspire positive attitudes toward science in young children. Attitudes, once formed, are enduring and difficult to change (Ajzen & Fishbein, 1980).

In this study, positive attitudes towards school were evident across most cases (5/6) prior to the SSIPSC intervention and across all cases post-intervention. These results are similar to those presented in Varley and colleagues' review of the implementation of the primary science curriculum in 2008 where over 80% of students (n=1030) reported that they enjoy school and find it interesting. The Growing Up in Ireland (GUI) study found that 27% of primary school students (age 9) (n=7563) like school always, with 67% of students indicating that they sometimes like school (William et al., 2009). Therefore, it seems that the students' attitudes towards school in this study are consistent with other national studies and the results of this study should be therefore interpreted in this context where the majority of students in all cases held positive attitudes towards school both pre and post-intervention.

Quantitative and qualitative findings in relation to students' attitudes towards school science in this study were presented in Section 4.7.2. Pre-intervention and post-intervention median scores indicated that most cases (5/6) presented 'positive' to 'very positive' attitudes toward school science at the initial and exit stage of the SSIPSC intervention. These findings are similar to other studies which have reported that Irish primary students have generally positive attitudes towards school science (TIMSS, 2015; Varley et al., 2008). Such positive findings are affirmative given international and national concerns regarding declining attitudes towards school science (DES, 2016; Hong et al., 2013; Osborne, Simon, & Collins, 2003; Potvin & Hansi, 2014). Furthermore, findings from this study, albeit from a small sample size, indicated that the students had positive attitudes towards school science irrespective of class level which is in contrast to other studies which found declining attitudes towards school science as students progressed through primary school (Murphy & Beggs, 2002; Pell & Jarvis, 2001).

Post-scale data for each case revealed that there were no statistically significant differences between students' attitudes towards school science pre and post the SSIPSC intervention. Only one case had more positive attitudes towards school science post-intervention with a small effect size ($0.1<r<0.3$). Three cases had the same median pre and post-intervention and three cases reported a decline in attitudes towards school science with a small to medium effect size. This seems to indicate that the SSIPSC intervention had a minimal to somewhat negative impact on students' attitudes towards school science. This is somewhat surprising given that a number of researchers have proposed that teaching science through SSIs promotes positive attitudes towards, and interest in school science (Dolan et al., 2009; Evagorou, 2011; Hong et al., 2013; Xia & Sandoval, 2011). This is the first study which has explicitly examined the impact of SSIs on primary school students' attitudes towards school science in an Irish context.

Qualitative data allowed for greater interpretation of these quantitative findings. Pre-intervention, the qualitative data raised questions regarding to students' perceptions of school science. For example, in three of the cases students referred to school science as 'explosions' and 'mixing chemicals' but were unable to provide examples of this type of school science when probed. This occurred from 3rd class cases to a 6th class case. It seems that some of these students may have been associating science with 'cartoon' images of scientists perceiving science to be what Solomon et al. (1992) call 'serendipitous empiricism'; that is a belief that scientists follow 'shot in the dark' type approaches where the outcomes of their experiments are unknown. A recent study in an Irish context reported similar findings regarding primary students' 'cartoon' perceptions of science and scientists (Murphy et al., 2019). Other students confused school science with outside of school science (4/6 cases), a finding supported by Kerr and Murphy (2012) who highlighted that children think about science in different ways and emphasised the necessity to differentiate between children's out-of-school and in-school experiences when measuring students' attitudes towards school science.

In terms of pedagogical practice, students in all cases stated they enjoyed hands-on investigations, experiments and investigations. Again this is a similar finding to other studies in a RoI primary school context (Murphy et al., 2012; Murphy et al., 2019). However, students indicated that they were provided limited opportunity for these investigations and found it difficult to recall such investigations during the focus group interviews. In addition, many students were critical of teacher-directed, text-book type science lessons often describing them as boring and repetitive. Teachers corroborated this finding speaking about their over-reliance on text-book science with some stating that they lacked confidence with hands-on science investigations. Over a decade earlier, Varley et al. (2008) raised similar concerns regarding the frequency with which students engage in hands-on science in an Irish context, proposing that in some cases students might be provided with relatively limited experience of hands-on investigations. Thus, while students in all cases had positive attitudes towards school science, especially hands-on science, at the initial stages of this study, students may have held inaccurate perceptions of what school science comprises and, furthermore, they may have limited experience of the science pedagogies they enjoy.

Post-intervention, students demonstrated more informed perceptions of the intents of school science in all cases. Most students stated that they had more frequent opportunities to engage in school science especially child-led investigations and hands-on science. The importance of learning 'real-world' science came to the fore in all cases where teachers and students indicated that they enjoyed the 'relevant' nature of the science lessons. Reference to science as explosions or potions or description of outside of school science did not emerge post-intervention. It is also interesting to note that three teachers felt that the students in their class had more positive attitudes towards secondary school science as a result of the SSIPSC intervention. Other studies have found that positive attitudes towards school science correlate to student interest and engagement with lifelong learning in science (George, 2006; Reid & Skryabina, 2003). A follow-up study would be insightful in this regard.

Therefore, the quantitative post-intervention findings, whilst not significantly different from the pre-intervention scale data, could be interpreted in a positive manner in that the students appeared to have more informed conceptions of the intents of school science post-intervention and still presented positive attitudes towards the subject. The mixed-methods research approach adopted in this study was crucial in reaching this conclusion where students' tacit knowledge of 'school science' was uncovered through qualitative focus groups. It could therefore be suggested that the students' perceptions of what 'school science' entails and the frequency of school science lessons might in fact weaken the reliability of the quantitative studies such as TIMSS and PISA where the students' perception of 'what science is' is not assessed.

Sadler and colleagues (2011) and others (Evagorou, 2011; Hong et al., 2013) provide some evidence that it may be the pedagogies associated with SSIs-based education, for example hands-on investigations, IBSE, collaborative group work, as opposed to the SSI itself that may be the determining factors influencing students' positive attitudes towards SSI interventions and science education. In the current study, findings revealed that the students had greater experience of these SSIs pedagogies, referred to above, and reported increased enjoyment of engaging with same. However, the relevance of the science content to the students' everyday lives emerged as a prominent theme in all cases. Students stated that they enjoyed science more because they saw its relevance to their own lives citing examples of what they had done in their everyday lives in response to the SSIs and many students emphasised how important it was to learn about SSIs. This echoes the findings of Zeidler et al.'s (2002) study who reported that students were more likely to 'buy in' to a science topic if it was based around social issues the students deemed important. Evidently the SSI was a way to anchor and connect the subject of science to life outside of school, thereby creating interest in the topic (Zohar & Nemet, 2002). This is particularly significant in an Irish primary science context where students have experienced difficulty connecting school science to their everyday lives (DES, 2012; Matthews, 2007; Varley et al., 2008). Furthermore, learning science at school has often been accused of being too abstract or detached from real-life existence which has a negative impact on student interest in science (Krapp & Prenzel, 2011). Therefore, this study has found that the SSIPSC intervention was effective at promoting more informed practices and views of school science with both the relevance of the SSI issue itself and their engagement with associated SSI pedagogies impacting these changes.

5.4 Did the SSIPSC Intervention facilitate Student-Led Citizenship?

Data in relation to this research question emerged in the post-intervention qualitative data analysis and was therefore retrospectively added as a research question in this study. The evidence suggests that students in all cases often moved beyond discussion of SSIs to action in response to the SSI, a movement indicative of Vision III scientific literacy principles. Post-intervention, students described action they had taken at home and school in response to the SSIs. Examples the students provided ranged from personal action in terms of reducing consumption of sugary drinks, whole school action in terms of a responsible energy usage campaign, to family-orientated action in response to the SSI of bees and biodiversity. This can be considered a form of democratisation of science in that students were advocating for others to be better stewards of the natural resources shared by their community (Mueller, Tippins, & Bryan 2012). Furthermore, students in many cases (4/6) cited that the 'citizenship component' had a positive impact on their enjoyment of, and engagement with school science developing positive attitudes towards the subject. Teachers corroborated these findings in the post-intervention interviews.

It should be noted that the promotion of a certain type of 'civic action' was not an explicit feature of the SSIPSC intervention but emerged implicitly in response to some of the SSIs that the students had engaged with. Many researchers have expressed concerns that imposing particular behaviours on students can compromise the integrity of SSIs-based education where the issues are complex, ill structured with multiple perspectives and multiple possible solutions (Pedretti & Nazir, 2011; Sadler, 2011 a, c; Zafrani & Yarden, 2017). Thus while the ultimate purpose of the SSI intervention was not to produce 'activists', a purpose suggested by Hodson (1999; 2010), findings demonstrate that high levels of student engagement fostered empowerment as the students used their learnings in a school context, connected it to their local context and then took action where they felt they could make a difference. Thus 'action' was not mandated by the researcher or teacher but student-driven. The SSIPSC intervention therefore facilitated students to take informed, reflective action and consider how their actions impact society. Many have advocated that this is not only integral to science education but also necessary to promote social and civic responsibility (Aikenhead, 2005; McInerney et al., 2011; OECD, 2018a, b; Smith & Sobel, 2014).

Other studies have found similar findings in relation to student-led activism as a result of SSIs education. For instance, Roth and Lee (2004) found that middle school students (aged 12-13) became active participants in their local community as a result of a three-year environmental project on water-related issues. Roth and Lee (2004) concluded that the project had the potential to promote lifelong participation and learning in science. Findings from this current study could also support this potential. However, a follow-up study is required to examine the long-term impact, if any, on students' active participation as a result of this study. Similarly, Barton and Tan (2010) investigated student (10-14-year-old) agency as a result of a year-long programme on energy situated in the local community and found that the students who were knowledgeable about SSIs were capable of taking action in their local community. The same could be said for some students in this study.

Many of the studies on SSIs and citizenship education are small scale studies which focus on one class unit. The theme of 'active citizenship' emerged across a number of cases in this study and adds to the current field of research (Sadler et al., 2007). As noted earlier, all cases did not take action and cases often differed in the action they took in response to the SSI. This aligns with Amos and Christodoulou's (2018) continuum of 'taking action' in response to SSIs, where at one end of the continuum students raise awareness of the issue, at the middle students have an intention to act, and at the other side students take action in response to the SSI. It would be interesting to explore Amos & Christodoulou's (2016) continuum in greater detail and try to ascertain why certain cases took action based on certain SSIs, even though the content, resources and pedagogical approach for all SSI units remained the same across cases.

This study provides empirical evidence to support Levinson (2013; 2018) and others that SSIs education can be a suitable context for the advancement of citizenship education and provides opportunity for students to take action should they feel compelled to do so (Levinson, 2013); active scientifically literate citizens emerged from this study. Furthermore, the evidence suggests that school science, for the students in this study, was no longer compartmentalised to 'school' or what Levinson (2013) refers to as 'simulation activities' but students were able to take their learning into their everyday lives, thus enhancing the relevance and applicability of school science. The next section will discuss findings pertaining to Case F which emerged as an outlier in this study.

5.5 Outliers in the Study: Case F

The results from Case F (3rd class, *n*=13) did not align with the other cases with regards to the above research questions (Section 5.1 - 5.4). Results specific to this case will be discussed here. There was a statistically significant difference ($p<.05$) in the development of the students' science content knowledge from pre-intervention to post-intervention and a small effect size ($0.1<r<0.3$) reported. However, many scientific inaccuracies remained in Case F's discussion of the SSI scenarios post-intervention. This seems to have had an impact on the students' ability to negotiate and make informed decisions pertaining to the SSI scenarios where Case F students were found to remain at low levels of 'appreciation of the complexity of the SSI' both pre and post-intervention.

With regard to the students' experience of IBSE, quantitative data indicated that Case F had had frequent to very frequent experience of IBSE pedagogies at the outset of the study. There was no statistical difference between the pre-intervention and post-intervention IBSE scale scores. However, Case F made no reference to child-led inquires, i.e. devising their own inquiry questions and/or an investigation to answer an inquiry question, in the qualitative focus groups at the initial or exit stages of the study. Furthermore, analysis of the students' practical skill assessment indicated that all students were at a level of 'good' pre-intervention and remained at this level post-intervention. The 'value of ongoing inquiry' under the construct of SSR presented similar findings where the students failed to recognise the need for inquiry or presented vague suggestions for inquiry both pre and post-intervention.

Quantitative findings relating to NoS indicated that the students in Case F had informed conceptions of NoS, as measured by the NoS scale, both at the initial and exit stages of this study. However, the students did not make reference to the tenets of NoS in their focus group interviews. Similar to the other SSR constructs, the students remained predominantly at low levels of 'approaching the SSI from multiple perspectives' pre and post-intervention where many failed to examine the issue carefully or assessed the issue from a single perspective. Similarly, Case F was the only case that provided no justifications for their arguments prior to the intervention. This improved post-intervention with half of the students providing a justification for their decision.

The students in Case F had a statistically significant ($p<0.05$) increase in positive attitudes towards school at the exit stage of the study. Qualitative data provided no insight as to why this might have been the case. Quantitative data also indicated that the students had less positive attitudes towards school science post-intervention; whilst this was not statistically significant, it had a small effect size. When speaking about school science lessons the students enjoyed/did not enjoy, the students in Case F did not refer to the content of the SSIPSC programme post-intervention; this did not occur in any of the other cases. Instead, the students spoke about the same science lessons they had referred to during the pre-intervention focus groups.

Unfortunately, the class teacher did not participate in the teacher interview nor did she complete the intervention activity schedule (Appendix H) so it is not possible to ascertain the reasons why this case was an outlier in this study. A number of possibilities could be inferred: for instance, the students may not have engaged with the SSIPSC intervention to the same extent as the other cases. Levinson (2013) maintains that the SSI must espouse personal and social investment in an authentic context to positively impact students' attitudes towards and engagement with science. Thus the SSI topics chosen for the SSIPSC intervention may not have been of relevance to the students in Case F and thus they became disconnected from the intervention. Transferability also appears to have been an issue. For example, students presented a high level of content knowledge in the quantitative questionnaire post-intervention but were unable to transfer that content knowledge to the SSI test scenarios. According to Haskell (2001), in order for knowledge transfer to occur, learners must have a knowledge base that is significant in terms of depth, breadth, and organisation. In other words, learners must have well developed schema in order to transfer knowledge. The results in this study are consistent with the Threshold Model Theory (Sadler & Fowler, 2006) in that the other cases appeared to have developed science content knowledge/inquiry skills/NoS understanding robust enough to contribute to their consideration of the SSI scenarios. It could be that Case F did not develop or reach the conceptual level required to transfer their knowledge outside the context of the specifics of the SSIPSC intervention. The above explanations are all inferences based on the evidence available. Further replication studies in different primary school contexts are required to see if findings from Case F occur in different classroom contexts. The next section will examine the relationship between the SSIPSC intervention and the different class levels of the participating cases.

5.6 The Impact of the SSIPSC on Different Class Levels

Previous studies in SSIs have questioned whether SSIs-based education is developmentally appropriate for primary school aged children given the complexity of the SSI issues (Evagorou, 2011; Sadler, 2011a). This study provides findings in support of SSIs education in upper primary science education. The cases in this study ranged from 3rd to 6th class and all class levels, with the exception of Case F (3rd class), demonstrated improvements in scientific literacy competencies relative to their class level, see Table 4.25. For instance, the 6th class cases had higher levels of science content knowledge at the initial and exit stages of the study. They also had fewer inaccurate science conceptions at the initial stages than the students in the 3rd and 4th class cases. Similarly, the 6th class cases provided more rationalistic justifications to the SSI squirrel scenario pre and post-intervention in comparison to the 3rd and 4th class cases. The 6th class were also the only cases to demonstrate counter-arguments and rebuttals during the SSI scenario discussion post-intervention. The students' attitudes towards school were consistent across all class levels, as were their attitudes towards school science where there was no indication that the older classes had less positive attitudes towards school science as studies in the U.K. and Northern Ireland have found (Kerr & Murphy, 2012). The students' experience of IBSE varied independently of class level. For instance, Case D (6th Class), Case F (3rd class) and Case G (3rd class) had the most frequent experience of IBSE prior to the SSIPSC intervention. This concurs with findings by Varley and colleagues (2008) who reported that students' experience of IBSE varied across schools and classrooms. In addition, Varley et al. (2008) and the DES report (2012) highlighted concerns regarding the lack of development of students' inquiry skills as they progressed from the junior to the senior classes. Limited development of students' science inquiry skills was also evident in this study pre-intervention. In terms of SSR, the 6th class students demonstrated the highest levels across the three sub-constructs ‘appreciation of the complexity of the SSI’, ‘approaching the SSI from multiple perspectives’, and ‘the value of ongoing inquiry’; however, the 3rd and 4thclass cases also demonstrated high levels in these sub-constructs but these were not as frequent. Thus it could be argued that the SSIPSC intervention had a positive impact on all cases retrospective to their initial ‘base line’ across the scientific literacy constructs presented above.

5.7 Chapter Summary

This chapter discussed the quantitative and qualitative findings presented in Chapter 4 alongside pertinent literature in the field of SSIs education under each research question guiding this study. Positive findings related to the development of distinct scientific literacy competencies, namely: science content knowledge, NoS understanding, inquiry skills and argumentation skills, were discussed adding empirical data to a limited field of SSI research in a primary/elementary context. The extent to which the SSIPSC intervention developed the students’ SSR reasoning competencies was examined. Quantitative findings indicated that the SSIPSC intervention had a minimal positive impact on students’ attitudes towards school science with the qualitative findings suggesting that the SSIPSC intervention made science more interesting and relevant to the students’ everyday lives whilst also developing more accurate perceptions of the intents of school science and more frequent opportunities for the students to engage in science lessons. Finally, the emergence of student-led citizenship as a prominent theme was discussed in accordance with other literature which has found that students feel empowered to take informed action in response to SSIs as a result of SSIs-based science education. The emergence of Case F as an outlier in this study was examined alongside explanatory literature in the field of science education, while analysis of the findings pertaining to each class level was also provided. The final chapter reflects on these findings and suggests some recommendations for policy, practice and future research while also contributing to the field of SSIs and science education generally.

Table 4.25

Overview of Findings pertaining to each Case per Class Level

	3rd Class		4th Class		6th Class	
Case	**Case G**	**Case B**	**Case A**	**Case C**	**Case D**	**Case E**
Demographics	26 students; Mixed	32 students; Boys School	28 students; Mixed	28 students; Mixed	9 students; Mixed; DEIS	23 students; Mixed
Science Content Knowledge	Enhancement in science content knowledge post-intervention (*p*<0.05), large effect size (Cohen, 1988). Reference to inaccurate science conceptions reduced from 22 pre-intervention to 3 post-intervention.	Enhancement in science content knowledge post-intervention (*p*<0.05), *large* effect size (Cohen, 1988). Reference to inaccurate science conceptions reduced from 17 (pre) to 4 (post).	Enhancement in science content knowledge post-intervention (*p*<0.05), *large* effect size (Cohen, 1988). Reference to inaccurate science conceptions reduced from 15 (pre) to 1 (post).	Enhancement in science content knowledge post-intervention (*p*<0.05), *large* effect size (Cohen, 1988). Reference to inaccurate science conceptions reduced from 21 (pre) to 2 (post).	Enhancement in science content knowledge post-intervention (*p*<0.05), *large* positive effect size (Cohen, 1988). Reference to inaccurate science conceptions reduced from 10 (pre) to 2 (post).	Enhancement in science content knowledge post-intervention (*p*<0.05), *large* positive effect size (Cohen, 1988). Reference to inaccurate science conceptions reduced from 10 (pre) to 2 (post).
Scientific Inquiry Skills	Same experience of IBSE pre and post-intervention. Enhanced scientific inquiry practical skills from pre to post. Increased opportunity for child-led investigations post-intervention (Qual data).	Greater experience of IBSE post-intervention (*p*<0.05), *large* effect size (Cohen, 1988). Enhanced scientific inquiry practical skills from pre to post. Increased opportunity for child-led investigations post-intervention (Qual data).	Greater experience of IBSE post-intervention (*p*<0.05), *large* effect size (Cohen, 1988). Enhanced scientific inquiry practical skills from pre to post. Increased opportunity for child-led investigations post-intervention (Qual data).	Greater experience of IBSE post-intervention (*p*<0.05), *large* effect size (Cohen, 1988). Enhanced scientific inquiry practical skills from pre to post. Increased opportunity for child-led investigations post-intervention (Qual data).	Greater experience of IBSE post-intervention *medium* effect size (Cohen, 1988). Enhanced scientific inquiry practical skills from pre to post. Increased opportunity for child-led investigations post-intervention (Qual data).	Greater experience of IBSE post-intervention (*p*<0.05), *large* effect size (Cohen, 1988). Same level of scientific inquiry practical skills from pre to post. Increased opportunity for child-led investigations post-intervention (Qual data).
Argumentation Skills	62% of students provided justifications at the exit stage (+20% from pre-intervention). Level of argumentation remained the same pre (level 2) and post-intervention (level 2)	94% of students provided justifications at the exit stage (+56% from pre-intervention). Level of argumentation remained the same pre (level 2) and post-intervention (level 2).	92% of students provided justifications at the exit stage (+17% from pre-intervention). Level of argumentation remained the same pre (level 2) and post-intervention (level 2).	89% of students provided justifications at the exit stage (+32% from pre-intervention). Level of argumentation remained the same pre (level 2) and post-intervention (level 2).	100% of students provided justifications at the exit stage (+0% from pre-intervention). Level of argumentation increased from pre (level 2) to post-intervention (level 3).	95% of students provided justifications at the exit stage (+13% from pre-intervention). Level of argumentation increased from pre (level 3) to post-intervention (level 4)

Table 4.25 (continued).

	3rd Class		4th Class		6th Class	
Case	**Case G**	**Case B**	**Case A**	**Case C**	**Case D**	**Case E**
Socioscientific Reasoning	Enhanced level of ‘appreciation of the complexity of the SSI’, ‘approaching the SSI from multiple perspectives’, and ‘the value of ongoing inquiry’ post-intervention.	Enhanced level of ‘appreciation of the complexity of the SSI’, ‘approaching the SSI from multiple perspectives’, and ‘the value of ongoing inquiry’ post-intervention.	Enhanced level of ‘appreciation of the complexity of the SSI’, ‘approaching the SSI from multiple perspectives’, and ‘the value of ongoing inquiry’ post-intervention.	Enhanced level of ‘appreciation of the complexity of the SSI’, ‘approaching the SSI from multiple perspectives’, and ‘the value of ongoing inquiry’ post-intervention.	Enhanced level of ‘appreciation of the complexity of the SSI’, ‘approaching the SSI from multiple perspectives’, and ‘the value of ongoing inquiry’ post-intervention.	Enhanced level of ‘appreciation of the complexity of the SSI’, ‘approaching the SSI from multiple perspectives’, and ‘the value of ongoing inquiry’ post-intervention.
Nature of Science	More informed conceptions of NoS post-intervention (not statistically significant). *Small* positive effect size (Cohen, 1988).	More informed conceptions of NoS post-intervention (not statistically significant). *Small* positive effect size (Cohen, 1988).	More informed conceptions of NoS post-intervention (not statistically significant). *Small* positive effect size (Cohen, 1988).	More informed conceptions of NoS post-intervention (not statistically significant). *Small* positive effect size (Cohen, 1988).	More informed conceptions of NoS post-intervention (not statistically significant). *Medium* positive effect size (Cohen, 1988).	More informed conceptions of NoS post-intervention (not statistically significant). *Small* positive effect size (Cohen, 1988).
Citizenship	Evidence of student-led action (Qual data): E.g. Reduced energy consumption of school: monitoring use of single plastic materials.	Evidence of student-led action (Qual data): E.g. Reduced consumption of drinks with high levels of sugar.	Evidence of student-led action (Qual data): E.g. Planting pollinator friendly plants on school grounds.	Evidence of student-led action (Qual data): E.g. Discussed action to increase habitats for bees with school principal.	Evidence of student-led action (Qual data): E.g. Contacted Local Lunch Company to reduce use of single-plastic materials.	Evidence of student-led action (Qual data): E.g. Built pollinator friendly habitats for school grounds.
Attitudes towards School Science	No statistically significant difference between students’ attitudes towards school science ($p>0.05$). No effect size reported.	No statistically significant difference between students’ attitudes towards school science post-intervention ($p>0.05$). Small positive effect size reported.	No statistically significant difference between students’ attitudes towards school science post-intervention ($p>0.05$). Small negative effect size reported.	No statistically significant difference between students’ attitudes towards school science post-intervention ($p>0.05$). Medium negative effect size reported.	No statistically significant difference between students’ attitudes towards school science ($p>0.05$). Medium negative effect size reported.	No statistically significant difference between students’ attitudes towards school science ($p>0.05$). No effect size reported.

6.0 Conclusion

This chapter discusses the findings in the context of the research questions. It begins by providing a summary of the study. Next, the main findings from the research are discussed, outlining the study's contribution to knowledge. The limitations of the study are identified followed by a series of recommendations and suggestions for future research in this field.

6.1 Summary of Research Approach

This research study set out to examine the impact of teaching science through Socioscientific Issues (SSIs) on primary school students' scientific literacy. Scientific literacy is widely considered to be the goal of science education (Beernaert et al., 2015; NRC, 2012; OECD, 2013; UNESCO, 2016). In the past decade, SSIs has emerged as a pivotal movement in science education (Zeidler, 2014). SSIs-based education puts scientific literacy into action where complex issues such as climate change or addressing a neighbourhood environmental crisis become the context for science teaching and learning. Several authors have conceptually explored how SSIs-based education promotes the development of scientific literacy competencies (Hodson, 2003; Zeidler & Keefer, 2003; Sadler, 2011a). Many studies have examined a SSIs-based approach in a secondary or tertiary educational context, however, there is a distinct lack of research pertaining to SSIs and primary/elementary science education, with no research existing in a RoI context. The potential impact of SSIs-based education in a primary school education is worthy of examination especially since primary/elementary school science is compulsory in a RoI context and it has been found to be a key determining factor in developing students' interest in, attitudes towards, and perceptions of science (Tytler & Osborne, 2012).

A comprehensive conceptualisation of scientific literacy served as a guiding framework for the study. This conceptualisation moved beyond the primacy of scientific content knowledge, otherwise referred to as Vision I scientific literacy, to an articulation of the competencies required to engage in science-related issues and with the ideas of science in a social context as an active citizen, Vision II and III scientific literacy. Literature relating to SSIs in a primary/elementary/lower secondary school context was used to determine key principles of SSIs education. This resulted in the development of an innovative conceptual framework, which served to unite discrete variables such as science content knowledge, scientific inquiry skills, understanding of the NoS, argumentation, and socioscientific reasoning skills within the context of SSIs with the overall goal of promoting scientific literacy (Vision I, II and III). It conceptualised what is perceived to be a broad goal of science education into something attainable and measurable and relevant to the students' everyday lives. The impact of teaching primary science through SSIs, referred to as the Socioscientific Issues through the Irish Primary Curriculum (SSIPSC) intervention, was the focus of this study. Seven teachers engaged in a professional learning programme that developed their understandings of SSIs and associated pedagogies. They taught the primary science curriculum through SSIs over a six-month period. The methodological approach was underpinned by a mixed-methods, multi-site case study which aligned with the researcher's pragmatic worldview. Quantitative measurement scales, student focus group interviews, practical skills assessment, and teacher interviews were used to gather data to determine the impact of the SSIPSC intervention on the students' scientific literacy competencies. The results of this study will now be summarised.

6.2 Summary of Research Findings

The primary research question underpinning this research study was to explore to what extent teaching science through Socioscientific Issues had an impact on Irish primary school students' scientific literacy. This question was broken down into four sub questions (Table 6.1) informed by the conceptual framework presented in Chapter 2, with research question 4 emerging retrospectively.

Table 6.1

Research Questions underpinning this Study

1. To what extent does SSIPSC contribute to developing primary school students' science content knowledge, NoS understanding, scientific inquiry skills, and argumentation skills?

Table 6.1 (continued)

2. To what extent does SSIPSC contribute to developing primary school students' socioscientific reasoning?
3. To what extent does SSIPSC develop students' attitudes towards and perception of school science?
4. Did the SSIPSC Intervention facilitate student-led citizenship?

Case F emerged as an outlier and has been previously discussed in Section 5.5. Students developed content knowledge aligned with the SSIPSC intervention and the content objectives of the 1999 Irish primary science curriculum, addressed inaccurate science conceptions, and also demonstrated their ability to apply this content knowledge to real life applications. Students in all cases presented informed conceptions of NoS pre and post-intervention, and, students in most cases (6/7 cases) were able to apply their NoS understanding to their discussion and negotiations of the SSIs at the exit stage. Post-intervention, five cases had enhanced experience of IBSE pedagogies with most cases (6/7) indicating that they were provided with opportunities to engage in child-led inquiry throughout the intervention; there was limited to no evidence of students' participation in child-led inquiry pre-intervention. This enhanced experience of IBSE had a subsequent positive impact on the development of the students' scientific inquiry skills. Evidence relating to students' argument formation indicated that most students provided rationalistic justifications to support decisions at the outset of this study. However, limited improvements in students' argumentation level were reported with findings highlighting potential methodological limitations pertaining to the assessment of this complex construct. The combined analysis of these results with other studies that have examined the relationship between SSIs-based education and discrete variables such as content knowledge (Wongsri & Nuangchalerm, 2010; Yager et al., 2006), NoS understanding (Bell & Linn, 2000; Khishfe, 2013; Soysal, 2015), inquiry skills (Amos & Levinson, 2019), and argumentation skills (Atabey & Topçu, 2017; Berland & Reiser, 2010; Evagorou, 2011) provide growing support for the efficacy of SSIs-based education in terms of developing these scientific literacy competencies in a primary/elementary school context.

The assessment of the students' socioscientific reasoning (SSR) competencies was a key feature of this study. SSR is a relatively under-researched construct and findings in relation to its development in a primary school context are mixed (Sadler, Klosterman, & Topçu, 2011). Students in most cases (6/7) demonstrated advancements in the SSR sub-constructs of 'appreciation of the complexity of the SSI', 'approaching the SSI from multiple perspectives', and 'the value of ongoing inquiry' at the exit stage of this study. This resulted in the analogous development of Vision II scientific literacy competencies where the students applied their content knowledge, NoS understanding, inquiry skills and argumentation skills to their understanding, discussions and decision-making in response to the SSIs. This study illustrates the intrinsic, reciprocal relationship between these scientific literacy competencies and the students' ability to engage in SSR whilst also highlighting the limitations in the recommended use of SSR as a measure of scientific literacy and complex student outcomes as a result of SSI-education.

The students in this study had positive attitudes towards school science at the initial and exit stages of the study; however, only one case presented more positive attitudes towards school science at the exit stage. Analysis of the pre-intervention qualitative findings indicated that many students held inaccurate perceptions of school science and while the students enjoyed hands-on investigations, the evidence suggested that many students had infrequent experience of school science at the initial stage of this study. Post-intervention, most cases (6/7) had more accurate perceptions of, and more frequent experience of school science but still maintained positive attitudes towards the subject. The students (6/7 cases) saw the relevance of school science to their everyday lives and had greater opportunities to engage in child-led investigations. Furthermore, such was the level of students' engagement with the SSIPSC intervention, that many cases took action in response to the SSIs in their home, school community and personal lives. This suggests that the students' perception of science was no longer confined to school but the students saw the relevance of science to their everyday lives.

6.3 Contribution to Knowledge

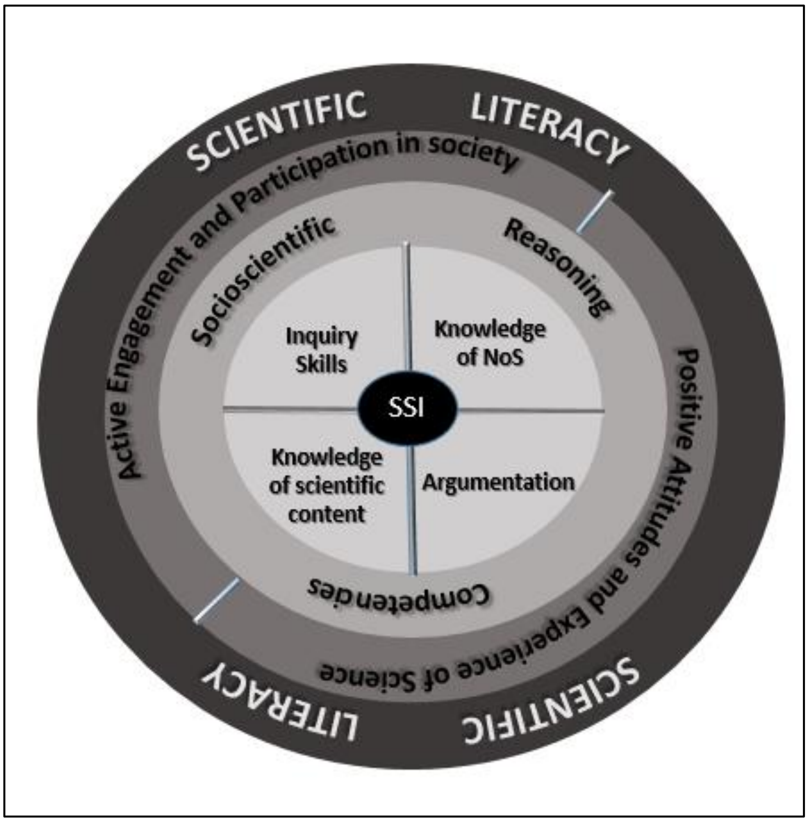
Based on findings presented above and discussions in Chapter 4 and 5, this study's contribution to knowledge will now be discussed with reference to international and national contributions. A systematic conceptual framework for developing students' scientific literacy through SSIs-based education will first be presented followed by a discussion of the efficacy of SSIs-based education for a primary/elementary context. The implications of the research findings for Irish science education is also presented.

6.3.1 Socioscientific Issues and Scientific Literacy: A Conceptual Framework

This study developed an innovative conceptual framework and considered SSIs and scientific literacy in all of their systemic complexity, see Figure 6.1 (previously shown as Figure 2.2). A number of international studies in an elementary/primary/secondary context have examined the impact of a SSIs intervention on discrete variables. For instance, some have examined the impact of a SSI intervention on students' science content knowledge reporting positive findings in primary/upper secondary school contexts (Yager at al., 2006; Wongsri & Nuangchalerm, 2010). Others looked at the relationship between SSIs and the development of NoS understanding (Bell & Linn, 2000; Khishfe, 2013). These studies and others reported findings pertaining to these distinct scientific literacy competencies and alluded to the potential of SSIs education to develop students' scientific literacy. The conceptual framework presented in this study is unique in that it is the first to investigate the potential impact of SSIs-based education across a number of constructs, examine the relationship between the constructs, and to consider their direct relationship to scientific literacy competencies. The outcomes of this study, orchestrated together, are the embodiment of Vision I, II and III scientific literacy with SSIs at its core. It moved beyond the rhetoric of scientific literacy as the goal of science education, to the realisation of scientific literacy and associated competencies through SSIs-based education.

Figure 6.0.1

SSIs-Based Education and Scientific Literacy Conceptual Framework



Research findings from this study indicated that the conceptual framework was fit for purpose in six of the seven participating schools and is a valid framework for future studies in SSIs-based education. The findings illuminated the reciprocal relationship between science content knowledge, inquiry skills, NoS understanding, argumentation skills and students' socioscientific reasoning. Both the SSIs and the pedagogies employed had an impact on students' attitudes towards, and perceptions of, science. From this, students in this study often felt motivated and inspired to take action in response to some SSIs, fostering their citizenship skills and community engagement. This framework is novel in that it addresses different features in relation to one another in a collective and inclusive manner that presents a more coherent and authentic relationship between SSIs and scientific literacy, Vision I, II and III. In its totality, this framework presents scientific literacy as something measurable and attainable through SSIs-based education.

The goals of science education emerged as a continuous theme throughout this study whereby different visions of scientific literacy were presented and discussed. The battle between visions has permeated the history of science education which has seen periods of shifting and overlapping reform movements, reflecting the tension between the different goals or visions of scientific literacy. The findings from this study support the researcher's stance, along with others (Donnelly 2006; Liu, 2013; Siarova et al., 2019) that Vision I, II and III scientific literacy need not be perceived as competing rivals but as fundamentally linked where one vision simultaneously supports the development of the other. Using the empirical evidence of this study to provide an example to illustrate this, students needed to develop a sufficient level of scientific content knowledge (Vision I scientific literacy) in order to be able to then apply it to the SSIs and understand the complexity of the issue and its implication on society (Vision II scientific literacy). It was through the development of this content knowledge related to the students' everyday experience that fostered agency in the students where many took action in response to the SSI (Vision III scientific literacy). Literature related to SSIs associates SSIs-based education with Vision II scientific literacy competencies (Bencze et al., 2010; Fensham, 2007; Sadler & Zeidler, 2009). The findings from this study suggest that such an association is limited and it should be broadened to encompass all three visions of scientific literacy. It is this holistic and comprehensive vision of scientific literacy that is presented in the conceptual framework above with this study's research findings presenting evidence of Vision I, II and III scientific literacy competencies grounded in relevant, meaningful contexts.

6.3.2 Socioscientific-Issues Based Education is Relevant and Appropriate for a Primary/Elementary Context.

There is a dearth of research pertaining to the teaching of school science through SSIs in a primary/elementary context at an international level (Sadler, 2011a) with much of the literature to date situated in a secondary and tertiary educational context. A number of researchers have questioned the suitability of SSIs-based education for a primary/elementary context given their complex, ill-structured and sometimes controversial nature (Evagorou, 2011; Sadler, 2011a). This study provides empirical data to support the use of SSIs-based education in an upper primary/elementary context (students aged 8-12). The SSIs served to motivate and engage the students in the science lessons whilst also making school science both relevant and important to their everyday lives. The students demonstrated their ability to develop scientific knowledge pertaining to the SSI, develop skills such as argumentation and reasoning, and apply the knowledge and skills to discuss and make informed decisions about scientific issues that permeate the media and impact their lives. It is important to note that the SSIs chosen for this study were considered to be relevant to the students' interests and lives and also aligned with the Irish primary science curriculum. Students in younger classes were not included in this study and the suitability of SSIs-based education in these classes should be examined in future studies.

6.3.3 Socioscientific Issues-Based Education should be situated in Primary Science Education in the RoI

To examine the findings of this study in terms of contribution of knowledge to the national context, it is necessary to briefly revisit evidence of the current position of the teaching and learning of primary science. Irish primary students have been found to have positive attitudes towards science especially hands-on investigations where they get an opportunity to work collaboratively in groups (DES, 2012; Murphy et al., 2019; Murphy et al., 2012; Smith, 2015a; Varley et al., 2008). However, there are research findings that indicate that students are being provided with limited opportunities for IBSE and development of scientific skills (DES, 2012; Murphy et al., 2012; Varley et al., 2008). Furthermore, it is apparent that the scientific content children engage with is not particularly relevant to their everyday lives (DES, 2016; Murphy et al., 2011; Murphy et al., 2012; Varley et al., 2008). The pre-intervention data of this study is consistent with the above. Furthermore, it could be added that pre-intervention many students held inaccurate perceptions of what school science is, something which is worthy of further exploration at a national level. This study provided evidence that the SSIPSC intervention, in the six of the seven participating classes, was effective at addressing these concerns. Whilst it could be argued that these concerns could be addressed through a non-SSIs intervention, this study produced compelling data to highlight a relationship between the ‘issues’ underpinning the SSIPSC intervention and students’ interest in science and their perception of the relevance of science to their everyday lives.

Turning to the position of SSIs education in the Irish education system, scientific literacy and SSIs are a feature of the Junior Cycle science curriculum (NCCA, 2015) but, as mentioned earlier, it is not an explicit feature of the Irish primary science curriculum. This study produced empirical data to support SSIs-based education in a primary/elementary context in the RoI. Science is a compulsory subject in both the Junior Cycle and primary education in the RoI and some researchers have produced empirical evidence to suggest that students’ attitudes towards, and interest in science is formed by age 13 (for example Tytler & Osborne, 2012). Students generally transition to Junior Cycle (secondary education) at age 12 which highlights the potential significant impact of primary education on students’ attitudes towards and interest in science. This study argues that upper primary education is a suitable context for SSIs education in the RoI for a number of reasons: (i) From a practical perspective there is no high stakes exam attached to primary science education as there is with the Junior Cycle. (ii) Within a secondary school context, the multidisciplinary approach required for SSIs education poses challenges where there often remains an overemphasis on the discipline of science and the focus of high-stake exams, to the neglect of social, ethical and other important components of SSIs (Morris, 2014). (iii) The primary curriculum advocates a flexible approach which encourages cross-curricular teaching which would allow for child-led inquiry, action, discussion and debate. Sadler and Zeidler (2009) note that “people do not live their lives according to disciplinary boundaries, and students approach socio-scientific issues with diverse perspectives that integrate science and other considerations” (p. 912). This is not always possible in a secondary school setting where specialist teachers teach different subjects. It is also significant that the teachers in this study felt that teaching science through SSIPSC allowed for a multi-strand, cross-curricular approach where content of the curriculum could be achieved more efficiently and effectively through a SSI approach.

6.3.4 Children's Learning in Science Education

Findings from this study also provide a theoretical contribution in relation to children's development and how children learn science. The importance of starting with children's initial ideas has been highlighted by many science educators and often features in both national and international science curriculum (DES, 1999; Harlen & Qualter, 2018). Systematic research into children's learning in science has revealed that children's initial ideas are often in conflict with scientifically accepted understanding of events and relationships. Findings from this study add to this growing body of research (for example Osborne & Freyberg, 1997; SPACE project in the UK) whereby a number of inaccurate science conceptions were identified, that were common across the different class levels and across different school. Research on children's learning in science highlights inaccurate science conceptions as significant barriers to children's learning in science (Harlen & Qualter, 2018), however, this study adds to this theory with evidence suggesting that the students' inaccurate conceptions also served as a significant barrier to informed student reasoning and decision-making pertaining to the SSI. The inaccurate science conceptions identified in this study would serve as a useful starting point for future SSI studies. Identifying these inaccurate science conceptions and providing opportunity for the students to examine and look for evidence from different perspectives resulted in the development of the students' science content knowledge and correspondingly their reasoning skills as more accurate science conceptions enabled them to see the complexity of the issue. This illustrates the constructivist philosophy of learning where the students were provided with experiences and ideas which often did not immediately fit into their past experiences. This dissonance compelled students to negotiate and discuss their scientific understanding in order to resolve conflicts and enhance the quality of their own arguments.

Data pertaining to the application and benefits of using Situated Learning Theory also emerged in this study. The SSIs that underpinned the SSIPSC intervention were both relevant to the students' everyday lives and situated within social, cultural and physical contexts. The SSIPSC learning environment provided students with opportunities to investigate, gather data, work collaboratively, engage in discussions and debate, develop reasoning skills and take action. In accordance with Kouzlin and colleagues (2003), this environment mirrored the culture and tools that citizens should use in real life situations when negotiating SSIs. This study presents evidence that the students were capable of applying knowledge and skills developed in school to their lives outside of the classroom where they took informed action in response to some SSIs at personal, local and community levels. Evidence from this study counters arguments presented by Levinson (2013) who criticised the use of SSIs dictated by the teacher/curriculum for being school simulation activities which would not prepare students for participation in authentic real-world contexts. Sadler (2009) maintains that in order to participate more fully as scientifically literate individuals, learners must understand the rules of engagement and standard operating processes of that community. Findings from this study suggest that the SSI-based learning environments lead students to the development of inquiry, reasoning and argumentation skills which has the potential to prepare students to engage in communities as active, informed citizens.

The benefits of inquiry based science education are widely reported and generally accepted both nationally and internationally. These benefits also materialised in this study whereby data suggests that many students had more enhanced experiences of IBSE and had greater opportunities to engage in child-led inquiry. This was found to have a positive impact on the development of children's inquiry skills and positive attitudes towards science. Findings from this study suggest that the SSIs provided an authentic context for IBSE whereby the students proposed inquiry questions regarding issues that they felt were important and relevant to their everyday lives. This enhanced their motivation to both investigate and take action in response to the SSIs.

Some have questioned whether SSIs-based education is developmentally appropriate for primary school aged children given their complex, controversial nature (Evagorou, 2011; Sadler, 2011). Others raised concerns pertaining to whether primary school aged children are developmentally capable of the higher order reasoning skills required for negotiating complex SSIs

(Koslowski, 2012). This study concurs with findings by Reiser et al. (2007) and provides evidence that students in upper primary school have the capacity to demonstrate sophisticated reasoning skills, analyse an issue from multiple perspectives, make informed decisions supported by empirical data, and engage with scientific discussions and endeavours in a meaningful manner.

These findings add to a growing body of research on children's learning in science and support the use of constructivist, inquiry-based, situated learning theories with primary school aged children. The importance of finding out children's initial ideas relating to the SSI and providing them with opportunities to gather evidence through inquiry based approaches was highlighted. Furthermore, the study provided evidence that upper-primary school aged children are developmentally capable of the higher-order thinking and reasoning skills required to examine, discuss and make informed decisions pertaining to SSIs.

6.4 Limitations of this Research Study

Case study research has often been criticised on the grounds that its findings are not generalisable (Yin, 2009). Usher (1996) questions whether generalisations are ever possible in educational research with Frankfort-Nachmias and Nachmias (1996) agreeing that few, if any, meaningful universal generalisations can be made in the social sciences. According to Bassey (2001):

> The public problem of generalisation in educational research, and throughout the social sciences, is that researchers are expected by policy-makers, practitioners and the public at large to make scientific generalisations, but cannot because they cannot identify, define and measure all of the variables that affect the events that they study (p. 8).

Thus whilst this study documents compelling evidence of development of scientific literacy competencies, classroom based research like this study will never produce the kinds of data that could legitimately be generalised to all students in all classrooms. Therefore, while generalising to a population was not the aim of this study, it does provide evidence pertaining to the efficacy of SSIs-based education across multiple primary school contexts. Six of these cases supported the conceptual framework presented and one case presented findings to the contrary. In accordance with Yin (2018), each case that replicates the findings in a multiple-site case study enhances the reliability of results while potential contaminating differences among the individual cases are also important to consider (Yin, 2018). Unfortunately, the teacher in this Case F did not participate in the teacher interview so the reason why the SSIPSC intervention had minimal impact on Case F students' scientific literacy competencies could not be ascertained. The students in Case F did not make reference to the content of the SSIPSC intervention in the post-interviews and referred to the science investigations/lessons they previously discussed in the initial focus groups indicating a possible lack of engagement with the intervention lesson content.

A control group was not a feature of this study and could be considered a limitation by some. It is difficult if not impossible to control variables in the situated world of real schools (Sadler, Dawson, Klosterman, Eastwood, & Zeidler, 2011). Finding a classroom that is similar in terms of size and population is one issue, however, finding a practicing teacher who will teach the control and experimental group over a similar time-frame posed unsurmountable practical difficulties. Furthermore, there are a number of other extraneous variables that could not be controlled for: students' interest in science, students' perception of the value of science, previous experience of science in school and outside school, to name but a few. The use of a multiple-site case study approach provided concrete evidence of the impact of the SSIPSC intervention on students' learning across seven different contexts thus provided evidence of transferability to different contexts and classes. In the absence of a control group, some may argue that the findings of this study may have occurred naturally through the teaching of the primary science curriculum; however, this is unlikely given that: the teachers had not taught primary science through the use of SSIs or any context prior to the study; the teachers did not provide opportunities for child-led inquiries prior to the study; and discussion, debate, argumentation and reasoning were not features of their science teaching prior to the SSIPSC intervention.

Other criticisms of case study design points to an inclination towards researcher bias and subjectivity due to the researcher being a participant (Cohen et al., 2011). In this study, the researcher designed and delivered the programme of professional learning as well as designing the SSIPSC intervention and associated teaching resources. Furthermore, the researcher conducted and analysed both the student focus group interviews and the teacher interviews. Thus, while researcher bias can impact case study research, it is important to note that every research method, including the scientific method, involves some form of subjectivity (McComas, 1998). A number of methods were used to reduce researcher bias in this study. The researcher presented her positionality, both personally and professionally, in relation to the study in Chapter 1. This involved the researcher acknowledging and disclosing her own self in the research, seeking to understand her part in, or influence on, the research (based on Cohen et al., 2011, p. 225). The research design consisted of a triangulation technique which required data from multiple data sources to converge. Member checking was implemented throughout the interviews to ensure the researcher was interpreting the participant's views accurately. Finally, a transparent data coding and analysis process was presented. This helped to reduce any biases induced by the researcher's subjectivity.

At the initial stages of this study the researcher was aware of the limitations and difficulties applying Toulmin's TAP framework and therefore choose to use Erduran et al.'s (2004) analytical framework which was built upon the principles of the TAP framework but consisted of five argumentation levels which served to indicate the quality of argument based on the number of rebuttals. Evagorou (2011) combined a 'counting evidence' element with Erduran et al.'s (2004) framework to overcome concerns that Erduran et al.'s (2004) framework did not sufficiently account for the quality of the argument within each level. Both Erduran et al.'s (2004) framework and Evagorou's (2011) 'counting evidence' component was utilised in this study. However, in spite of this, evidence from this study highlighted that this combined framework did not overcome difficulties regarding the assessment of the quality of the argument in that students' level of argumentation could be classified as level five (highest level) by making reference to a number of pieces of evidence but the evidence used could be inaccurate/irrelevant or scientifically incorrect.

Therefore, using this framework, the quality of the argumentation was somewhat reduced to the counting of rebuttals or evidence to the neglect of the assessment of the quality of the argument within. Furthermore, using Evagorou's counting framework was limiting for the assessment of dialogic argumentation. For example, 'counting evidence' encourages you to look at individual student arguments within a discussion, however, difficulties emerge when students build on each other's evidence and deciding where and when the 'evidence' to support an argument started and finished proved problematic. The decision was taken to count the evidence individual students used within the SSIs discussion which did indicate a general pattern, however, it was limiting and may not have captured the true depth of discourse that occurred in the focus groups. Thus Evagorou's (2011) counting of evidence component may be more suitable to written arguments or monologue than to dialogical or interactive forms of discourse. McDonald and Kelly (2012) raise an interesting point regarding the use of Toulmin's TAP framework or an adaptation of it to analyse socioscientific argumentation. Toulmin's TAP framework (1958) was devised to analyse scientific argumentation which is the kind of "science discourse most closely associated with the end of the scientific process when scientists articulate claims for an external audience. It is the most formal and normative kind of science discourse, and thus lends itself well to structural analysis" (Grimes et al., 2019, p. 10). This is different to the purpose of socioscientific argumentation whereby the goal of is not for students to engage in argumentation as scientists would but for students to engage in practices that help them participate in conversations pertaining to SSIs as citizens where scientific argumentation alongside consideration of moral, economic and other factors are key. This highlights theoretical and application difficulties associated with applying Toulmin's TAP framework to socioscientific reasoning. Notwithstanding these limitations, the analytical framework used in this study provided evidence of a pattern of improved argumentation practices which demonstrated the effectiveness of the SSIPSC intervention in terms of developing students' argumentation skills.

Another limitation which may have compromised findings pertaining to students' level of argumentation is that of the influence of the researcher in the students' focus groups. Every effort was made to minimise this influence by creating a relaxed environment, informing the students that there were no right or wrong answers, that their responses would not be disclosed to the class teacher and that the student's identify would be protected in the writing of the thesis (Krueger & Casey, 2000). However, argumentation requires the students to engage in social discourse with each other and the presence of the researcher may have negatively impacted natural discourse where the students spoke and responded to the researcher as opposed each other when discussing the SSI test-scenarios. Cazden (1988) note how the teacher controls classroom talk, deciding whether anybody should speak and the teacher chooses whether or not to grant permission. Therefore, it is not surprising that presence of the researcher impacted the students' natural conversational discourse and possibly impacted the students' use of counter arguments and rebuttals. Naylor and colleagues (2007) highlighted this as a potential impediment to the assessment of argumentation. Future research should consider the use of a stimulus such a concept cartoon where the cartoons put forward a number of alternative viewpoints for discussion so that the students are cast in the role of adjudicating between the alternative ideas rather than the researcher.

There were some limitations associated with the measurement tools that are important to acknowledge. Firstly, the science content knowledge scale (Appendix I, Section E) in the student questionnaire was not a standardised or validated measurement of science content knowledge. Others such as Klosterman and Sadler (2010), have criticised the validity of this type of science content knowledge scale, considered to be a proximal content knowledge assessment, given its alignment with the content of the SSIPSC intervention. As stated previously, there is no national standardised science assessment available for a primary school context in Ireland and questions in international tests such as TIMSS were considered to be too broad for the current study. To reduce this limitation, qualitative data added further depth to the quantitative data whereby students were provided with opportunities to refer to science content knowledge in their descriptions of their favourite science lessons and apply science content knowledge to support their discussion and arguments relating to the SSI scenarios in the student focus groups.

Teachers also referred to the development of the students' science content knowledge in the semi-structured teacher interviews. This triangulation of data enhanced the validity of the quantitative data. Furthermore, the science content knowledge questions were piloted with three non-participating classes and experts in the field of science education who verified the content validity of the science content knowledge scale.

Some, such as Eivers (2010), have highlighted concerns regarding the impact of using real-life contexts and open ended response questions, such as that used in the argumentation scenario in the student questionnaire (Appendix I, Section G), on student reading and writing load. These type of questions increase the influence of reading and writing skills on the measurement of student performance in a particular domain, in this context students' scientific argumentation skills. Others, such as Bodin (2007), concur with Eivers (2010) stating that it can become unclear whether student difficulties derive from understanding the text rather than limitations in the students' argumentation skills. Therefore, students' reading or writing skills may have an unnecessarily large effect on how well (or poorly) the students perform in such questions. To alleviate a potential dependency on the students' literacy skills, the class teacher read the scenario text aloud for the students and checked for understandings (see teacher guidelines for distributing the questionnaire, Appendix J). Students who have literacy difficulties completed the questionnaire with a Special Needs Assistant who reread the context for the student and transcribed student responses to the scenario, where necessary. Furthermore, the piloting of the questionnaire provided a good indication that the level of the text and language used was appropriate for the class levels involved in this study.

Inter-rater reliability is a statistical measure of agreement between two or more coders of data (Cohen et al., 2011). This is essentially a triangulation process between different researcher's interpretations and coding of qualitative data. Some suggest that by having multiple people code qualitative data, it enhances the accuracy and consistency of findings and mitigates the subjectivity of a single coder/interpreter (Mays & Pope, 1995; Miles & Huberman, 1994). Inter-rater reliability was not a feature of this study and some might highlight this as a perceived limitation; however, the researcher agrees with authors such as McDonald et al. (2019) and Morse (1994) who assert that inter-rater reliability is not the only way to enhance reliability in qualitative research. In this research study, a detailed account of the coding process, thematic analysis map, the qualitative code book and samples of coded interview transcripts were provided by the researcher (Appendix S to X). The researcher consistently coded the pre-intervention and post-intervention data and NVIVO proved a useful resource for assessing the consistency of the researcher's coding where all data pertaining to a particular theme could be accessed on one document/screen. Furthermore, one of the benefits of a pragmatic mixed methods research design is that it facilitates triangulation which serves to further enhance the reliability of the qualitative findings.

Overall the limitations of this study, although noteworthy, do not undermine the conclusions and recommendations made in this chapter. These limitations were taken into account by the researcher when drawing conclusions and making recommendations.

6.5 Recommendations for Policy

6.5.1 Scientific Literacy Competencies should be an Explicit Feature of the Irish Primary Science Curriculum

The term scientific literacy is not an explicit feature of the Irish primary science curriculum but it is alluded to in the broad curricular aims (DES, 1999a). Curriculum content is largely dominated by science content knowledge with limited reference to the development of science skills or competencies related to scientific literacy. Furthermore, reference to science skills are confined to the processes of science investigations rather than their applications beyond the school context. Vision I scientific literacy competencies take a significant and salient place. The primary curriculum is over 20 years old; it was developed for a different time with different government priorities, different technologies and for a different society. The 1999 curriculum does fully not represent the skills or competencies required for active participation in today's society. A science curriculum must go beyond the mere acquisition of scientific knowledge

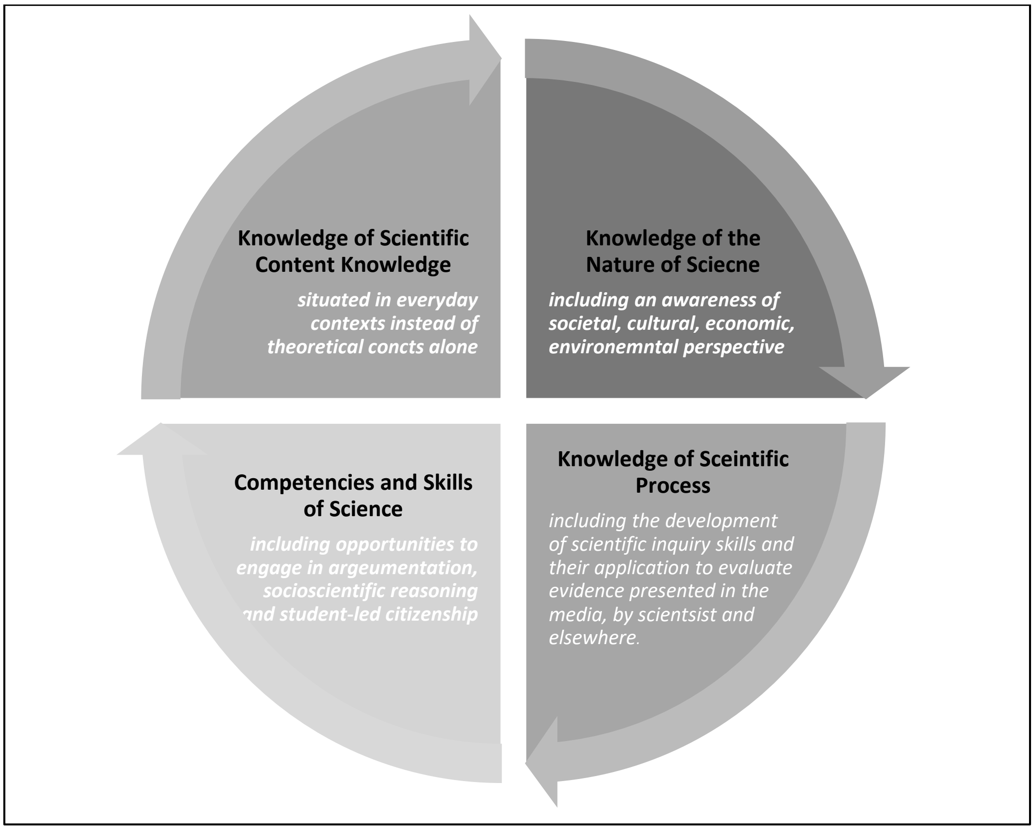
(Siarova et al., 2019) and include the ability to apply this knowledge in practice, think scientifically, critically assess information, actively engage in informed discourse, and take informed action using empirical evidence and reasoning skills (Siarova et al., 2019; Sadler, 2011a). This broader vision for science education needs to be coherently integrated into the Irish primary science curriculum.

The Irish primary science curriculum is due to be revised following the publication of a new primary curriculum framework in 2020/2021. The findings of this study assert, along with others (Siarova et al., 2019; Wang, Lavonen, & Tirri, 2019), that scientific literacy competencies (Vision I, II and III) must be explicitly included in the Primary Science Curriculum. Past policy documents and curricula have been criticised for failing to clearly define what the basic principles of scientific literacy are or what skills and attributes of a scientific literate citizen should be developed (Day & Bryce, 2013; Siarova et al., 2019). This study provides empirical evidence that the scientific literacy competencies presented in this study are suitable and attainable in a primary school context. Not only do these scientific literacy competencies support the key competencies of the proposed primary curriculum framework (NCCA, 2020) including 'Becoming an active citizen', 'Learning to be a learner', and 'Fostering wellbeing', they align well with the definition of scientific literacy underpinning the current Junior Cycle science curriculum (NCCA, 2015). Thus, this study argues that the scientific literacy competencies, as shown in Figure 6.2, should underpin the development of the revised Irish primary science curriculum of 2024.

Other countries have included Vision II and III elements in their curriculum aims, however these often do not materialise in the curriculum objectives (Siarova et a., 2019). For example, in Australia, an advisory group of science educators and science teachers put forward a strong case for the inclusion of the use Vision II and III scientific literacy competencies to determine the content of the Science Understanding Strand across all the years of compulsory schooling. However, the bureaucrats, who controlled the writing of the curriculum, chose to frame the science content in the disciplinary strands of Vision I scientific content knowledge which according to Fensham (2016) was what the authorities had been more comfortably familiar with. Mere reference to scientific literacy competencies in future curriculum aims is not enough, it must be entrenched in the objectives of the curriculum if it is to have meaningful impact on classroom practice (Siarova et al., 2019).

Figure 6.0.2

Scientific Literacy Competencies for the Future Irish Primary Science Curriculum



6.5.2 Socioscientific Issues need to be an Explicit Feature of the Irish Primary Science Curriculum

SSIs-based education puts the scientific literacy competencies in Figure 6.2 into action where complex issues such as climate change or biodiversity issues become the context for science teaching and learning. Without SSIs, it could be argued that it would be difficult if not impossible to achieve Vision II and III scientific literacy competencies (Zeidler, 2014). If a new vision for primary science education is to be supported, then SSIs must be explicitly included in the curriculum objectives, where appropriate. Furthermore, a pedagogical framework to support the teaching of primary science through SSIs should be provided in the form of accompanying supporting documents such as Primary Science Teacher Guidelines and other such supports. The SSIs pedagogical framework (see Section 3.1.2) used in this study proved effective at guiding the teachers' practice and emphasised the importance of providing students with opportunities to gather evidence, engage in reasoning, form opinions, consider multiple perspectives, and consider the impact of their decisions on the environment and society as a whole. Exemplars that illustrate how a SSIs-based approach can be implemented in classroom practice to develop scientific literacy competencies must be provided. Teachers must be given guidance in selecting focal issues for SSIs-based teaching and learning. This guidance is already available in practitioner literature in a USA educational context (Zeidler & Kahn, 2014) and Swedish educational context (Ekborg et al., 2009) and could be revised/adapted for inclusion in the Irish primary science teacher guidelines. In Hong Kong a separate subsection, STSE Connections, was embedded in each science strand of the Curriculum which included examples that teacher could use to develop students' awareness and understanding of STSE (Ling Wong et al., 2011). A similar subsection on SSIs could be included in the forthcoming revised Irish primary curriculum.

6.5.3 Increased Provision for Professional Learning

Fensham (2016) argues that a disconnection between curriculum development and teachers' professional development is a prescription for failure for any future direction of science education. Oates (2010) agrees that the curriculum cannot be considered isolated from other vital factors that affect the educational system, namely teachers. Therefore, it is crucial to provide professional learning opportunities necessary for teachers to adapt and transform their practices (Osborne & Dillon, 2008). Teacher professional learning has been regarded as one of the most important factors for improving the quality of teaching in schools (Desimone, 2009). It is particularly critical because, if effective, it can influence teachers' learning, the method and practice of teaching, and student learning (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; Murphy et al., 2015; Smith, 2014; Wellcome Trust, 2014). The teachers (n=7) in this study had not taught science through SSIs prior to this study. Many of the teachers had difficulties implementing IBSE pedagogies, lacked confidence with the teaching of science and over relied on science textbooks to support their planning and teaching of science. A number of studies have reported similar findings highlighting that Irish primary teachers' often lack confidence, content knowledge and pedagogical knowledge with the teaching of science especially with regards to IBSE (Clerkin et al., 2016; Varley et al., 2008; Murphy et al., 2015; Smith, 2015a, 2015b). The professional learning underpinning this study was supported by 'best-practice' professional learning as defined by literature in the field (Garet et al., 2001; Loucks-Horsley et al., 2003; Smith, 2014). For instance, the professional learning was ongoing and sustained, involved the active engagement of the participants, was job-embedded, and collaborative and collegial in nature. Based on the findings in the current study, this research asserts that the model of professional learning, offered and provided by the researcher, was successful in implementing change in teachers' practice and had correspondingly positive effect on students' experience of school science. Therefore, a key recommendation of this study is the provision of professional learning opportunities to support the teaching of primary science through SSIs. Recommendations from national studies continuously highlighted the need for teacher professional learning and greater time allocation for science in initial teacher education, but neither have materialised (DES, 2012; Varley at al., 2008). In an era of curriculum reformation in the RoI, opportunities for nationwide professional learning are promising. Furthermore, the model of professional leaning used in this study aligns with the key principles of the national framework for teacher professional learning, Cosán (TCI, 2016), due to be implemented in 2020. From a policy perspective, provision of professional learning supports a key aim of the national STEM policy (DES, 2017a; DES, 2017b), whereby professional learning programmes for primary teachers are to be developed in order to expand and develop teacher knowledge in STEM subjects. Past movements to promote scientific literacy, namely STS and STSE, were found to be ineffective due to the lack of professional learning support for teachers (Orpwood, 2001; Pedretti & Nazir, 2011; Tal & Kedmi, 2006; Zeidler et al., 2005). Without professional learning, the current SSI movement is more likely to follow in the path of predecessor scientific literacy movements rather than having a meaningful impact on the quality of teaching and student learning.

Notwithstanding the positive findings of this study, it must be acknowledged that the researcher had a key role to play in the professional learning provision and thus the model may not be feasible to implement on a larger national scale. As a community there is a need to generate better ways to develop and disseminate curriculum and teaching innovation that meets the needs of individual teachers and schools. The promotion of specialist STEM teachers 'STEM Champions' as advanced by the national STEM policy (DES, 2017a) provide opportunities to support the dissemination of best practice in STEM Education. Here, the teachers could engage with professional learning in SSIs-based education and then then disseminate their learnings and support colleagues in their school context. Indeed, this occurred in two of the schools in the current study where the class teacher supported other teachers to implement the SSIPSC programme in their school context. This would transform the current model into one that is more sustainable and would support a communities of practices (Lave & Wenger, 1991) approach to professional learning, a model strongly advocated by the Cosán framework for teacher learning.

6.6 Recommendations for Practice

The conceptual framework underpinning this study could be used in primary schools to develop primary students' scientific literacy through SSIs-based education. This framework was applied to the current primary science curriculum (DES, 1999a) and proved successful at meeting the curriculum objectives whilst also extending students' learning to include scientific literacy competencies such as argumentation and socioscientific reasoning. A cross-curricular approach is advocated where the SSI can serve to support other areas of the curriculum, for instance discussion and debate as part of the literacy framework (Gormley, Birdsall, & France, 2019). The conceptual framework will require teachers to consider their current pedagogical approach to teaching science. It requires a shift away from text-book dominated, didactic approach to child-centred inquiry where students are provided with opportunities to develop inquiry skills, gather evidence in relation to the SSI, and engage in meaningful discussion and debate (Fensham, 2016; Lee et al., 2019). A strong support framework in terms of professional learning, classroom resources, and opportunities for teachers to discuss their own conceptions of the purpose of science education are advocated (Hancock et al., 2019; Lee et al., 2019; Smith et al., 2011). This is in line with findings from Smith et al. (2011), Dawson (2011) and Day and Bryce (2011) who concluded that the way in which teachers think about and understand scientific literacy, personalised the meaning in terms of practice, which then shapes the action of teaching and learning for scientific literacy.

6.7 Recommendations for Future Research

The researcher recommends that the current study is replicated to confirm the findings of the research study in other school contexts. This is particularly important given that one case, Case F (3rd class), did not align with the findings presented in the other cases and it was not possible to determine the extent of the implementation of the SSIPSC intervention.

Limitations in the research design should also be addressed in future studies. For instance, the use of concept cartoons and recording of children's discussions pertaining to the SSI scenarios in a whole class context should be considered in future studies as means of mitigating researcher influence on the focus group discussions. This would also reduce the potential influence of the children's English literacy skills on their interpretation and responses to written argumentation contexts. Inter-rater reliability could be considered when coding qualitative data which may add to the reliability of the findings. A validated content knowledge scale is also recommended, which would provide more reliable and valid findings pertaining to the children's science content knowledge developments. Such a scale is not currently available for a primary Irish context. Finally, greater consideration could be given to the argumentation analysis framework where the content of the students' arguments, quality and type of evidence used and dialogic features of the students' argumentation could be measured or considered in a meaningful manner. However, within a thesis project some trade-off between breadth and depth is unavoidable.

In addition, some findings emerged that require further investigation: students' level of argumentation did not improve over the 6-month intervention in most cases (5/7 cases). Further research is required to ascertain if it was the methodological approach as alluded to by Naylor et al. (2007), the analytical framework utilised, or a shortcoming in the content of the SSIPSC intervention that was the reason for this students did not recognise the necessity for social inquiry in the context of socioscientific reasoning. This could be a concern if students do not see the value of social inquiry within socioscientific issues and warrants further investigation to determine why this was the case (Bencze & Carter, 2011; Kinslow & Sadler, 2018; Sadler & Zeidler, 2008; Sadler et al., 2007; Sadler 2011a). Finally, other competencies such as critical thinking and problem solving have been highlighted by many researchers in the field as key components of scientific literacy (Siarova et al., 2019; Vieira & Vieira, 2016). Explicit attention to these competencies is warranted in future studies.

This study examined the impact of the SSIPSC on students' scientific literacy and experience with science. It was beyond the scope of this thesis to collect and analyse data related to the teachers' experience of the SSIPSC intervention. An examination of the impact of the SSIPSC professional learning on the teachers' experience of SSIs, their science content knowledge, pedagogical knowledge and confidence teaching science is therefore recommended.

The measurement of scientific literacy competencies continues to be problematic (Fensham, 2016; Romine et al., 2017; Sadler et al., 2007; Siarova et al., 2019). This is not surprising given the complex, multi-dimensional nature of scientific literacy and the competencies there within. Existing measurement tools have been criticised for focusing on students' level of scientific knowledge and other measurable constructs to the neglect of other critical elements like active engagement, citizenship, and the discourse associated with argumentation and reasoning (Siarova et al., 2019). The mixed methods assessment strategies applied in this study allowed for a holistic measurement of scientific literacy competencies. Whilst, this assessment was resource and labour intensive, it did provide a better understanding of the nuances of factors associated with SSIs. The difficulties associated with the framework used to analyse students' level of argumentation were also acknowledged. This study recommends future research into the development of a scalable form of assessment for scientific literacy competencies that can be used at both a national level and in local contexts in school. For instance, Romine, Sadler and Kinslow (2017) developed and validated a quantitative measurement instrument to measure SSR for college level students, an adaptation of this instrument could prove effective in a primary/elementary context.

6.8 Concluding Remarks

This study provided empirical data on the use of a SSIs-based approach to develop Irish primary school students' scientific literacy competencies. These data provide evidence for the future direction of primary science education in Ireland. It argues for the broadening of the curriculum, from a focus on content knowledge objectives to the explicit inclusion of other competencies including knowledge of NoS, inquiry skills, argumentation skills and opportunities to engage in socioscientific reasoning. The use of 'real world' SSIs developed students' interest and promoted positive attitudes towards science whilst providing an authentic context for both the development and application of the above scientific literacy competencies. Furthermore, SSIs provided students with opportunities to participate in society as informed citizens capable of engaging in the negotiation and resolution of challenging science-based societal problems. Science should be learned in school very much the way it is practised outside of school. It is anticipated that the findings in this study and its subsequent recommendations, if addressed by the relevant stakeholders, could serve to transform primary science education so that it enables students to actively engage and participate in the world in which they reside, and transform and shape for generations to come. For this we need scientifically literate individuals and to achieve this, findings from this study assert, a SSIs-based educational approach is required.

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Appendices

Appendix A Professional Learning Course Overview

Title of Course	**Preparing Primary School Teacher for Real World Science**					
Date of Course	1st to the 5th July					
Course Target Audience	Primary Teacher	√	Post-Primary		Primary and Post-Primary Teachers	
At what class group/year group level(s) is summer course content pitched?	3rd to 6th Class					
Venue	DCU Institute of Education, St. Patrick's Campus, Drumcondra, Dublin.					
Anticipated number of Course Participants	20					
Anticipated number of Course Groups/Tutors (See specific criteria on tutor ratios)	1					

List the overall course aims	*'Socioscientific issues' in science education are every-day social issues which relate to science. They are open-ended problems which have multiple solutions. An informed understanding of socioscientific issues is key to developing primary students' scientific literacy. Examples of socioscientific issues include: Global warming, biodiversity, vaccinations, genetically modified food.* *Aims of Course:* • Enable primary school teachers to explore the importance of science in our everyday lives. • Help primary school teachers to identify and address socioscientific issues relevant to the primary students' everyday lives. • Engage teachers in critical discussion of everyday science through the use of socioscientific issues. • Analysis of socioscientific issues from environmental, social, ethical and economic perspectives. • Develop pedagogic principles for teaching socioscientific issues in science education. • Provide primary school teachers with research informed pedagogical tools, guided inquiry-based science education

	inquiry materials, and explicit teaching skills for use when teaching socioscientific issues in science education. • Provide primary school teachers with opportunities to develop their content knowledge and confidence regarding teaching socioscientific issues in science education. • Develop teachers' inquiry skills, 'working' scientifically skills, problem solving skills and critical thinking skills. • Apply a framework for teaching socioscientific issues in science education. • Embed 'socioscientific issues' in primary science whole school plans and teachers' planning frameworks.
How will participants' engagement in this course improve the quality of teaching, learning or leadership in schools?	Research has shown that many teachers' lack content knowledge, pedagogical knowledge and confidence when teaching primary science. Many primary students are not seeing the relevance of science to their everyday lives. Additionally, there is an over-reliance on traditional didactic approaches to science education (See Primary Science Curriculum Review (Varley, Murphy & Veale, 2008). This course will provide teachers with the content knowledge, pedagogical knowledge and confidence to teach science that is relevant to the students' everyday lives situated within the strands and stand units of the primary science curriculum (DES, 1999a). Core curriculum aims will be achieved as a result. Inquiry-based science methodologies, design and make activities principles of argumentation, socioscientific-reasoning, child-led investigations, the local and national environment, ICT, will be used to develop teachers' pedagogical skills and confidence. Research has shown that teaching socioscientific issues is key to enhancing students' scientific literacy. It will enable students to make informed decisions regarding scientific issues presented in their everyday lives. Additionally, this course will facilitate the development of teachers' leadership skills in the field of primary science education. Discussion of School Improvement Plans, School Self-Evaluation, Whole School Plans and individual teachers' plans will be a feature of the course.
What specific learning methodologies will be used?	• Modelling the use of a 'socioscientific issue in a science education framework. • Experiential learning: Teachers will engage and reflect on the use of Inquiry-based learning, fair test investigations, child-led investigations, design and make activities, field trips, argumentation and socioscientific reasoning to teach socioscientific issues in science education. • Participants will have the opportunity to critically reflect on their current practice and evaluate the methodologies, approaches and framework presented.

How does this course promote the use of ICT in schools?	• Teachers will use technology on a regular basis to record and measure findings. For example, the use of data loggers to measure temperature. • ICT will be used to find out information regarding socioscientific issues in science education. Use of good sources of information, fake news, will be evaluated. • ICT such as flip grams will be used to present results of investigations. • Reflective blogs will be used by the participants throughout. • Lego Education will be embedded into the course to model solutions to socioscientific issues in our everyday lives, developing teachers’ creativity, problem-solving and critical thinking skills. • Use of an online forum to support a professional learning community and provide feedback to participants during the implementation stage (September 2019).

Overview of Professional Learning Face to Face Course

<u>Day 1: 10 am – 2.30pm</u> **Specific Learning Outcomes for participants**	**Content description**	**Methodologies used to engage participants**	**Participants' activities, tasks or assignments to achieve the learning outcomes**
• Discuss and evaluate current practice in science education (School Self Evaluation: SSE). • Defining a socioscientific issue and explaining characteristics of a socioscientific issue in science education. • Understand the complexity of socioscientific issues in science education. • Recognise how everyday objects can be considered socioscientific issues in science education. • Develop inquiry skills of observation and classification of an everyday object (Kitchen Paper & Cups). • Conduct an inquiry-based science investigation using the principles of a fair test investigation. • Integrate ICT to record and present finds of investigations. • Use concept mapping as a means of mapping a journey of every-day objects. • Plan a decision-making activity developing students' argumentation skills. • Complete a reflective blog demonstrating developing understanding of socioscientific issues in science education	• Self- reflection – how do I teach science now? What works well? Are there any challenges? (SSE) • Critically analyse advertisements and explore their use as a context for child-led inquiry. • Observation and classification activity: Conduct investigation using fair test template. • Use data loggers to record measurement. Record results using flip gram (Numeracy & literacy). • Distribute sources of information on journey of paper cup, plastic cup, polystyrene cup. Map journey using concept maps. Evaluate concept maps. • Engage in a decision making activity: context of a coffee shop. • Divide into groups: Plan a decision making activity using a different everyday object e.g. plastic bags. • Complete reflective blog (SSE).	• Paired/Group Work • Talk and Discussion • Teacher Directed Activities • Concept mapping. • Use of ICT - data loggers, creation of graphs, video stories, flip gram	• Observing and classifying objects. • Planning and conducting investigations • Maintaining a learning record/self-reflective log • Measuring results using data loggers. • Creating graphs to present results using ICT. • Planning a feasible decision-making activity for everyday objects.

<u>**Day 2: 10 am – 2.30pm**</u> **Specific Learning Outcomes for participants**	**Content description**	**Methodologies used to engage participants**	**Participants' activities, tasks or assignments to achieve the learning outcomes**
• Understand the basic scientific knowledge and arguments about global warming. • Explain global warming as an example of a socioscientific issue. • Understanding controversy, uncertainty and types of argumentation in a chosen local socioscientific issue (Wind Energy). • Design and make a wind turbine using the principles of design and make: explore, plan, make and evaluate. • Participate in a wind-energy debate using different perspectives highlighting environmental, social and economic concerns. • Discuss argumentation as a pedagogical approach. • Devise an approach to critically evaluate information presented in the media. • Complete a reflective blog demonstrating developing understanding of socioscientific issues in science education. • Evaluate whole school approach to science education using whole school plans (SSE).	• Reflective Practice: Discuss key points from participant's reflective blogs (SSE). • Exploring the topic of global warming: Presentation of ideas, gathering and evaluating information representing both sides. • Child-Led Investigation: How the no. of blades, shape of blades, length on blades affect energy produced; • Design and Make a Wind Turbine. • Wind Energy Argumentation – Develop content knowledge on wind energy, read newspaper articles on wind energy. • Reflection on the idea of a socioscientific issue: what it is, characteristics, why teach it. • Reflective Blog: Complete daily. • School Self Evaluation – Identify opportunities for teaching a socioscientific issue within the plan.	• Self-Reflective blog • Paired/Group Work • Talk and Discussion • Investigative Approach – child-led, open-ended investigations • Design and Make activity. • Argumentation	• Planning and conducting investigations • Exploring, planning, making and evaluating a wind turbine. • Participating in a debate making informed arguments using information presented. • Maintaining a learning record/self-reflective log. • Reviewing whole school plan to teaching science education.

<u>Day 3: 10 am – 2.30pm</u> **Specific Learning Outcomes for participants**	**Content description**	**Methodologies used to engage participants**	**Participants' activities, tasks or assignments to achieve the learning outcomes**
• Develop participants' conceptual understanding of water: journey of water form source to tap, water conservation, water filtration process. • Develop participants PCK through modelling teacher-directed investigations, IBSE and design and make activities. • Develop participants' basic computational skills using LEGO education. • Evaluate the use of LEGO Education for teaching key concepts and skills of the primary science curriculum • Embed science education with LEGO education to illustrate solutions to problems along the journey. • Introduce the principles of socioscientific reasoning. • Examine the potential of discussion/concept cartoons/argumentation frameworks to promote socioscientific reasoning.	• Reflective Practice: Discuss key points from participant's reflective blogs (SSE). • Explore problems with water on a global and national context. Examine sources of information. Water audit: How much water do you use? • Integration with Geography: Explore the journey of water. • Materials and Change: Explore the filtration process. Design and make a water filter. • Conservation of water. Explicit links to green school flag. • Lego Education: Introduction to WeDo. Develop computational thinking. Consider links to Primary Science Curriculum (Numeracy & Literacy). • Junior LEGO League Challenge: Identify a problem along the water journey and illustrate using Aqua kit. • Evaluate using 'socioscientific issues in science education' framework. • Complete Reflective Blog.	• Self-Reflective Log • Paired/Group Work • Talk and Discussion • Design and Make activities. • Integration with digital learning and geography. • Lego Education.	• Completion of reflective logs. • Devising a fair test investigation to investigate materials for filtration investigation. • Programming WeDo model in LEGO education. • Devising a solution to a problem along water journey and illustrating using LEGO. • Evaluating the opportunities for embedding LEGO Education with science education.

<u>Day 4: 10 am – 2.30pm</u> **Specific Learning Outcomes for participants**	**Content description**	**Methodologies used to engage participants**	**Participants' activities, tasks or assignments to achieve the learning outcomes**
• Develop teachers' conceptual understanding of bees and pollination. • Become aware of the importance of bees in our society. • Examine the threats to bees and pollination and the possible causes. • Discuss the social, economic, and environmental aspects of the current issue. • Develop participants' PCK through modelling IBSE, teacher-led and child-led approaches. • Align the socioscientific issues with the curriculum and identify opportunities for development of scientific skills throughout. • Develop a programme of work suitable for teaching bees and pollination in primary school. • Engage in a process of argumentation regarding the promotion of biodiversity in the local area. • Examine how people in the community can be used to further examine socioscientific issues using a community approach.	• Reflective Practice: Discuss key points from participant's reflective blogs (SSE). • Contextualise problems with pollination through media discourse. Model inquiry approach to science education • Use of everyday environment: Observe, identify the plants bees are attracted to. Identify characteristics. • Gathering reliable sources of information to evaluate threats to bees and pollination. Devise a framework that will facilitate the critical interrogation of these sources in the senior classroom. • Use sources of information to form arguments pertaining to the promotion of biodiversity in the local area. • Design and make a bee habitat. • Field Trip: Visit DCU. Meet beekeeper. Ask questions, develop content knowledge. • Align with 'socioscientific issue' framework presented in day 2. • Complete Reflective Blog.	• Paired/Group Work • Talk and Discussion • Teacher Directed Activities • Use of ICT – evaluate reliable sources of information for primary school students. • Design and Make activity. • Interview an expert: beekeeper in DCU.	• Engaging in reflective practice • Observing and recording data • Designing and making a bee habitat. • Devising question for the bee-keeper. • Forming an informed understanding of threats to bees. Summarising findings in a poster.

<u>Day 5: 10 am – 2.30pm</u> **Specific Learning Outcomes for participants**	**Content description**	**Methodologies used to engage participants**	**Participants' activities, tasks or assignments to achieve the learning outcomes**
• Identify a socioscientific issue in science education which is applicable to each teacher's educational context. • Apply framework to planning a 'socioscientific issue' in science education. • Devise resources for chosen socioscientific issue • Present the socioscientific issue in science education and receive feedback. • Review current teaching and learning of science and identify changes that could be made as a result of participation in this course (SSE). • Evaluate and revise whole school plans in science education. • Discuss School Self Evaluation and School Improvement Plans including evaluation tools. • Discuss and explore the opportunities for an online forum to support personal and professional practice in science education (SSE).	• Reflective Practice: Discuss key points from participant's reflective blogs. • Divide into pairs. Each pair chooses a socioscientific issue in science education suitable for a primary class. Apply framework. Develop content knowledge on issue presenting different perspectives. Develop resources and integrate methodologies developed throughout the course. Present and provide feedback. Collate and distribute resources to other members of the course. • Whole School Evaluation Plans: Identify opportunities for including socioscientific issues in science education plan. Revise plans accordingly. Evaluate plan in terms of opportunities for different methodologies and approaches: e.g. IBSE, argumentation. • Refocus on SSE– how your understanding of a socioscientific issue has in science education developed/changed as a result of participation in the course, opportunities, challenges.	• Paired/Group Work • Talk and Discussion • Apply framework to plan a socioscientific issue in science education.	• Completion of reflective logs. • Presenting a socioscientific issue including resources to group. • Focusing on SSE

Appendix B Overview of the SSIPSC Programme

SSI Topic	**Connection to the Irish Primary Science Curriculum**	**Overview of the Unit**	**Connections to SSIs**
Kitchen Paper	*Strand:* Materials *Strand Unit:* Properties and characteristics of materials Materials and change	▪ Analysing advertisements that make reference to scientific evidence to support claims. ▪ Identifying claims made in kitchen paper advertisement – E.g. Bounty scientifically proven to be twice as absorbent as other brands. ▪ Plan fair test investigations to investigate claims. ▪ Conduct, analyse and present data. ▪ Compare findings with those presented in the advertisement.	Many advertisements target consumers through reference to 'scientific evidence' to support claims. Consumers need to have skills to critically evaluate the information that is presented to us. This unit focuses on the development of skills associated with SSI reasoning ('the value of ongoing inquiry' and 'appreciation of the complexity of the SSI') and the development of scientific inquiry skills. ▪ Appreciate the need for scientific inquiry. ▪ Apply inquiry skills in order to interrogate data presented in the students' everyday lives. ▪ Identify potential sources of bias that may influence information or the presentation of information about a scientific issue. ▪ Examine ethical advertisement.
Everyday Objects Cups	*Strand:* Materials; Energy and forces; Environmental awareness and care. *Strand Unit:* Properties and characteristic of materials; Heat; Environmental awareness; Science and the	▪ Observe the characteristics of different types of cups – material, size, functionality, etc. ▪ Devise an investigation question to examine the characteristics of the cups – For example which cup is the best insulator? ▪ Explore the life journey of the different cups.	The decisions we make pertaining to our choice of everyday objects, such as cups, is considered an important scientific and environmental issue. There is no one 'correct answer' to this issue whereby every consumer should consider economic, environmental and social factors associated with 'cups'. ▪ Investigate the personal, environmental, economic and social factors associated with everyday objects, cups.

	environment; Caring for the environment.	▪ Scenario: Which coffee cups should a local coffee owner purchase: Consider environmental issues; customer preferences, economic issues, etc. Different groups represent a different shareholder presenting different perspective on the issue.	▪ Recognise different perspectives on the issue (coffee shop owner, government (coffee cup tax), customer. ▪ Develop student argumentation skills ▪ Develop student SSI reasoning skills: recognising the complexity of the issue; valuing the necessity for ongoing inquiry and examining the issue from multiple perspectives. ▪ Engage in SSI discourse; applying reasoning and argumentation skills.
Sugar Tax	*Strand:* Living Things; Materials *Strand Unit:* Human Life; Properties and characteristics of materials	▪ Discuss the potential of a 'sugar tax' in an Irish context. ▪ Investigate how much sugar is in everyday food/drinks. Predict, measure and communicate findings. ▪ Develop an understanding of food and nutrition. ▪ Develop an understanding of the digestive system. ▪ Listen to and discuss the different perspectives on this issue: parents, canteen owner, children, government, nutritionist. ▪ Differentiate between evidence and opinion. Evaluate the quality and source of evidence used to support a claim. ▪ Form an opinion on the issue supported by evidence. Communicate opinion and	Obesity in children and adults is a serious issue in Ireland. It leads to many health related problems, including diabetes and heart disease. Adding a tax on 'high sugar' foods is considered a controversial issue which explores complex issues such as individual choice, government control and the question of 'what is healthy?'. ▪ Investigate the scientific, economic, ethical and social factors associated with a sugar tax. ▪ Develop the scientific knowledge necessary to understand SSIs such as obesity. ▪ Analyse evidence presented and question the source and validity of evidence presented. ▪ Investigate possible solutions to the issue. ▪ Recognise and consider alternative perspectives on the issue. ▪ Develop an ability to weight up arguments for and against a sugar tax.

		engage in counter-arguments, where appropriate.	▪ Make informed decisions in regard to the student's own health.
Renewable and non-renewable energy Wind Energy	*Strand:* Environmental Awareness and care; Energy and forces. *Strand Unit:* Environmental awareness; Science and the environment; Caring for the environment; Forces.	▪ Students read and discuss newspaper headlines/articles relating to the Climate Action plan. ▪ Different perspective from scientists are examined: scientists who claim climate change is a natural phenomenon V scientists who claim climate change is caused by humans. ▪ Develop an understanding of renewable and non-renewable sources of energy. Critically analyse different sources of energy in terms of their advantages/disadvantages. ▪ Apply knowledge about renewable and non/renewable resources to explain climate change. ▪ Explore why the development of windfarms is a controversial issue in many communities. ▪ Examine common statements/opinions about wind energy and investigate whether they are scientific or myths. ▪ Design, make and evaluate a wind turbine demonstrating how one form of energy is converted into another. ▪ Case Study: Development of a wind farm on local farm.	Climate change is widely considered to be a complex environmental socioscientific issue. It is a multifaceted issue and there are many different perspectives on the issue. It is tentative in nature where evidence pertaining to climate change is continuously developing. It is an issue that be examined at a global, local and personal level. • Students examine why scientists/citizens have different perspective of an issue. • Develop scientific knowledge to understand the complexities of climate change. • Evaluate the environmental, economic, social impact of the development of a windfarm. • Ethical dilemmas associated with climate change should also be discussed, where appropriate. For example, how to balance the rights and responsibility of the developed and developing world. • Interpret and analyse different forms of climate change data. • Represent different stakeholders in the wind farm scenario and use evidence/data to support claims. Engage in counter arguments. • Evaluate the climate action plan targets and potential impacts on different stakeholders.

Noise Pollution	*Strand: Living things; Energy and Forces; Materials; Environmental awareness and care.* *Strand Unit:* Human life; Animal life; Properties and characteristics of materials; Sound; Environmental awareness; Science and the environment; Caring for the environment	▪ Newspaper Articles: 'Dublin residents in court case over nightmare noise pollution from Dublin Port'. ▪ Develop an understanding of noise pollution and different sources of noise pollution. ▪ Develop an understanding of the ear and hearing. ▪ Investigate how sound travels. ▪ Gather and analyse evidence on the impact of noise pollution on human and animal life. ▪ Developmental Compass Rose: This is a tool that encourages the students to ask a range of questions about the issue of noise pollution at Dublin Port. It is a useful inquiry framework to raise questions around environmental, social, economic and political issues. ▪ Investigate and present possible solutions to the issue at Dublin port. Here some students may look at the insulating properties of different materials.	Noise pollution is a growing problem world-wide and one which has impacts on both human health, biodiversity and living conditions. It affects urban and rural locations in terms of locations of factories, motorways, wind turbines, etc. Political and economic factors have a strong influence on decisions pertaining to this issue. ▪ Recognise that this is a multifaceted issue. ▪ Consider the different stakeholders involved in the Dublin Port noise pollution case study using the Developmental Compass Rose tool. ▪ Consider and evaluate multiple solutions pertaining to the SSI. ▪ Develop an understanding of the scientific knowledge underpinning the issue. ▪ This issue could be explored at a personal and local level.
Animal Welfare	*Strand:* Living things; Environmental awareness and care.	▪ Students read newspaper headlines articles related to animal culling in Ireland (deer; badger; squirrels; seals). For example, fishermen off the coast of Cork and Kerry are calling for the culling of seals	Students debate the question of whether animals should be culled, thereby modelling the research, reasoning and discourse skills that are necessary for informed citizenship. ▪ Evaluate the moral and scientific factors associated with the issue of animal culling.

	Strand Unit: Plant and animal life; Environmental awareness; Science and the environment; Caring for the environment	which is said to be the cause of a depleted fish stock. ▪ Develop an understanding of the characteristics and life cycle of the animals. ▪ Analyse historical data pertaining to the squirrel/deer/badger/seal population.	▪ Issue is relevant to the students at a personal and local level. ▪ Opportunities to engage in argumentation and reasoning. ▪ Consider multiple solutions to the issue. ▪ Make an informed, evidence based decision based on the evidence available.
Bees	*Strand:* Living things; Environmental awareness and care. *Strand Unit:* Plant and animal life; Environmental awareness; Science and the environment; Caring for the	▪ Introduce the students to the All-Ireland Pollinator Plan. Develop inquiry questions regarding the issue of the declining bee population, ▪ Develop an understanding of bee and their role in society. ▪ Develop and understanding of pollination. Design and make a model to illustrate the pollination process. ▪ Observe bees in an outdoor environment. ▪ Analyse food dependent upon bees and consider the impact a decline on different stakeholders. Consider student's own weekly food consumption and the potential impact of the declining bee population on daily food. ▪ Investigate causes of the decline of the bee population. Examine the stakeholders involved with each of these causes. E.g. Importing bees with diseases infecting Irish bee colonies. ▪ Introduce 'Robotic bees' as a possible solution to the problem. Students present	The issue of bees and the declining bee population is a relevant context for the students to engage with. It is a multifaceted issue underpinned by moral, social, environmental, economic and social factors. The issue engages the students in the practice of explaining and arguing about the causes, consequences, and possible solutions related to the problem of bees. ▪ Consider the different stakeholders impacted by the declining bee population. ▪ Evaluate possible solutions and consider the impact of the solutions on different stakeholders. ▪ Consider the ethical factors associated with the issue.

		arguments for and against this solution using evidence to support their claims. Counter-arguments will also be encouraged.	
Water Crisis	*Strand:* Environmental awareness and care. *Strand Unit:* Environmental awareness; Science and the environment; Caring for the	▪ Introduce the issue from a Global Perspective linking to the UNESCO Sustainable Development Goals. ▪ Examine a case study of Turkana, Kenya where PlayPumps were installed as a scientific solution to the water supply issue but had social consequences. ▪ Examine the issue from a local perspective: How much water we use daily; where does our water come from; what process does our water come through. ▪ Examine newspaper articles regarding issues with water in an Irish context: pollution, water shortage, leaking pipes, unsustainable use of water. ▪ Consider the impact of the issues with water on different stakeholders. ▪ Propose solutions to a local water issue. Proposal must be supported by data. Opportunities for questions and discussion provided.	The issue of water sustainability is interdisciplinary both in terms of connecting to science (water cycles, sources, filtration, water pollution) and relevant social systems (e.g. governmental and economic systems). It also has strong connections to the students from a personal, local and global perspective. Consideration of the dynamic and interdependent nature of these issues is required to comprehend the issue, its consequences and how the issue can be resolved. ▪ Personal, local and global issue. ▪ Underpinned by ethical, economic, environmental and social factors. ▪ Multiple possible solutions. ▪ Relevant to the students' everyday lives.

Appendix C Sample Unit from the SSIPSC Intervention

Theme	**Sugar Tax – Where does the sugar go?**
Background	This unit introduces the children to Sugar Tax and explores the links between sugar consumption and the digestive system. Children investigate the sugar content of everyday items they eat and develop a simple understanding of food and nutrition. The children weigh up arguments for and against banning sugary drinks for all children under 18 years of age.
Curriculum	**Strand:** Living Things **Strand Unit:** Human Life **Skill:** Predicting; Analysing evidence; Investigating and experimenting. **Curriculum Objectives:** Develop a simple understanding of food and nutrition; Understand the importance of a balanced diet; Develop a simple understanding of the digestive system.
Resources	Headlines: Sugar Tax Ban in Ireland; can of coke, labels of drinks, digestive system template, information packs – the Digestive System; Sample 3-D models (teacher use only), Evidence and argument cards, PowerPoint presentation, useful websites for teacher and children, Diet coke: Why is it bad for you; How much sugar in fizzy drinks activity sheet.
Set a context	Display headlines regarding the sugar ban in Ireland; Display the question “Should we ban sugar drinks in Ireland for everyone U-18?” Discuss in small groups. Listen to the children’s opinions. Record their opinions. *Option: Create a bar chart of children’s opinions.* Show a can of coke. Children predict how much sugar is in the can of coke. Measure out 10 teaspoons. Discuss. Provide opportunity for children to devise inquiry question to help them answer guiding question “Should we ban sugar drinks to everyone in Ireland under 18?”. Present these questions. Watch video clip which gives different perspectives on the issue (e.g. parent, food companies, government, etc.). Discuss.

Development

1. ***Investigate: How much sugar is in that?***

Investigating Display the labels of a number of different soft drinks/energy drinks/fruit juices. Group discussion: which drinks have the most sugar/least sugar? Examine the labels of different drinks. Note 1 teaspoon is 4.2 grams of sugar. Differentiated drinks sheet has sugar content already calculated. Calculate how many teaspoons of sugar are in each drink. Place the correct number of teaspoons of sugar in a zip-lock bag. Compare the amount of sugar in different drinks. Group discussion comparing findings with predictions.

Refer to inquiry questions: remove questions that have been answered. Have any other questions emerged? Add them to the display.

Safefood Ireland (in resource folder) contains sugar content of other drinks that the children may drink.

Information on diet drinks also included.

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2. ***The Digestive System: Where does the sugar go?***

Elicit children' prior knowledge: Distribute outline of body. Allow the children to draw the digestive system. Analyse drawings and highlight commonly held inaccurate conceptions.

Developing understanding: Allow children opportunity to devise inquiry questions. There questions will inform their exploration of resources.

Distribute information packs/games/resources to develop children' knowledge. See PowerPoint for video on digestive system.

See useful website resource for games and information packs. There is also a 'practical' illustrative activity you can do with you class to replicate the digestive system.

Provide children opportunity to present key learnings with reference to their inquiry questions.

3-D Model: Divide the children into groups. Make a 3-D model of the digestive system using a variety of resources (straws, balloons, crepe paper, kitchen roll tubes). Allow each group to sketch a plan of a model, collect resources and make their model. Group presentation of different models. Get each group to compare their 3-D model to their original drawing.

Assessment: Assess each groups model using the rubric provided in your resource folder.

3. ***Debate: Should we ban sugary drinks sales to under 18a***

Refer back to their original opinion and use the scientific evidence they have collected to support their opinions. Has anyone changed their mind? Why/why not? Refer back to original poll of decisions.

	Evidence Cards: Divide the children into groups. Allow them to sort evidence cards into two groups: strong pieces of evidence and weak pieces of evidence. Emphasise the source of the evidence and how different scientists may come to different conclusions. Each group must decide if there is enough evidence to ban sugary drinks based on the evidence cards. Once the groups have decided they share with the class and give reasons to support their conclusion. Note there are differentiated evidence cards for each group.
Conclusion	Refer back to inquiry questions posed at the start of the unit. Discuss results of argumentation: Even though the children may have decided that there is not enough evidence to ban sugary drinks, they should be aware that over consumption of sugary drinks are harmful to their bodies. Emphasise the importance of supporting arguments with debates, gathering reliable evidence.
Extension Activity	This could be done with foods also where children analyse sugar content of everyday foods they consume.

Appendix D Sample of Resources to accompany a Unit of the SSIPSC Intervention

D.1 Overview of Resources for Unit 3: Sugar tax and digestive system

General Resources

- Overview of unit
- Powerpoint with notes
- Investigation role cards
- Useful Websites: The Digestive System
- Assessment Rubric: 3-D Model of the Digestive System

Printables

- How much sugar is in your drink investigation sheets (Photocopy 1 per group)
- Information sheet: Why diet drinks are not good for you
- Safefood Ireland Poster: How much sugar is in your drink?
- The Digestive System Outline (Photocopy 1 per child)
- Exemplar of 3-D model of digestive system: Teacher use only.
- Evidence and argument cards (Photocopy 1 per group)

Resources in Resource Box

- Sugar
- Ziplock Bags

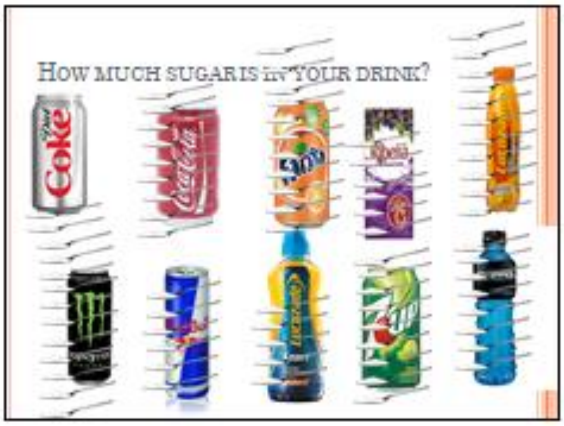
Additional Resources Required

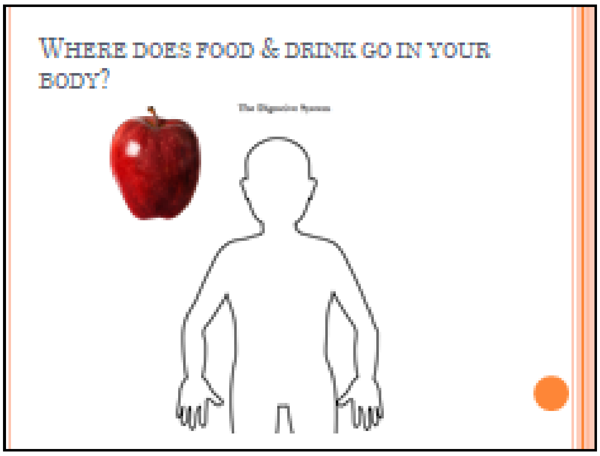
- Consider the practical illustrative activity of the digestive system See useful websites for more details.

Digital Resources

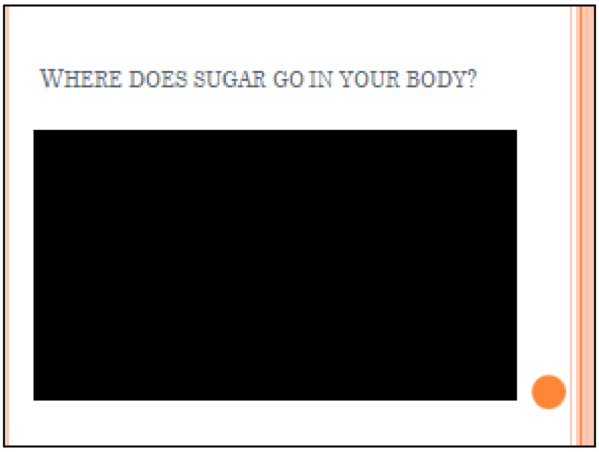
- Powerpoint
- Videos to support children's learning: On powerpoint.
- Useful websites resource sheet.

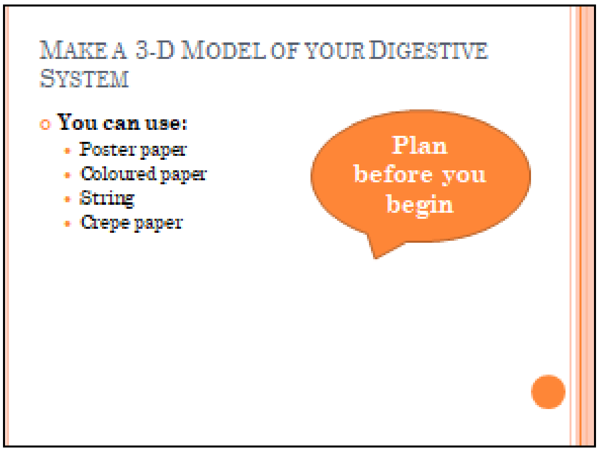
D.2 Powerpoint presentation




Where does food & drink go in your body?
The Digestive System


Video of the Digestive system


Where does sugar go in your body?

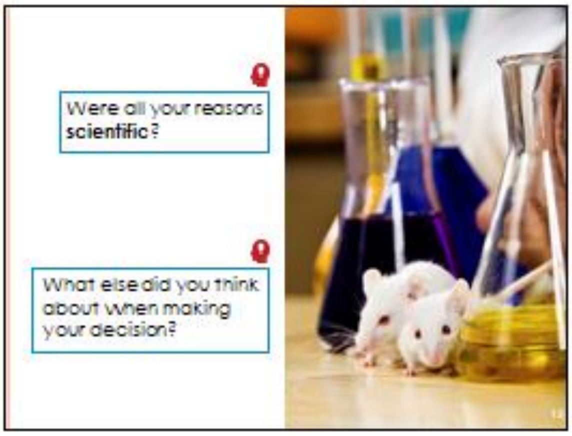

Make a 3-D Model of your Digestive System
You can use:
Poster paper
Coloured paper
String
Crepe paper
Plan before you begin


Leo Varadkar, Taoiseach
"We are considering a ban on fizzy drink sales to under-18s. What do you think?"
Weigh up the pros and cons.
Do you support a ban?


Sort the evidence that sugar causes obesity:
weak evidence
strong evidence
Is there enough evidence to ban sugary drink sales to under-18s?


Evidence cards
SS1
A
Dr Hoebel found that when rats drink sugary water, their brains release a hormone, dopamine. This gives a feeling of pleasure, leading to addiction.
He says that this shows that sugar is addictive to rats.
B
The World Health Organisation says that too much food and drink overall increase body weight, not just too much sugar.
C
University scientist Francesca Sartor asked 11 slim people to drink more sugary drinks than normal.
After four weeks they were 1 kg heavier on average.
D
Richard Johnson of Florida University drew this graph.
The top line shows sugar intake per person. The bottom line shows obesity rates.
E
Magalie Lenoir of Bordeaux University gave rats the choice of sweetened water or cocaine. 94 % chose sweetened water.
She thinks this is because sweet foods trigger reward signals in the brain.
F
Peter Benton of Swansea University read more than 100 scientific papers to find out if sugar addiction is a cause of obesity.
He concluded that animal addictions do not predict human addictions.
G
Robin Lustig of California University found that sugar is like alcohol and tobacco.
It acts on the brain to make you want it again.
H
Alan Barclay of the Australian Diabetes Council said that sugar consumption in Australia has decreased by 20% since 1980.
In the same time the number of overweight people has doubled, and the number of people with diabetes has tripled.


Argument cards
SS2
1
2
3
4
5
6
7
8


Were all your reasons scientific?
What else did you think about when making your decision?

D.3 Sugar Investigation Activity Sheets

Estimate how many teaspoons of sugar are in each drink?

<table>
<tr>
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</table>

Can you find how many grams of sugar are in each drink?

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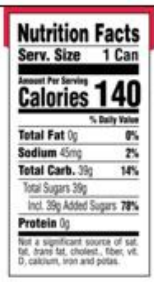
<tr>
<td></td>
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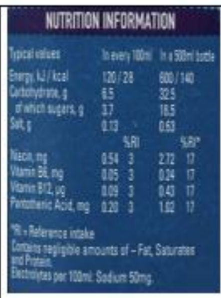
<td></td>
</tr>
<tr>
<td>Can of Coke
350 ml in a can</td>
<td>Can of Diet Cole
350 ml in a can</td>
<td>Can of Fanta
350 ml in a can</td>
<td>Bottle of Lucozade
370 ml in a bottle</td>
<td>Bottle of Lucozade Sport
500 ml in a bottle</td>
</tr>
<tr>
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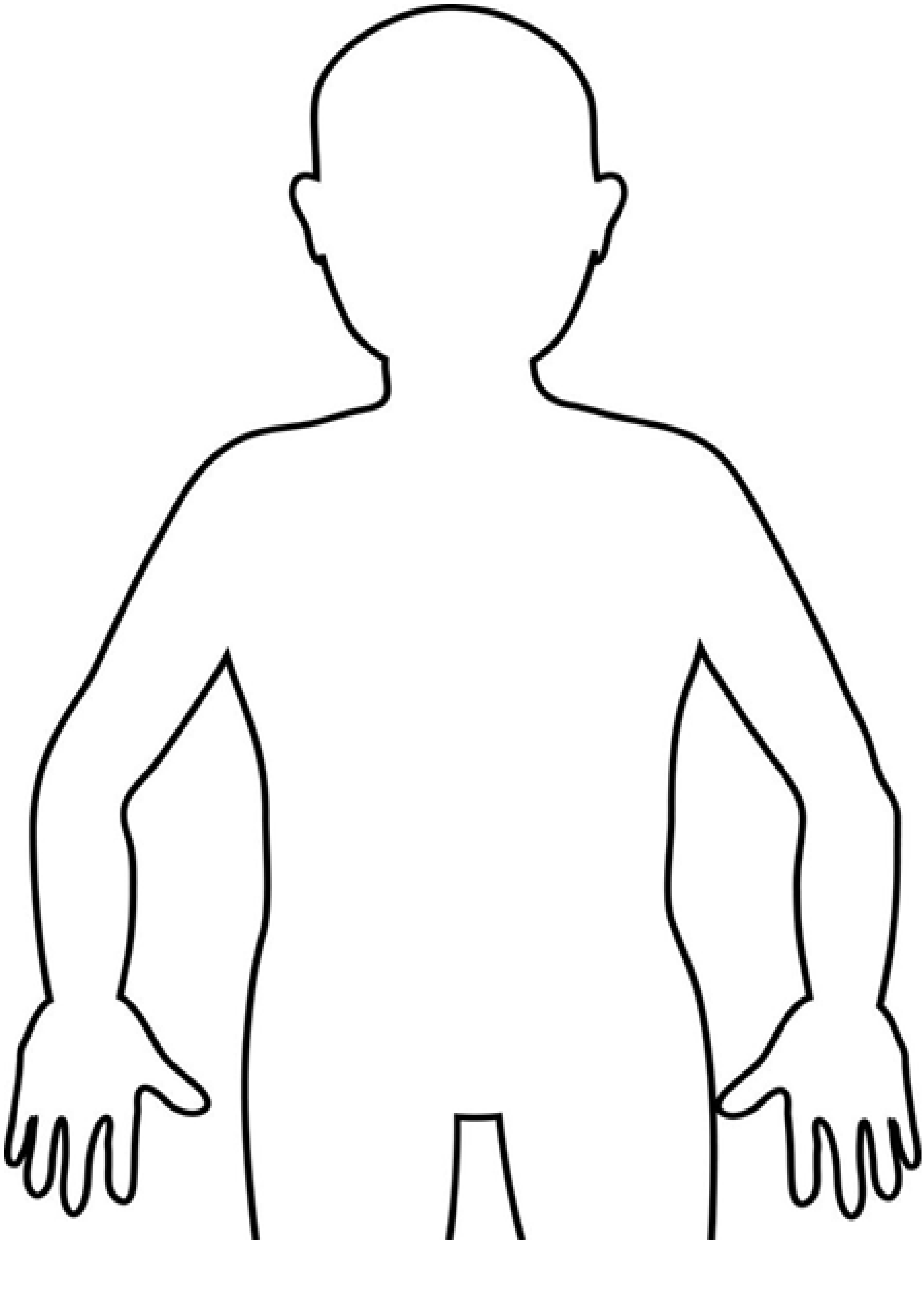
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Can of Monster
Per 100ml</td>
<td>Carton of Ribena
Per 250 ml</td>
<td>Can of 7 UP
350 ml in a can</td>
<td>Red Bull
Per 100ml</td>
<td>Powerade
Per 600ml</td>
</tr>
</table>

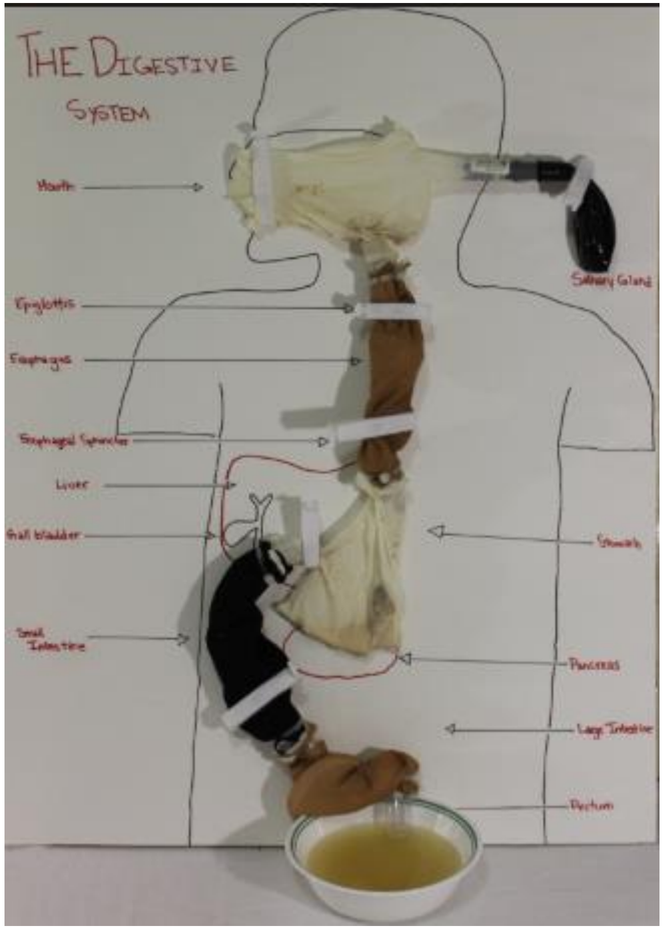
Find out how many teaspoons of sugar are in each drink?

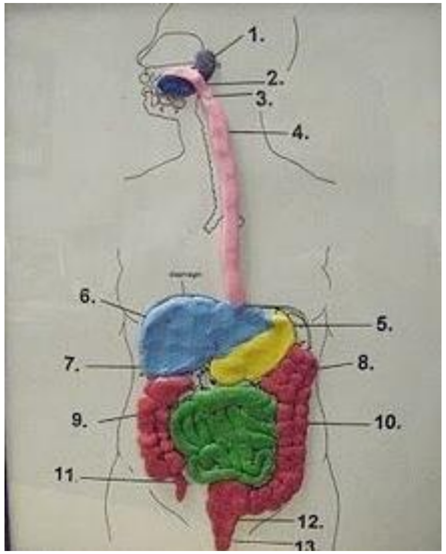
Drink	Millilitres in the drink	Sugar in the drink	Number of teaspoons of sugar in the drink (Divide the sugar by 4.2)	Sugar in 200ml of the drink	Number of teaspoons of sugar in 200ml of the drink
Can of Coke	350	39		22	
Can of Diet Coke	350	0		0	
Can of Fanta	350	48		27.5	
Bottle of Lucozade	380	48		25	
Bottle of Lucozade Sport	500	18.5		7.4	
Can of Monster	500	55		22	
Carton of Ribena	250	26		21	
Can of 7UP	350	38		22	
Can of Red Bull	250	25		20	
Bottle of Powerade	600	34		11	

D.4 Outline of Human Body: The Digestive System



D.5 Exemplars of 3-D Models of the Digestive System





D.6 The Digestive System: Useful Websites

The Digestive System: Some useful websites

- https://www.stem.org.uk/resources/elibrary/resource/35396/digestive-system-experiment

This shows how you could carry out a practical science lesson by replicating the digestive system with everyday foods from your kitchen. Suitable for all.

- https://www.stem.org.uk/resources/elibrary/resource/36133/digestive-system

Lesson plans, videos and interactive games that can be used to teach the digestive system. Suitable for 7-11 year olds.

- https://kidsbiology.com/human-biology/digestive-system/

Useful website for the children to find out more information about the digestive system.

- https://www.sheppardsoftware.com/health/anatomy/digestion/digestion_game_1.htm

Interactive game and quiz on the digestive system

- https://www.natgeokids.com/uk/discover/science/general-science/digestive-system/

May be suitable for teachers or older children

- https://kidshealth.org/en/kids/digestive-system.html

May be suitable for teachers or older children

- https://www.neok12.com/Digestive-System.htm

Interactive game and quiz on the digestive system

D.7 Safefood Ireland: The facts about sugar in drinks

safefood

The facts about sugar in drinks

Check before you choose

- Sugary drinks, a leading cause of tooth decay, are also linked with **excess weight in children**, which **increases their risk of heart disease, cancer and type II diabetes.**

- If choosing other drinks read the label to **check the sugar level, ideally choose no added or low-sugar options.**
- Limit fruit juice or a smoothie to a small glass, once a day. **Always choose unsweetened.**
- If your family is in the habit of drinking sugary drinks, **reduce them gradually. Only give them with a meal to reduce tooth decay.**
- If choosing squash or cordial, **water it down well.**
- Water is tastier when it's cold:
  - Put a jug of water in the fridge
  - Make it fun, use colourful cups and straws
- **Do not introduce sugary drinks to toddlers** in the first place then you won't have to wean them off later.

Fizzy Drinks (Regular)

drink/ description	sugar per 200ml serving	equivalent in teaspoons of sugar
Club Orange	26.4g	6
Fanta Orange	24g	6
7UP	22.4g	6
Pepsi	22.4g	6
Coca Cola	21.2g	5
Lucozade	17.4g	4
Sprite	13.2g	3

Fizzy Drinks (Diet)

drink/ description	sugar per 200ml serving	equivalent in teaspoons of sugar
Fanta Zero	1.6g	0
Diet Coke	0g	0
7UP Free	0g	0
Pepsi Max	0g	0

Smoothies

drink/ description	sugar per 200ml serving	equivalent in teaspoons of sugar
Aldi Del Rivo (Oranges, Mangoes and Pineapple Smoothie)	27g	7
Naked (Mighty Mango Juice Smoothie)	25.3g	6
Juice Press (Raspberry and Blueberry Smoothie)	25.4g	6
Tesco (Strawberry and Banana Smoothie)	23.4g	6
Innocent (Mango and Passion Fruit)	22g	6
Lidl (Strawberry, Blackberry, and Raspberry)	17g	4

High Fruit Squashes or Cordials

drink/ description	sugar per 200ml serving	equivalent in teaspoons of sugar
Sainsbury's High Juice Squash (Blackcurrant)	17.6g	4
Lidl Lindhouse High Juice (Blackcurrant)	16g	4
Asda High Juice (Blackcurrant)	15.4g	4
Lidl Lindhouse High Juice (orange)	12.8g	3
Tesco High Juice (Orange Squash)	12.2g	3
Asda High Juice (Florida Orange)	12g	3
Sainsbury's High Juice Squash (Orange)	12g	3

Regular Squashes or Cordials

drink/ description	sugar per 200ml serving	equivalent in teaspoons of sugar
Ribena (Strawberry or Blackcurrant)	20g – 20.8g	5
Vimto Original Squash	9.4g	2
Miwadi Orange	4.1g	1
Dunnes Stores (Orange Squash)	1.6g	0
Asda Orange (Double Strength Squash)	0.32g	0
Tesco (Double Strength Orange, Every Day Value)	0.16g	0

Ready To Drink Fruit Juice Drinks

drink/ description	sugar per 200ml serving	equivalent in teaspoons of sugar
Amigo (Orange Juice Drink)	23.2g	6
Lidl plein sud (Orange Juice Drink)	22g	6
Ribena (Blackcurrant)	21g	5
Capri Sun (Apple and Blackcurrant Juice Drink)	20g	5
Sunny D (Citrus Juice Drink)	16.5g	4
J20 (Apple and Mango Juice Drink)	12.4g	3
Aldi Rio D'oro Sun Shots (Apple Juice Drink)	6.1g	2
Tesco Fruit Splash (Orange Juice Drink, No Added Sugar)	2.2g	0
Fruice Juicy (Tropical Juice Drink, With Added Vitamins)	1.8g	0
Robinsons Fruit Shoot (Low Sugar)	1.6g	0
Dunnes Stores (Apple and Blackcurrant Juice Drink, No Added Sugar)	0.4g	0
Vimto (No Added Sugar)	0g	0

Fruit Juice Drinks (Sweetened)

drink/ description	sugar per 200ml serving	equivalent in teaspoons of sugar
Del Monte (44% Fruit Juice Drink) Tropical Flavour	23.6g	6
Ocean Spray Cranberry Classic (25% Fruit Juice From Concentrate)	22g	6
Sainsbury's (Cranberry Juice Drink)	21g	5

No Added Sugar Squashes or Cordials

drink/ description	sugar per 200ml serving	equivalent in teaspoons of sugar
Aldi (High Juice Orange)	2.08g	0
Sainsbury's (High Juice Orange)	2g	0
Tesco (High Juice Orange)	2g	0
Robinsons (Orange and Pineapple)	1.4g	0
Ribena (Blackcurrant)	1g	0
Dunnes Stores (Orange Squash)	0.5g	0
Aldi (Apple & Blackcurrant Squash)	0.4g	0
Miwadi Orange	0.32g	0
Fruice Orange (Double Strength)	0.24g	0
Kia Ora Orange	0.2g	0
Sainsbury's (Squash Double Concentrate, Orange Basics)	0.01g	0

Unsweetened Fruit Juices (No Added Sugar, From Concentrate or Not)

drink/ description	sugar per 200ml serving	equivalent in teaspoons of sugar
Jaffa Gold Orange Juice	23.4g	6
Copella (Not From Concentrate) Orange Smooth	20g	5
Tropicana (Not From Concentrate) Orange Original	20g	5
Squeez (from Concentrate) Orange	18.2g	5
Innocent (Not From Concentrate) Orange With Bits	16.4g	4
Sainsbury's (100% Pure Squeezed Smooth Orange Juice)	15.2g	4

4g is approximately 1 teaspoon. Assessment of the drinks was carried out in March 2016 by safefood based on drinks commonly available for purchase in retail outlets on the island of Ireland and does not represent a complete list.

For more handy tips and great ideas for you and your family, visit www.safefood.eu

D.8 Evidence Cards (Engaging Sciecne.eu)

Note: These were differentiated for different class levels

Student sheets

engage

Ban cola

Sheet no.	Title	Notes
SS1	Evidence cards	Reusable, cut into cards, one per group
SS2	Argument cards	Reusable, cut into cards, one per group

engage

Evidence cards

SS1

A **Strong** or **weak** evidence?

Dr Hoebel found that when rats drink sugary water, their brains release a hormone, dopamine. This gives a feeling of pleasure, leading to addiction.

He says that this shows that sugar is addictive to rats.

B **Strong** or **weak** evidence?

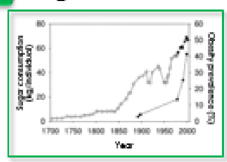
The World Health Organisation says that too much food and drink overall increase body weight, not just too much sugar.

C **Strong** or **weak** evidence?

University scientist Francesco Sartor asked 11 slim people to drink more sugary drinks than normal.

After four weeks they were 1 kg heavier on average.

D **Strong** or **weak** evidence?



Richard Johnson of Florida University drew this graph.

The top line shows sugar intake per person. The bottom line shows obesity rates.

E **Strong** or **weak** evidence?

Magalie Lenoir of Bordeaux University gave rats the choice of sweetened water or cocaine. 94 % chose sweetened water.

She thinks this is because sweet foods trigger reward signals in the brain.

F **Strong** or **weak** evidence?

Peter Benton of Swansea University read more than 100 scientific papers to find out if sugar addiction is a cause of obesity.

He concluded that animal addictions do not predict human addictions.

G **Strong** or **weak** evidence?

Robin Lustig of California University found that sugar is like alcohol and tobacco.

It acts on the brain to make you want it again.

H **Strong** or **weak** evidence?

Alan Barclay of the Australian Diabetes Council said that sugar consumption in Australia has decreased by 20% since 1980.

In the same time the number of overweight people has doubled, and the number of people with diabetes has tripled.

Student sheets

D.9 Assessment Rubric: 3-D model of digestive system

Scoring Rubric

1 pt.	2 pts.	3 pts.	4 pts.	5 pts.
Team presentation demonstrates a lack of understanding of the path of food through the digestive tract and lacks creativity, collaboration, and effort.	Team presentation demonstrates a cursory understanding of the path of food trough the digestive path although team made reasonable effort on design of presentation.	Team presentation demonstrates general understanding of the path of food through the digestive tract but contains some inaccuracies.	Team presentation demonstrates accurate understanding of the path of food through the digestive tract, but lacks collaboration or creativity.	Team presentation demonstrates accurate understanding of the path of food through the digestive tract in a creative, collaborative manner.

Appendix E Sample of the Concrete Resources provided to each Teacher (Resource Box).

What's in your box…

<table>
<tr><td>

Unit 1: Kitchen Paper

- 5 Beakers
- 1 measuring Jug
- Kitchen Paper *5 different brands*
- 1 roll of String
- Clothes Pegs
- Droppers 7
- Syringes 5

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Unit 2: Everyday Objects: Cups

- Different types of paper/plastic cups *A variety of cups included*
- Poster Paper *Coloured and plain*
- 1 Measuring jugs
- Thermometers

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<tr><td>

Unit 3: Sugar Tax

- Sugar
- 5 Beakers
- Zip-lock bags

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Unit 4: Energy

- Polystyrene balls X 7
- Tissue paper
- Skewer sticks
- Plastic spools
- Roll of string
- Polystyrenes cups X 10
- Paper Plates (large) X 20
- Cardboard X 10 sheets

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<tr><td>

Unit 5: Bees

- Honey
- Nets
- Magnifying glasses

</td><td>

Unit 6: Water Sustainability

- Tights *2 pairs*
- Bag of sand
- Coffee filter paper *6 sheets – brown filters.*
- Lab filter Paper *10 sheets*
- Funnels 5
- Beakers 5
- Measuring Cylinders 1
- Towels (Enough to line a funnel) *3 pieces*
- Jay cloth (Enough to line a funnel)20 *pieces*
- Marbles
- Kitchen paper *1 roll*

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</table>

Appendix F Timeline of Professional Learning

Time Fame	Details
July 2nd – July 6th 2018	***Face to face professional learning*** Face to face summer professional learning course, Institute of Education, DCU (25 hours). Details of course can be found in Appendix A.
October 1st – 5th 2018	***Individual professional learning*** Each teacher (*n*=7) was met individually at school. SSIPSC Programme, Resource Folder and Resource Box were given to the teachers. Discussion pertaining to learning activities, pedagogies, content knowledge where required.
November 8th 2018	***Online professional learning*** Online discussion forum where teachers shared their experience of the programme to date. Teachers uploaded photographs of investigations. Opportunities and challenged were discussed. All teachers participated in discussion forum to some extent.
December 6th – 11th 2018	***Individual professional learning*** Each teacher (*n*=7) was met individually at their schools. Some teachers required more support than others. For example, some teachers needed assistance moving their investigation from teacher-directed to child-led. Others required support on use of thermometer and other instruments.
January 13th 2019	***Face to face professional learning*** Face to face professional learning (2 hours) at Institute of Education, DCU. This included reflection of programme to date and discussion of future units. Additional teacher content knowledge regarding to climate change provided to the teachers. Additional pedagogical knowledge pertaining to design and make and developing an environment for argumentation also included. 6/7 teachers participated.

February 6th 2019	***Online professional learning*** Online discussion forum where teachers shared their experience of the programme to date. Teachers uploaded photographs of investigations. Opportunities and challenged were discussed. 6/7 teacher participated in discussion forum to some extent.
March 7th – March 13th 2019	***Individual professional learning*** Each teacher (*n*=6/7) was met individually at their schools. Feedback was provided. Additional support was provided where necessary.

* Through the intervention period the researcher was available via email/phone to discuss the programme with the teachers. Many teachers availed of email as a form of communication.

Appendix G Overview of SSIPSC Programme

November	**Week 1**	**Week 2** ***Science Week 11 – 18 Nov***	**Week 3**	**Week 4**
Topic Based on 1 hour (approx) a week of Science	**Children's Questionnaire (*20 min)*** **Skill Assessment** *(30-40min)*	**Kitchen Paper** Strand: Materials Skills: Observing; Investigating and experimenting	**Everyday Objects: Cups** Strand: Materials Energy & Forces Environmental Awareness and Care; Energy and Forces Skills: Observing; Predicting	**Everyday Objects: Cups** Strand: Materials Energy & Forces Environmental Awareness and Care; Energy and Forces Skills: Estimating and measuring
December	**Week 1**	**Week 2**	**Week 3**	**Week 4**
Topic Based on 1 hour (approx) a week of Science	**Everyday Objects: Cups** Strand: Materials Energy & Forces Environmental Awareness and Care; Energy and Forces Skills: Recording and communicating	**Sugar Tax** Strand: Living things Materials Skills: Predicting Investigating and experimenting	**Sugar Tax** Strand: Living things Materials Skills: Analysing; Recording and Communicating	
January	**Week 1**	**Week 2**	**Week 3**	**Week 4**
Topic	**Renewable and Non-Renewable Energy** Strand: Environmental Awareness & Care Skills: Analysing; Questioning	**Wind Energy** Strand: Environmental Awareness and Care Energy and Forces Skills: Explore, plan, make, evaluate	**Wind Energy** Strand: Environmental Awareness and Care Energy and Forces Skills: Explore, plan, make, evaluate	**Wind Energy** Strand: Environmental Awareness and Care Skills: Recording and communicating; Analysing
February	**Week 1**	**Week 2**	**Week 3**	**Week 4**
Topic	**Noise Pollution** Strand: Living things Materials Energy and forces	**Noise Pollution** Strand: Materials Environmental Awareness and Care Energy and Forces	**Animal Welfare** Strand: Living things Environmental Awareness and Care Skills: Questioning; Investigating and	***Mid-Term Break***

	Skills: Investigating and experimenting; Observing; Prediction	Skills: Investigating and experimenting; Observing	experimenting; observing; Recording and communication	
March	**Week 1** *Engineering Week*	**Week 2**	**Week 3**	**Week 4**
Topic	**Animal Welfare** Strand: Living things Environmental Awareness and Care Skills: Questioning; Investigating and experimenting; observing; Recording and communication	**Bees** Strand: Living things Environmental Awareness and care; Materials Skills: Investigating and experimenting Observation	**Bees** Strand: Living things Environmental Awareness and care; Materials Skills: Evaluating Analysing Recording and communicating	**Bees** Strand: Living things Environmental Awareness and care Skills: Estimating and measuring Investigating and experimenting
April	**Week 1**	**Week 2**	**Week 3**	**Week 4**
Topic	**Water Crisis** Strand: Materials Environmental Awareness and Care; Energy and Forces Human Life Skills: Observation Predicting; Analysing	**Water Crisis** Strand: Materials Environmental Awareness and Care; Energy and Forces Skills: Explore, plan, make evaluate	***Easter Break***	***Easter Break***

Appendix H Sample Implementation Schedule for Teachers

Month	Week	Unit[7]	Completed
November	2	<u>**Kitchen Paper**</u> **Set the context** Kitchen Paper Advertisement (see resource folder). Form **inquiry questions.** **Fair Test Investigation:** Which paper towel absorbed the most liquid? Which paper towel is the most durable? **Communicate** findings	
November	3	<u>**Everyday Objects: Cups**</u> **Set the context:** Coffee shop is opening (see resource folder). **Observation** of different types of cups: similarities and differences Form **inquiry questions:** Which cup keeps the heat for longer? Do ridges on cups keep my drink warmer for longer? **Fair test investigation:** Investigate inquiry questions in groups **Communicate** findings	
November	4	<u>**Everyday Objects: Cups**</u> **Review** results from fair test investigation (week 3) **Observe** the characteristics of three different types of cups: plastic, paper, ceramic. **Journey of my cup:** Conduct research where does each cup come from and go? **Map journey of cup:** Discussion and communicating findings.	
December	1	<u>**Everyday Objects: Cups**</u>	

[7] Details of each unit alongside accompanying resources provided to teacher in a resource folder.

		Review results from fair test investigation (week 3) and journey of cup (week 4). **Set the context:** Coffee shop is opening. Which type of cups should we use? **Forming arguments:** Divide students into groups (e.g. café owner, customer, government) Gather evidence to support argument **Debate:** Present and discuss findings. Model balancing findings to reach a decision. **Whole Class Discussion**	

Appendix I Student Questionnaire

Children's Questionnaire on Primary Science Education

Section A: Ask your teacher if you need help filling this in

I am a	boy ☐	girl ☐	other ☐	
I am in	3rd class ☐	4th class☐	5th class ☐	6th class ☐

When you get to a question put a tick in the box that is closest to your opinion.

Try the following example

	Strongly Agree 	Agree 	Disagree 	Strongly Disagree 
I like watching T.V.				
I like dancing				

Now you are ready to start!

Section B: What I think about being in school…

	Strongly Agree 	Agree 	Disagree 	Strongly Disagree 
I like school				
I find school interesting				
I enjoy doing school-work				

Section C: What I think about learning science in school…

	Strongly Agree 	Agree 	Disagree 	Strongly Disagree 
School science is interesting				
Science is better than other subjects				
I look forward to science lessons				
I am looking forward to learning science in secondary school				

Section D: In school

	Very Often	**Often**	**A few times**	**Never**
In school we work in groups when we are doing science investigations/experiments				
In school we do activities that show us how scientists use their creativity in their work				
In school we carry out science investigations ourselves				
In school we plan how we are going to carry out science investigations ourselves				
	Very Often	**Often**	**A few times**	**Never**

In school we talk about whether we are carrying out a fair test				
In school we make predictions before we carry out science investigations				
In school we record what happens when we are doing investigations				
In school we record the results of our investigations in different ways				
In school we discuss the results of our investigation in science class				

Section E: Try and answer the following questions…

List three disadvantages of wind energy:
John noticed that some insects were eating his flowers. He was going to use insect spray to kill the insects. His friend Tom said that he should not use the spray because it can kill bees also. Why are bees important?
Which material is the most *absorbent?* Please tick one box only Glass □ Metal □ Rock □ Plastic □ Towel □
Which of these materials can be separated using a sieve? Please tick one box only Salt and water □ Sand and water □ Oil and water □ Sugar and water □
Name three *non-renewable* sources of energy

True or false. Please circle the correct answer. A **worker** is a male (boy) bee.   True   False
Where can micro plastics (small pieces of plastic) be found? Name three items below.
Name three parts of the digestive system:
Sarah is going to test which kitchen paper soaks up the most water. She has 4 different types of kitchen paper. What does she need to keep the same during this test?
Name three sources of noise pollution:

Section F: What I think about science and scientists…

	Strongly Agree 	Agree 	Disagree 	Strongly Disagree 
Scientists use their creativity when they plan and carry out experiments				
Different scientists can have different answers to the same questions				
Scientists use their opinions when they are explaining things				
The ideas in science books sometimes change				

Good answers are based on results from many different science experiments				
Sometimes scientists change their minds about what is true in science				

Section G: Your teacher will read this for you. Write your opinion in the box below

Should we kill the grey squirrel to save the red squirrel?

There are two types of squirrels found in Ireland, the red and grey squirrel. The red squirrel is native to Ireland while the grey squirrel was first brought from North America in 1911. The red squirrel is becoming extinct in Ireland. The grey squirrel may be the cause of the extinction of the red squirrel. While the grey squirrel does not kill the red squirrel themselves, they can carry a harmful disease that can kill the red squirrel. The grey squirrel also eats the acorns that the red squirrels depend on to survive. In the UK, grey squirrels are being shot, trapped or poisoned to protect the red squirrel.

Should Ireland do the same to protect the red squirrel?

Write your opinion below. Give a reason for your answer

Appendix J Teacher Protocol Questionnaire Administration

J.1 Teacher guidelines for distributing questionnaire

This questionnaire will take **approximately 20 minutes** for the children to complete.

The questionnaire has been piloted in a number of Irish schools.

It will be used to measure children's interest in school science, attitudes towards science and development of scientific content knowledge and skills.

Prior to distributing the questionnaire

I would like you to explain to the children that:

- This is a questionnaire about school science and their interest in science.
- This is not a test. There are no right or wrong answers. Please answer as honestly as you can.
- The questionnaires do not have their names on them so nobody will know who they are.
- If they have any question they can ask their teacher throughout.

Distributing the questionnaire

You will find a recording sheet attached to this letter. On the top right hand corner of each questionnaire you will see a code:

For example **SA2** – **S** (Start) **A** (School Identifier) **2** (Student Identifier).

Can you please record which child gets which number (Student Identifier).

For example: Jack Mullins SA**1**

So Jack will have SA**1** for the pre-questionnaire and FA**1** for the post-questionnaire. This will enable me to analyse Jack's results anonymously. Codes are used to protect the identity of the children. You will keep the record sheet.

There are spare questionnaires in your folder.

Completing the questionnaire

Please complete the sample questions together.

Children should put a tick in the box closest to their opinion. The children should be able to complete sections B-F independently.

The teacher should read section G with the children.

Some children may require help with some of the words. If they are unsure of an answer they should leave the answer blank.

Collecting the questionnaire.

Please collect all questionnaires and store them safely in the folder

provided. I will arrange a time to collect them off you.

If you have any questions, please feel free to contact me.

Nicola.Broderick@DCU.ie

J.2 Children’s Questionnaire Recording Sheet

Children’s Questionnaire Recording Sheet

The children should get the same **number** for the Pre-Questionnaire and Post-Questionnaire. This sheet is for the teacher only. It is used to protect the identity of the children. Please tick when a child has completed the pre-questionnaire (November 18) and post questionnaire (April 19).

Number	**Name**	**November** **Pre-Questionnaire Code**	**Please tick**	**April** **Post-Questionnaire Code**	**Please Tick**
1		SG**1**		FG**1**	
2		SG**2**		FG**2**	
3		SG**3**		FG**3**	
4		SG**4**		FG**4**	
5		SG**5**		FG**5**	
6		SG**6**		FG**6**	
7		SG**7**		FG**7**	
8		SG**8**		FG**8**	
9		SG**9**		FG**9**	
10		SG**10**		FG**10**	
11		SG**11**		FG**11**	
12		SG**12**		FG**12**	

Appendix K Factor Analysis to support Construct Validity

Attitudes towards school

The 3 items in the attitude towards school scale (Appendix H) were subjected to confirmatory factor analysis (CFA) using SPSS Version 25. Prior to performing CFA, the suitability of data for factor analysis was assessed. Inspection of the correlational matrix revealed many coefficients of .3 and above. The Kaiser-Meyer-Olkin value was .69, exceeding the recommended value of .6 (Kaiser, 1970, 1974 as cited in Pallant, 2016) and Bartlett's Test of Sphericity (Bartlett 1954, as cited in Pallant, 2016) reached statistical significance, supporting the factorability of the correlation matrix.

Factor analysis revealed the presence of one component with eigenvalues exceeding 1, explaining 71% of the variance. An inspection of the scree plot revealed a clear break after the first component. This was further supported by the results of Component Matrix which showed that all items loaded strongly on component 1 (above .77). The results of this analysis support the use of the Attitudes towards School scale in this study.

Item	**Pattern coefficients** **Component 1**	**Communalities**
I like school	**.907**	**.823**
I find school interesting	**.846**	**.715**
I enjoy school work	**.778**	**.605**

Attitudes towards school science

The 5 items in the attitude towards school science scale (Appendix H) were subjected to confirmatory factor analysis (CFA) using SPSS Version 25. Prior to performing CFA, the suitability of data for factor analysis was assessed. Inspection of the correlational matrix revealed many coefficients of .3 and above. The Kaiser-Meyer-Olkin value was .78, exceeding the recommended value of .6 (Kaiser, 1970, 1974 as cited in Pallant, 2016) and Bartlett's Test of Sphericity (Bartlett 1954, as cited in Pallant, 2016) reached statistical significance, supporting the factorability of the correlation matrix.

Factor analysis revealed the presence of one component with eigenvalues exceeding 1, explaining 59% of the variance. An inspection of the scree plot revealed a clear break after the first component. This was further supported by the results of Component Matrix which showed that all items loaded strongly on component 1 (above .3). The results of this analysis support the use of the Attitudes towards School Science scale in this study.

Item	Pattern coefficients	Communalities
	Component 1	
I look forward to science lessons	**.838**	**.701**
School science is interesting	**.820**	**.672**
School science Is better than other subjects	**.782**	**.612**
I look forward to secondary school science	**.618**	**.386**

Experience of Inquiry Based Science Education

The 9 items in the experience of Inquiry Based Science Education scale (Appendix H) were subjected to confirmatory factor analysis (CFA) using SPSS Version 25. Prior to performing CFA, the suitability of data for factor analysis was assessed. Inspection of the correlational matrix revealed many coefficients of .3 and above. The Kaiser-Meyer-Olkin value was .878, exceeding the recommended value of .6 (Kaiser, 1970, 1974 as cited in Pallant, 2016) and Bartlett's Test of Sphericity (Bartlett 1954, as cited in Pallant, 2016) reached statistical significance, supporting the factorability of the correlation matrix.

Factor analysis revealed the presence of one components with eigenvalues exceeding 1, explaining 48% of the variance. An inspection of the scree plot revealed a clear break after the first component. This was further supported by the results of Component Matrix which showed that all items loaded strongly on component 1 (above .6). The results of this analysis support the use of the Experience of Inquiry Based Science Education scale in this study.

Item	Pattern coefficients	Communalities
	Component 1	
In school we plan how we are going to carry out science investigations ourselves	**.801**	**.641**

In school we carry out science investigations ourselves	**.760**	**.578**
In science we do activities that show us how scientists use their creativity in their work	**.739**	**.546**
In science we talk about whether we are carrying out a fair test	**.713**	**.508**
In school we record what happens when we are doing an investigation	**.660**	**.436**
In school we make predictions before we carry out science investigations	**.645**	**.415**
In school we discuss the results of our investigations with our class	**.640**	**.409**
In school we record the results of our investigations in different ways	**.636**	**.405**
In science we work in groups	**.624**	**.389**

Nature of Science

The 6 items in the experience of Nature of Science scale (Appendix H) were subjected to confirmatory factor analysis (CFA) using SPSS Version 25. Prior to performing CFA, the suitability of data for factor analysis was assessed. Inspection of the correlational matrix revealed many coefficients of .3 and above. The Kaiser-Meyer-Olkin value was .704, exceeding the recommended value of .6 (Kaiser, 1970, 1974 as cited in Pallant, 2016) and Bartlett's Test of Sphericity (Bartlett 1954, as cited in Pallant, 2016) reached statistical significance, supporting the factorability of the correlation matrix.

Factor analysis revealed the presence of one components with eigenvalues exceeding 1, explaining 39% of the variance. An inspection of the scree plot revealed a clear break after the first component. This was further supported by the results of Component Matrix which showed that all items loaded strongly on component 1 (above .5). The results of this analysis support the use of the Nature of Science scale in this study.

Item	Pattern coefficients Component 1	Communalities
Scientists use their creativity when they plan and carry out investigations	**.643**	**.414**
Scientists can have different answers to the same question	**.649**	**.422**
Scientists use their opinions when they are explaining things	**.639**	**.409**
Ideas in books sometimes change	**.588**	**.346**
Good answers are based on the results from different science questions	**.649**	**.422**
Scientists sometimes change their mind about what is true	**.577**	**.333**

Appendix L Sample Practical Skill Assessment

L.1 Teacher Guidelines

Task:	**Stopping a Car**		
Class:	Third/Fourth	**Strand:** **Strand Unit:**	Energy and forces Forces
Concept:	A rough surface is most effective at slowing down a toy car.	**Task Focus:**	Students will investigate which materials slow down a toy car the most.
Prior Knowledge:	Students should have investigated how materials can differ in terms of their texture.	**Skills Focus:**	Investigating (fair testing) Interpreting Recording Estimating and measuring
Materials:	Per group: A toy car; Ramp (e.g. piece of strong card); Ruler or tape measure. Scissors (to cut material to size for fair testing); Some materials e.g. felt, cooking foil, sandpaper, greaseproof paper, bubble wrap; Chalk or similar, to mark stopping point of car; Some books/cubes to raise the ramp; Worksheet.		

<u>Teacher Information</u>

The choice of materials can be changed, depending on availability. Ensure that there are some rough and some smooth materials to test.

Friction is the force that slows down moving objects. Rough surfaces such as sandpaper are likely to slow things more effectively than smooth surfaces. It not necessary that students use the word 'friction' at this stage.

<u>How to do this task.</u>

• Choose one material. Put this material at the bottom of the ramp.

• Let the toy car roll from the top of the ramp on to the material until the car stops.

• Put a chalk mark where the car stops.

• You are going to test all the other types of material, to see how far the car travels each time.

1. How can you make sure this is a fair test? Write your suggestions on the sheet.

• Now test all the other types of material. For each material, measure the distance that the car travelled and record it in the table.

2. Which material was best at stopping the car?

3. Why do you think that material was best at stopping the car? Explain your answer

I.1 Sample Student Skill Assessment

Skill Assessment: Stopping a car

This investigation will help you to find out which materials slow down a toy car the most.

Equipment: Toy Car, ramp, chalk, some books/cubes, ruler.

What to do:

- Choose one piece of material. Put this at the bottom of the ramp.
- Let the toy car roll rom the top of the ramp onto the material until the car stops.
- Put a chalk mark where the car stops.
- You are going to test different types of materials, to see how far the car will travel each time.

1. **How will you make it a fair test? What will you keep the same each time you test? Write down your ideas here.**

2. **Predict which material will be the best at stopping the car? Explain your answer.**

3. **Now test all other materials. For each material, measure the distance the car travels and record it**

Material	Distance travelled (cm)
1	
2	
3	
4	

4. **Which material was best at stopping the car?**

5. **Why do you think that material was best for stopping the car? Explain your answer.**

6. **Based on your results, is there any other investigation question that you would like to investigate?**

Appendix M Student Semi Structured Focus Group Interviews

Student Focus Group Interview Questions

General Introduction

- Introduce yourself.
- Explain the purpose of the interviews.
- Inform the students of their anonymity.
- Answer any questions the students may have.

Section A: Attitudes towards and experience of school/school science.

1. Do you like **school** science? ***Prompt*** Why/why not?
2. Tell me about your favourite science lesson this year?

   Prompt What did you like about it?
3. Is there anything you do not like about school science? ***Prompt*** Why/why not? Least favourite science lesson this year.
4. Pretend I'm going to teach you for science this year. What kind of things would you want me to do? What kind of things would you not want me to do with you?

Section B (i): Argumentation

Should we kill the grey squirrel to save the red squirrel?

There are two types of squirrels found in Ireland, the red and grey squirrel. The red squirrel is native to Ireland while the grey was first brought from North America in 1911. The red squirrel is becoming extinct in Ireland.

The grey squirrel may be the cause of the extinction of the red squirrel. While the grey squirrel does not kill the red squirrel themselves, they carry harmful disease that can kill the red squirrel within two weeks. The grey squirrel also eats the acorns that the red squirrels depend on to survive. In the UK, grey squirrels are being shot, trapped or poisoned to protect the red squirrel. Should Ireland do the same to protect the red squirrel?

- Based on the information you have; what decision/recommendation do you think Ireland should make?
- How do you know that this/these are the right decision?
- Can you think of a reason why someone might disagree with your solution?
- What other information would you like to have before making a final decision?
- Why do you think the people have different opinions about the red squirrel?
- Did you ever discuss these kinds of issues in school science? Can you provide me with an example?

Section B (ii): Socioscientific Reasoning Scenarios

Read the scenario to the children and get the children to retell the scenario in their own words.

John and Tom are neighbours. John sells fruit and vegetables to the local food market. He noticed that some insects are eating and killing his flowers and plants. He used insect spray to kill the insects.

Tom is a beekeeper. He is worried that his bees are being poisoned. Many bees in Ireland are in danger of becoming extinct. He told John that he should not use the spray because it can kill bees also. John said that he followed the instructions when he was using the insect spray and scientists are not certain about the links between the insect spray and bee health. Tom wants the government to ban insect spray.

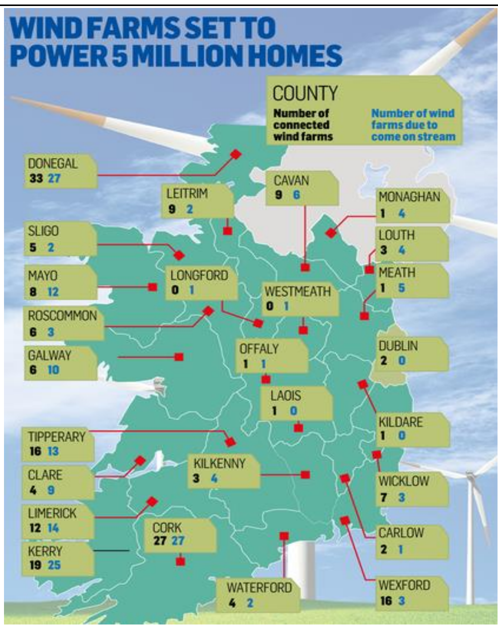
- Why are bees important?
- Why are bees in danger of becoming extinct?
- Why do you think the scientists have different opinions about what is happening to the bees?

- What do you think John should do? What do you think Tom the beekeeper should do?
- Based on the information you have; do you think the government should ban insect spray? Why or why not?
- How do you know that this/these are the right decision?
- Would everyone agree with your answer? Why/why not? (Prompt).
- What other information would you like to have before making a decision?

Read the scenario to the children and get the children to retell the scenario in their own words.

Ireland must reduce *carbon emissions* by 20% by 2020. At the moment, we are way off this target and will be lucky to have reduced carbon emissions by 1% by 2020. Ireland faces fines of up to €600 million a year for failing to meet this target.

Ireland must produce more *renewable forms of energy*. Communities are now being encouraged to build wind farms under a new Government Plan.



Adapted from the Irish Times Newspaper Report.

Questions to promote discussion:

A. The E.U. will fine Ireland up to €600 million for not reducing carbon emissions.

- Can you describe carbon emissions in your own words?
  - *How do we produce carbon emissions? (Prompt)*
- Why do we need/not need to reduce our carbon emissions in Ireland?
  - Give a reason for your answer (Prompt).
- How can we reduce our carbon emissions?
  - Why does this reduce it? (Prompt)
  - Why are the government recommending the use of wind energy? Can you describe how wind turbines work? (Prompt)
  - Can you think of any other energy sources that do not produce carbon emissions? (Prompt)
- Based on the information you have; do you think we should invest in Wind Farms? Would everyone agree with your answer? Who? Why? (Prompt).
- How do you know that this/these are the right decision?
- What other information would you like to have before making a decision?

Appendix N Teacher Semi Structured Interview

Introduction

- Remind participant of confidentiality and anonymity
- Attain permission to record.
- Outline duration and structure of interview:

This interview should take no longer than 30 minutes. It seeks to get your views on your involvement in the SSIPSC programme. The questions will relate to your experience and the impact of the programme on the students in your class and your own teaching and learning. I will check my prompts during the interview.

- State date, time, place and interview with…
- Ask participant class they are teaching and how long have they been teaching for (in this school and elsewhere), qualifications and experience of teaching science education.

Questions on Children's Learning

- Do you think students' attitudes towards science have changed since participation in the programme? Can you give an example of this?
- Did the children enjoy the lessons? How do you know? Did the children find the lessons interesting? Can you elaborate please?
- What influence, if any, do you think, the programme had on the development on the students' scientific skills? Could you give me an example of how participating in the programme activities has helped develop the students' science skills?

  Which science skill do you think was the most difficult to develop? Why?

  Prompt: Observing; Predicting; Investigating; Analysing; Questioning; Recording and Communicating.
- How effective do you think participating in the programme has been in developing the children's scientific content knowledge? e.g. climate change? Can you provide an example?
- In your opinion how did the students benefit from the programme?

- Did the students engage in discussion or debate about scientific issues? Did they do so prior to the programme? Can you provide an example of this?

Questions on Classroom Practice

- Can you describe a regular/typical science lesson that you would have taught before participating in this programme?
- Have you introduced new science strategies or teaching methodologies into your science lessons as a result of the CPD? Please give examples?
- Has your view of teaching science and/or attitudes towards teaching science changed as a result of your involvement in the project? How?
- Do you feel more confident about teaching science as a result of participating in the project? Why / why not?
- What barriers/difficulties, if any, did you experience while teaching the programme? How did you overcome them/ Did you overcome them?
- What were you hoping to gain from participating in this project and what did you gain most?
- Do you think you will implement the programme in your future teaching of primary science?
- What changes would you recommend are made to the programme?

Appendix O Sample Case Analysis: Case B

Case B is an all-boys case in the Dublin area. 32 third class students participated in the study. Their class teacher Eva had seven years teaching experience including a number of years teaching in Dubai and Australia. This was her second year teaching in the all-boys school. Eva completed her Bachelor of Education Degree in Marino Institute of Education, Dublin and had not participated in a science related professional learning programme prior to the SSIPSC programme. Eva stated that the class enjoyed science and were very enthusiastic about the subject. Eva was interested in science and wanted to learn some new science pedagogical approaches

O.1 Descriptive Analysis of Quantitative Data from Students' Questionnaire.

Data from the students' questionnaires were input into SPSS. Descriptive statistics for each scale are provided below.

O.1.1 Attitudes towards School

Table O.1 provides details of the percentage of students who strongly agreed, agreed, disagreed or strongly disagreed to the questions pertaining to students' attitudes towards school. The majority (>80%) of the 3rd class students in Case B like school and find it interesting. Analysis indicated that approximately 10% more students had more positive attitudes towards school post-intervention with 10% more students finding school more interesting at the exit stages. While there was a 20% increase in the cohort of students who indicated that they enjoyed school work post-intervention, there was also a larger cohort of students who strongly disagreed with this statement post-intervention; 13% of students strongly disagreed with this statement pre-intervention with 31% of students disagreeing with this statement post-intervention.

Table O.1.

Case B: Attitudes towards Case Scale

Question *n*= 32	**Pre/Post**	**Strongly Agree** (%)	**Agree** (%)	**Disagree** (%)	**Strongly Disagree** (%)
I like school	**Pre**	13	69	9	9
	Post	25	56	3	16

Table O.1 (continued)

I find school interesting	**Pre**	19	63	13	6
	Post	41	50	3	6
I enjoy school work	**Pre**	6	34	44	16
	Post	22	38	9	31

O.1.2 Attitudes towards School Science

The next scale examined students' attitudes toward school science, see Table O.2 for descriptive analysis of students' responses. 10% of students found science more interesting post-intervention with 20% more students indicating that they are looking forward to science lessons post the SSIPSC intervention. Approximately three quarters of students indicated that they are looking forward to secondary school science both prior to and after the intervention.

Table O.2.

Case B: Attitudes towards School Scale

Question *n*= 32	**Pre/Post**	**Strongly Agree** (%)	**Agree** (%)	**Disagree** (%)	**Strongly Disagree** (%)
School science is interesting	**Pre**	34	44	6	15
	Post	47	44	9	0
School science is better than other subjects	**Pre**	22	19	19	41
	Post	28	16	34	22
I look forward to science	**Pre**	25	31	31	13
	Post	22	53	13	13
I look forward to secondary school science	**Pre**	47	25	9	19
	Post	34	41	16	9

O.1.3 Experience of Inquiry Based Science Education

Nine of the questions in the students' questionnaire related to their experience of Inquiry Based Approaches to Science Education. Prior to the intervention approximately 90% of students indicated that they had infrequent to no opportunities to engage in some aspects of IBSE; more specifically using creativity in their work, carrying out investigations themselves, planning investigations themselves, discussing fair test investigations and recording the results of their investigations in different ways, see Table O.3 below. Over half of the students (60%) had some experience of making a prediction with 30% reporting that they had frequent opportunities to discuss the results of their investigation during science class. Data from Table O.3 indicates that the students had greater experience of IBSE approaches to science education post-intervention.

Table O.3.

Case B: Experiences of Inquiry Based Science Education.

Question *n*=28	**Pre/Post**	**Very Often** (%)	**Often** (%)	**A few times** (%)	**Never** (%)
In science we work in groups	**Pre**	6	16	72	6
	Post	34	44	22	0
In science we do activities that show us how scientists use their creativity in their work	**Pre**	6	0	13	81
	Post	13	56	28	3
In case we carry out investigations ourselves	**Pre**	3	0	3	94
	Post	9	47	34	9
In case we plan how we are going to carry out investigations ourselves	**Pre**	3	0	0	97
	Post	6	52	36	6
In case we talk about whether we are carrying out a fair test	**Pre**	0	3	0	97
	Post	9	44	41	6
In case we make predictions before we carry out science investigations	**Pre**	16	44	38	3
	Post	31	50	13	6
In case we record what happens when we are doing investigations	**Pre**	13	10	26	52
	Post	16	50	9	25
In case we record the results of our investigations in different ways	**Pre**	0	13	53	34
	Post	25	47	16	13
In case we discuss the results of our investigation in science class	**Pre**	27	3	52	19
	Post	22	50	25	3

It is apparent from Table O.3 above that the students in Case B did experience more frequent opportunities to engage in IBSE post-intervention. Analysis of the data indicates that approximately 60% of students had experience of the different tenets of IBSE methodologies post-intervention. Most notably the students had greater experience planning and conducting fair test investigations post the SSIPSC intervention.

Seven students were randomly selected to conduct a practical science investigation both prior to and after the SSIPSC intervention. The students were required to plan and record the results of their investigation. Details of skill assessment undertaken by the students can be found in Appendix K. Kilfeather, O'Leary and Varley (2007) scoring rubric was used to assess student development of working scientifically skills. Details of the scoring rubric employed can be found in section 3.10.1.

Table O.4.

Case B: Analysis of Students' Working Scientifically Skills.

Student	Working Scientifically Skills		Sample Skill Development	
	Pre SSIPSC	**Post SSIPSC**	**Pre SSIPSC**	**Post SSIPSC**
A	Weak	Excellent	No fair test variables considered or applied. Appropriate procedure not identified. Conclusion drawn is inaccurate.	Student identified and applied two fair test variables. Accurate record and interpretation of results. Appropriate conclusion drawn 'steepness of rank affects distance travelled'.
B	Fair	Good	No fair test variable identified or applied. Results of distance travelled recorded and interpreted. No conclusion drawn.	Student identified one relevant factor for a fair test that is carried out with reasonable efficiency. Observations and measurements accurately recorded. Good analysis of findings 'height of the ramp affects momentum and then distance travelled'.
C	Fair	Good	No fair test variable identified or applied. Prediction justified. Some aspects of observations and measurements are accurately recorded.	Identified one relevant factor for a fair test that is carried out with reasonable efficiency. Prediction justified 'the higher the ramp the faster it will go'. Accurate measurement and record of data. Accurate interpretation 'We used a sport car with a low suspension. When we raised the ramp to 40cm the car hit the table and flipped. Cards with low suspension are very bad for high ramps'.

Table O.4 (continued).

Student	Working Scientifically Skills		Sample Skill Development	
	Pre SSIPSC	**Post SSIPSC**	**Pre SSIPSC**	**Post SSIPSC**
D	Weak	Good	Fair test variables are not identified or controlled. Results recorded but not interpreted. No conclusion drawn. Lack of understanding of the purpose of the investigation.	Identified and applied one relevant factor for a fair test investigation – 'do not push the car as you do not know how hard you will push it'. Accurate record of findings. Valid rule outlining relationship identified 'If the ramp is too high the car will flip over'.
E	Fair	Good	Fair test variables are not identified or controlled. Inaccurate record of findings – use of inches and centimetres. Conclusion drawn is not based on findings recorded.	Identified and applied one fair test investigation factor. Accurate record of results. Accurate interpretation of results 'if the ramp gets too high the bumper will hit the floor'.
F	Weak	Excellent	No fair test variables identified or controlled. Inaccurate record of findings. No interpretation of data.	Identifies and applied all the relevant factors for a fair test investigation. Accurate record of measurements and findings. Accurate analysis of data 'higher the ramp the more chance that it will flip'.
G	Weak	Good	No fair test variables identified or controlled. No justification for prediction. Inaccurate record of findings. No interpretation of data.	One relevant factor for a fair test identified and controlled – 'The car has to be set the same'. Accurate collection and record of data. Some interpretation – 'more blocks the car goes further'.

Analysis of the above data in Table O.4 indicates that all students demonstrated 'good' to 'excellent' working scientifically skills post-intervention. Prior to the SSIPSC intervention four out of seven students demonstrated weak working scientifically skills. For instance, no student identified variables to be controlled for the fair test investigation. Students also experienced difficulty recording data with one student recording distance in both inches and centimetres prior to the intervention. In addition, students did not interpret the results correctly with three students ignoring the evidence collected when interpreting the findings. Post-intervention all students identified at least one variable to control during the investigation with one student identifying all variables to be controlled post-intervention. Interpretation of findings also improved with the students using the evidence gathered to interpret the results of the investigation. One student who did not draw a conclusion prior to the SSIPSC intervention clearly outlined the relationship between the ramp and distance travelled post-intervention, "We used a sport car with a low suspension. When we raised the ramp to 40cm the car hit the table and flipped. Cars with low suspension are very bad for high ramps" (Student C, post-intervention). These finding correlate with the quantitative data from the students' questionnaires. Pre-intervention only 3% of students indicated that they had experience discussing a fair test investigation. Post-intervention over 50% of students indicated that they had frequent opportunity for this. The questionnaire data also indicated that 20% more students had greater opportunity to predict post-intervention. Analysis of the skill assessment indicates that the students gave more informed predictions supported with justifications post-intervention. Furthermore, all students improved their recording skills post-intervention; the questionnaire data also provided evidence of more frequent opportunities to record results post the SSIPSC intervention.

O.1.4 Conceptions of Nature of Science

Descriptive analysis of data pertaining to students' perceptions of Nature of Science can be found in Table O.5 below. Many students held informed conceptions of NoS from the outset of the study. For instance, over 90% of students were of the opinion that scientists use their creativity when they plan and carry out investigations with 90% agreeing that scientists can have different answers to the same questions. Similarly, over 85% of students could be said to have informed conceptions of the tentative NoS as the students indicated that the content in science books can change and that scientists sometimes change their mind about what is true. Awareness of the subjective NoS was also evident as many students (94%) agreed that scientists use their opinions when they are explaining things.

Table O.5.

Case B: Conceptions of Nature of Science

Question *n*=28	**Pre/Post**	**Strongly Agree** (%)	**Agree** (%)	**Disagree** (%)	**Strongly Disagree** (%)
Scientists use their creativity when they plan and carry out investigations	**Pre**	27	67	7	0
	Post	66	34	0	0
Scientists can have different answers to the same questions	**Pre**	52	42	0	7
	Post	56	41	0	3
Scientists use their opinions when they are explaining things	**Pre**	55	39	3	3
	Post	47	44	0	9
Ideas in books sometimes change	**Pre**	27	60	7	7
	Post	19	72	3	6
Good answers are based on results from different science experiments	**Pre**	32	58	3	7
	Post	22	59	6	13
Scientists sometimes change their mind about what is true	**Pre**	34	59	3	3
	Post	38	50	3	9

Comparison of the pre and post question data illustrates that while the students had informed views of NoS prior to the intervention, they developed more informed conceptions across most aspects of NoS at the outset of the SSIPSC intervention. For instance, approximately 40% more students strongly agreed with the statements ‘ideas in science books sometimes change’ post-intervention. There was also a 20% increase in the number of students who agreed with the statements 'good answers are based on the results from different science investigations' and 'scientists sometimes change their mind about what is true'.

O.2 Analysis of Scale Data from Students' Questionnaire.

A Wilcoxon Signed Rank test was used to analyse the pre-intervention and post-intervention scale data from the students' questionnaires with Cohen's (1988) criteria used to interpret the effect size. A Wilcoxon Signed Rank Test indicated that the median post-test ranks were lower than the median pre-test ranks for the (i) IBSE, (ii) NoS, (iii) attitudes towards school and (iv) attitudes towards school science scale. A lower median score post-intervention indicates that the students had more frequent experiences of IBSE, more adequate conceptions of NoS and more positive attitudes towards school and school science post-intervention. Data further revealed a statistically significant difference between the students' experiences of IBSE post the SSIPSC programme, z = -4.6, p<0.001, with a large effect size (r=0.61). See Table O.6 below.

Table O.6. ***Case B: Pre-Intervention and Post-Intervention Scale Data***

SCALE	**Initial** Pre Median	**Exit** Post Median	**P**	**Z**	**R**	Effect Size: Cohen (1988) criteria
Inquiry Based Science Education Scale *n*=28	3.33	2.11	.00	-4.59	0.61	Large
Nature of Science Scale *n*=28	1.86	1.79	.23	-1.21	0.16	Small
Attitudes towards school *n*=32	2.33	2.0	.13	-1.51	0.19	Small
Attitudes towards school science *n*=32	2.1	2.0	.28	-1.07	0.13	Small

O.3 Analysis of Scientific Content Knowledge

The students answered 10 questions in relation to scientific content knowledge pre-intervention and post-intervention. Pre-intervention median score was 7 with the post-intervention median score increasing to 16. A Wilcoxon Signed Rank Test revealed a statistically significant increase in the development of students' scientific content knowledge post SSIPSC intervention, z= -4.68, $p<0.001$, with a large effect size (r=0.59).

O.4 Analysis of Argumentation Skills

Details of students' responses to the squirrel scenario can be found in Table O.8. Data indicates that the number of students who decided to 'kill' the grey squirrel was reduced by half post-intervention, with the number of students who decided 'not to kill' the grey squirrel increasing from two students to 15 students. Samples of typical student responses in each category are presented below (Table O.8). 38% of students provided justifications for their decision pre-intervention. This doubled post the SSIPSC programme with 93% of students providing justifications to support their decisions.

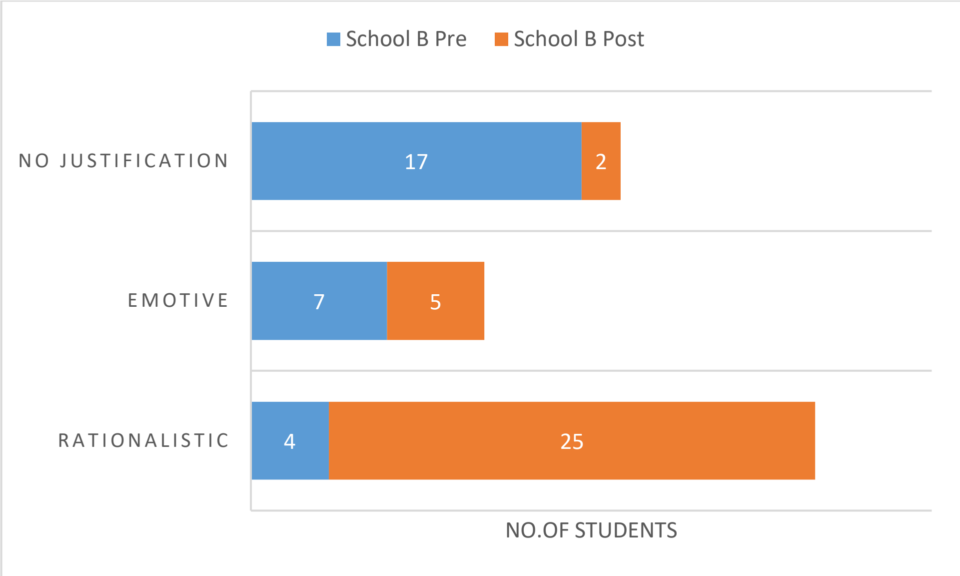
Table O.8.

Case B: Pre-Intervention and Post-Intervention Scale Data

Claim	Pre	Sample Quote	Post	Sample Quote
Kill	**23**	*Yes. because we need to keep our country safe and protected*	**10**	*Yes. The red squirrel is native. The grey squirrel in not. The red squirrel is going extinct and there are plenty of grey squirrels in other countries. The grey squirrel is native to America.*
Intermediate	**4**	*We should put the grey squirrels in a zoo to protect the red squirrels*	**5**	*No I don't think we should kill shoot the grey squirrel. We should bring them back to North America*
Do not kill	**2**	*No. Squirrels are harmless*	**15**	*The grey squirrel should not die. It might not be their fault. We need to do more research*
Justification	**11/29**	11 students provided a justification	**28/30**	28 students provided a justification

The students' responses were then analysed in terms of justification and categorised into emotive or rationalistic, see Figure O.1.

Figure O.1. **School B: Categorisation of students' justifications into 'Emotive' and 'Rationalistic'.**



Changes in justification from pre-intervention to post-intervention were recorded and analysed. Data indicated that 21 students provided more rationalistic justifications for their decision post-intervention. Seven students provided emotive justifications pre-intervention and this reduced to two post-intervention. Changes of argument and samples of students' responses can be found in Table O.9 below.

Table O.9.

School B: Samples of Changes to Students' Justifications.

Sample change
Emotive to Rationalistic ***Emotive (pre)*** "Yes we need to keep our country safe and protected" (pre). B18 ***Rationalistic (post)*** "No because it only says they [the grey squirrel] might be causing the disease. It might not be the grey squirrel's fault. We should find out first" (post). B18
No Justification to Rationalistic ***No Justification (pre)*** "Kill the grey squirrel" (pre). B31 ***Rationalistic (post)*** "Yes kill the grey squirrel. The red squirrel is native. The grey squirrel in not. The red squirrel is going extinct and there are plenty of grey squirrels in other countries. The grey squirrel is native to America" (post). B31

Table O.9 (continued).

Sample change
Emotive to No Justification ***Emotive (pre)*** "Yes shoot, trap or poison the grey squirrel because he is bad, so kill the grey squirrel" (pre). B7 ***No Justification (post)*** "Kill the grey squirrel". (post). B7

O.5 Qualitative Data Analysis

Five students in Case B, an all-boys school, participated in the focus group semi-structured interviews prior to and after the SSIPSC intervention. These students were randomly selected. The semi-structured interview schedule can be found in Appendix L. The interviews were transcribed and analysed thematically using NVivo (Version 11). A number of themes emerged from this analysis which will now be discussed.

O.5.1 Attitude towards School

All students (5 students) in Case B had positive attitudes towards school pre-intervention. They enjoy learning in school and playing with their friends; "I like school, because well you can learn and you need to learn to be able to do stuff and you can make friends on yard" (Case B, pre-intervention). Student E spoke about the connection between school and future careers stating that "if you didn't have school, when you're a grown-up you wouldn't be able to get a job and you wouldn't have any money" (pre-intervention). Three students stated that school is fun. Post-intervention all students maintained their positive attitudes towards school.

O.5.2 Attitude towards School Science

Most students (4/5) held positive attitudes towards school science pre-intervention. Student A indicated his intention to become a space scientist stating that he therefore needed to be "good at stuff like science and maths and all that kind of stuff" (pre-intervention). Student C held similar positive attitudes towards science citing his favourite aspect of science to be learning about space "I know loads about space…. And other stuff…. Well I can't really think of the other stuff" (Student B, pre-intervention). Space is not part of the primary science curriculum but part of the primary geography curriculum. Some students (2/5) indicated that they like learning about science as it is fun and interesting. One student disagreed with the others in the focus group stating that he didn't like science because "we don't really do any like real science [in school]. Like we don't really like put potions together or stuff like that" (Student E pre-intervention).

Post-intervention all students (5/5) were positive about school science. All students maintained that they did more science this year than previous years. They considered science to be fun, interesting and challenging. The importance of learning about 'real' science came to the fore in the group's discussion. The below students' comments are indicative of this positive attitude.

"[Pre-intervention] most of the experiments were done in the class, they were always just like, baking soda and vinegar. Even when we were doing it ourselves, we never learned why they react, but every experiment always depended on baking soda and vinegar. We made papier-mâché volcanos and we put a bottle and then we put vinegar in it, and then we put a tablespoon and it looked like it was erupting. But we didn't know why they reacted. And then we blew up a balloon using the same experiment but yet we still don't know why they reacted. *What is different about this year's science?* [researcher] Because we're actually learning about real-life stuff that are living. It makes sense" (Student B, post-intervention).

"What I love about school science is that it's very interesting. And it's very fun and you're learning a lot and I just like it because well it's – it's better than – I think science is better than like maths" (Student C, post-intervention).

"Last year we didn't do that much science projects and this year we did lots" (Student A, post-Intervention).

O.5.3 Experience of Inquiry Based Approaches to Science Education

The students then described and discussed specific school science lessons they enjoyed/did not enjoy. These descriptions provided opportunity to analyse the type of science lessons the students engaged with prior to and after the SSIPSC intervention. See Table O.10 below.

Table O.10.

Case B: Analysis of Categories of Science Lessons.

Theme: Category Title and Descriptor	Example of Children's Responses Initial Interviews	Example of Children's Responses Exit Interviews
Completion of worksheets/workbooks	I don't like science. We have to write down stuff [step by step procedure] in our copies and it takes ages (Student A, pre-intervention).	
Teaching doing activities and the children observing	It was when we were in Miss Fintan's class we done the plant thing where one plant was out in the sun and one plant was in the cupboard and… the one in the cupboard turned orange and the one along the window just turned green. (Student E, pre-intervention).	
Hands on activities prescribed by the teacher	…when we put the whole orange in it didn't float, it sunk, but then when we took off a bit [of the skin] it then floated and then we did a thing with a banana. We put the whole banana in and it sunk and then we took off the banana skin and then it floated. (Student B, pre-intervention).	My favourite was when we were planting the flowers because it was really different from like what we normally do…The flowers were for the bees because if we plant flowers it helps the bees get more pollen…Bees [use it] then to make honey and like make flowers and trees and stuff (Student B, post-intervention).
Teacher Explaining facts	I don't like when she talks about animals. It's so boring (Student C, pre-Intervention).	The global warming [lesson was my favourite lesson]. I thought it was really interesting because I didn't know anything like that before. I didn't know coal or oil was bad for the earth or anything… it's really interesting and I really liked it (Student C, post-Intervention).

Table O.10 (continued).

Theme: **Category Title and Descriptor**	**Example of Children's Responses** **Initial Interviews**	**Example of Children's Responses** **Exit Interviews**
Child-led investigation	N/a	My favourite science lesson was the cars, how fast the cars would go on the ramps. I liked that science lesson because it was really fun and I learned a lot. We were changing the height on the ramp….Alex came up with the question to investigate (Student A, post-intervention).

Initially, all students in Case B found it difficult to describe a school science lesson they enjoyed/did not enjoy pre-intervention. The students' responses were short and they often required probing. They often confused it with science they would like to do in school, non-science lessons or science activities they had completed with a parent/guardian at home. Two of the students stated that they had little experience of school science and found it difficult to remember a science lesson. Students' A and B response are illustrative in this regard.

"My favourite science lesson was the volcano thing where you put salt and everything in it and then it comes out" (Student A).

"So, did you actually make one of those volcano things?" (Student B)

"I done one with my Dad" (Student A).

"I don't know if this is science? Halloween last year, we carved out a pumpkin and it was fun" (Student B).

These lessons the students described were categorised according to opportunities for skill development. The number of times that the students made explicit reference to a skill when discussing science lessons, they enjoyed/ did not enjoy was recorded in Table O.11. Analysis of the number of references the students made can be found in the table below.

Table O.11.

Case B: Analysis of Student Scientific Skill Development

Scientific Skills	**Pre-Intervention** **No. of References**	**Post-Intervention** **No. of References**
Working Scientifically		
Questioning	0	4
Observing	1	1
Predicting	0	0
Investigating and experimenting	1	10
Estimating and measuring	0	2
Analysing	0	0
Recording and communicating	0	1
Designing and Making		
Exploring	0	1
Planning	0	1
Making	0	1
Evaluating	0	1
Total no. of references	**2**	**22**

While the students in Case B were generally positive about school science pre-intervention, the students' difficulty recalling science lessons may indicate that they had limited experience of science lessons. Furthermore, students described lessons where they watched teacher demonstrations or followed the teacher's step by step instructions, listened to teacher instructions or wrote down material from the board. Some students (2/5) described this type of science as 'boring' and 'too-easy'. It is therefore hard to conclude whether the students' scientific skills, especially those of questioning (students raising questions) and investigating and experimenting are being fully developed. Questions regarding the suitability of the lessons could also be raised as two of the students recalled floating and sinking lessons from 2nd class illustrative of a junior and senior infants lesson. Student C's response provided some evidence to support this "Like I like science, when we do it at home and stuff like that, but I don't really like it when I do it in school, because we don’t really do any like real science…like it’s really easy to do and we don’t like really do anything really hard or anything that’s really cool or like sort of like that” (Student C, pre-intervention).

Post-intervention the students in the focus group provided examples of science lessons that could be associated with more inquiry-based approaches to science lessons. It is apparent from Table O.11, that the students were provided with opportunities to ask questions, carry out fair test investigations, work collaboratively in groups and engage in design and make activities; these were not described by the students during the pre-intervention interviews. The importance of controlling variables and testing in a fair and reliable manner was emphasised by student C “Because if it wasn’t fair then let's say you gave one 200 millilitres but then the other like half a litre it means that you can't exactly figure out which is better because the one that the 200 millilitres might have soaked it up quicker but the one with 500 millilitres would have had more water so you can't tell then which one would have been better” (post-Intervention). Opportunity to develop measuring and recording skills is also apparent. It further emerged from the students’ descriptions that these lessons were relevant to their everyday lives and that they enjoyed learning about what they deemed ‘important science’. They equated the lessons to what scientists do, in particular when discussing the importance of working collaboratively and ensuring a fair and reliable fair test investigation process.

Students also described lessons where they took action in the post-intervention focus group. For instance, students described planting flowers to ensure the bees have enough pollen and nectar. Other students highlighted the importance of taking action to reduce energy consumption in school, turning off lights and walking to school where possible. The students themselves stated that this was something they had never engaged with before and it made science more interesting and relevant to them. It is also important to note that the lessons that students described in the exit interview were exclusively the inquiries the teacher had engaged with as part of the SSIPSC programme which seem to have provided the students with more frequent opportunities to develop their inquiry skills and make science more relevant to their daily lives.

O.5.4 Nature of Science

Evidence from the qualitative data suggests that the content of the SSIPSC intervention provided opportunity for the students to develop some general aspects of NoS, described in the literature review, Section 2.4.2. Students pre and post interview transcripts were analysed for evidence of adequate conceptions of general aspects of NoS namely that:

Scientists make observations and inferences.

Science is not a lone pursuit rather it involves collaboration.

Scientists use their creativity in their work.

There is no one scientific method.

There is a tentative and developmental nature to scientific knowledge

Students showed evidence of these tenets when they were describing their favourite science lesson or when responding to SSI scenarios. Students were not explicitly asked about these tenets of NoS but they emerged implicitly in the focus group interview. Table O.12 provides some examples of student responses and the tenet of NoS they relate to.

Table O.12.

Case B: Analysis of Students' references to Tenets of NoS

Tenet of NoS	**Example of Children's Responses** **Initial Interviews**	**Example of Children's Responses** **Exit Interviews**
Collaborative NoS	Scientists don't work together. They don't want to agree with each other's ideas.	Everyone had their different opinions and I say in groups they – we have to like figure out a way how we put all our opinions together to make it work.

Table O.12 (continued).

Case B: Analysis of Students' references to Tenets of NoS

Tenet of NoS	Example of Children's Responses Initial Interviews	Example of Children's Responses Exit Interviews
Creativity in scientific inquiry	N/a	No. we all made them [Design and make a wind turbine] in different ways. Some had more spinners. One group had like eight, I think. Some had like pencils on them and stuff and spoons and forks.
No one scientific method	Well the teacher told us how to do it so we just followed her.	We all didn't do it the same way [Kitchen paper investigation] because like some people had different ideas on how to solve the problem
Tentative NoS	N/a	Scientists can get stuff wrong, like when they were trying to figure out what happened to those dinosaurs and some said a meteor killed them and others said it was volcano…they don't know because they're not sure.

Little evidence of students' conceptions of NoS could be found in the pre-intervention interview data. It would appear that the SSIPSC programme provided the students with some opportunity to implicitly explore or develop some conceptions of NoS. For instance, when the students were discussing their favourite science lesson they referred to the collaborative NoS where they had to work together to decide on an investigation often making a connection between school science and scientists working collaboratively. They also referred to the different methods used by different groups to answer scientific inquiry questions in the post-intervention focus group interview. The students drew on examples of school science to demonstrate their understanding. The SSI scenarios also allowed opportunity for the students to consider why scientists may have different opinions on evidence collected. Pre-interview the students maintained that the scientists did not agree whereas post-intervention they referred to the subjective NoS and how scientists' prior experience and opinions may affect their interpretation of evidence. Creativity in the students' own investigations became apparent when discussing the design and make activity. Adequate conceptions of the tentative NoS was also apparent as the students alluded to how scientists sometimes get "things wrong" or get new evidence when making decisions. Thus, it would appear that the SSIPSC programme provided students with an opportunity to discuss and explore some of the tenets of NoS.

O.5.6 Argumentation

The students were provided with the same scenario as was presented in the children's questionnaire. See Appendix L for details of scenario. Using Evagorou and colleagues' (2012) framework, students' responses were classified in the 'Kill the grey squirrel' category, 'Intermediate' category and the 'Do not kill the grey squirrel' category. See Table O.13 below for examples of the students' responses.

Table O.13.

Case B: Sample Student Responses to the Squirrel Scenario

Category of Students' Response	Sample of Students' Response
Kill the grey squirrel	**Quote 1.** Yeah, because I think if the grey squirrel gets killed then it will be better for the red squirrel to live, and as you said the red squirrel was the one that was from in Ireland. So that's why
	Quote 2. Well I think we should kill the grey squirrel because it's mean. They're stealing their nuts
	Quote 4. Scientists should bring pine martins into the grey squirrels territory…pine martins are squirrel natural predators
Intermediate (Kill but control the grey squirrel)	**Quote 5.** Well I think we could just build a habitat for the grey squirrel to live in and then just give it some food to keep them away from the red squirrel
Do not kill the grey squirrel	**Quote 6.** We need an anecdote to protect the red and the grey squirrel.

Categorisation of students' responses pre and post-intervention can be found in the table below.

Table O.13.

Case B: Categorisation of the Students' Responses to the Squirrel Scenario

Decision made	Pre-Intervention	Post-Intervention
Kill the grey squirrel	2	0
Intermediate	2	1
Do not kill the grey squirrel	1	4

Post-intervention one student still maintained that the grey squirrel needed to be controlled whilst all other students decided not to kill the grey squirrel. Furthermore, the students discussed the feasibility of their decisions. This did not occur pre-intervention. For instance, the below students maintained that it would be difficult to trap all the grey squirrels so it was not the easiest solution.

"just take the grey squirrel to another country but it would be hard to just trap it in a cage" (Student A, post-Intervention).

"I definitely not agree with XXX solution because I think It's going to be hard to find every single squirrel in Ireland and then bring it over to a different country" (Student C, Post-Intervention).

Some students (2/5) refused to make a decision post-intervention requesting more information before they did so. This did not occur pre-intervention and is indicative of rationalistic reasoning. The students were able to suggest follow-up investigation questions that would provide them with the required information making references to the importance of fair test investigations while doing so. Some students indicated that scientists had a key role to play in gathering further evidence.

In general, the students had positive attitudes towards engaging with discussion and debates pertaining to SSIs. Their class teacher Eva highlighted that because 'discussion' is not an explicit skill in the primary science curriculum it was often something she never considered including in her science lessons: "Definitely not. I think because it wasn't in the curriculum and because it wasn't in the book", however post-intervention she stated that providing opportunities for the students to engage in argumentation would be a key component of her future science lessons.

O.5.7 Socioscientific Reasoning

Students were provided with two scenarios to discuss in order for their socioscientific reasoning skills to be examined. These scenarios can be found in Appendix L. Sadler, Barab and Scott (2007) devised a framework to analyse students' socioscientific reasoning skills. Students' responses were categorised into

(i) appreciation of the complexity of the SSI
(ii) approaching the SSI from multiple perspectives
(iii) the value of ongoing inquiry

Students were provided with an opportunity to discuss the scenarios in their groups. Quotations which provided evidence of any of the above components were analysed and categorised according to levels, with level 4 representing a higher level of the competency than level 1. See Table O.13 below for sample of students' categorisation in relation to the bee scenario.

Table O.13.

Case B: Sample Student Responses to the Bee and Biodiversity SSR Scenario

	Levels			
	1	**2**	**3**	**4**
Appreciation of the complexity of the SSI (Sadler et al., 2007)	*Offers a very simplistic or illogical solution without considering multiple factors.*	*Considers pros and cons but ultimately frames the issue as being relatively simple with a single solution.*	*Construes the issue as relatively complex primarily because of a lack of information. Potential solution tends to be tentative or inquiry-based.*	*Perceives general complexity of the issue based on different stakeholder, interests, & opinions. Potential solutions are tentative or inquiry-based.*

Table O.13 (continued).

	Levels			
	1	**2**	**3**	**4**
Exemplar Quote	"I think they should ban insect spray [to protect the bees], because bees, like they give you honey and if you're sick honey kind of makes you better, like if you have something" Student D	"Because bees are good. They make all the plants, like if there were no bees there would be no trees, no plants, no anything. But then they could make a special spray that would, that could kill insects and not bees" Student B.	"Well, because they're eating his plants, but you see if he kills bees, then you see, bees… well without bees we wouldn't have stuff like apples. Apples grow on trees. Bees pollinate and then they help the trees. We'd have a very dull planet if they didn't and he probably doesn't want them there because he's creating his own food and he can sell it at the market to get money" Student C.	*No student provided an example in this category*
Approaching the SSI from multiple perspectives (Sadler et al., 2007)	*Fails to carefully examine the issue.*	*Assesses the issue from a single perspective.*	*Can examine a unique perspective when asked to do so.*	*Assesses the issue from multiple perspectives.*
Exemplar Quote	*No student provided an example in this category*	"I think they should ban insect spray, because bees, like they give you honey and if you're sick honey kind of makes you better" Student D	Student B: "I think they should ban insect spray because bees are good. They make all the plants". Interviewer: "Would everyone agree with your solution?" Student C: "Well not the farmer, because they're [insects] eating his plants"	"Well, because they're eating his plants, but you see if he kills bees, then you see, bees… well without bees we wouldn't have stuff like apples. Apples grow on trees. Bees pollinate and then they help the trees. We'd have a very dull planet if they didn't and he probably doesn't want them there because he's creating his own food and he can sell it at the market to get money" Student C.
The value of ongoing inquiry (Sadler et al., 2007)	*Fails to recognise the need for inquiry.*	*Presents vague suggestions for inquiry.*	*Suggests a plan for inquiry focused on the collection of scientific OR social data.*	*Suggests a plan for inquiry focused on the collection of scientific AND social data.*

Table O.13 (continued).

	Levels			
	1	**2**	**3**	**4**
Exemplar Quote	I think that maybe instead of that thing, the insect spray, you could get a shovel and you could hit the bees with it.	"Some scientists might come up with another way to help the farmer.	"So, they could get a few stuff, like some antidotes and then they could test it, they could get a few bees and test it on them and other insects and then they could see 'Does this kill insects, but not kill bees?' So, they're [scientists] not quite sure, but if they did that they would". (Student A)	*No student provided an example in this category*

The number of references the students made to each competency in each level was counted for both the bee and energy scenarios, see Table O.14. Students in Case B provided enhanced levels of 'appreciation of the complexity of the SSI', 'approaching the SSI from multiple perspectives', and 'the value of ongoing inquiry'. For example, pre-intervention no student had reached level 4, 'approaching the SSI from multiple perspectives', whereas post-intervention there was four statements categories under level 4. It should be noted that the students did not reach level 4 inquiry post-intervention with no suggestion for both scientific and social inquiry provided by the students for either SSI scenario.

Table O.14.

Case B: Analysis of Students SSR Reasoning Competencies

Component of SSI Reasoning	**Pre SSIPSC Intervention** *No. of references*				**Post SSIPSC Intervention** *No. of references*			
Levels	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Appreciation of the complexity of the SSI	10	1	1	0	3	4	3	1
Approaching the SSI from multiple perspectives	4	2	2	0	0	1	4	4
Value of ongoing inquiry	1	2	3	0	1	5	3	0

O.5.8 Student Led Citizenship

Student-led citizenship emerged as a theme in the student focus groups. When discussing the students' favourite science lessons and the SSI scenarios, the students made reference to action they had taken in their own lives, at school and at home in response to the SSI. For instance, student D reported that he and his family had taken action in response to the bee and biodiversity SSI: "Well yeah. I planted, my family planted flowers outside our house, lavender and other stuff and in the back garden so that they can get more flowers, meaning that they can pollinate more" (post-intervention). Student C agreed stating that" My favourite was when we were planting the flowers because it was really different from like what we normally do and was something we could do to help" (post-intervention). The students in Case B demonstrated informed understanding of the role of bees in terms of pollination, something the students were not familiar with prior to the SSIPSC intervention, thus, it could be said that the students were taking 'informed action' in response to the SSI. Three of the students in the focus group made reference to reducing their consumption of sugary drinks after their engagement with the SSIPSC Unit on Sugar Tax and the Digestive System with two students describing action they had taken at home to reduce energy wastage: "if there's a light on you could turn it off or let's say watch less TV or stuff" (Student A, post-intervention). Eva, their class teacher also highlighted enhanced parental involvement as a result of the SSIPSC intervention both in terms of the students communicating their findings to their parents/guardians and also parents getting involved in the action the students were taking: "Parents are coming into me telling me they are being driven mad about recycling at home and they know all about the bees and the parents are planting stuff at home, doing a lot of things that we wouldn't have done in school without the SSIPSC programme" (Eva, Case B, 3rd class)

Many students referred to the 'Action' element of the SSIPSC intervention as being one of the main reasons why they found school science more interesting than previous science lessons. Eva agreed stating the students were making connections between science and their everyday lives which made school science more relevant and engaging for the students:

“I think a lot of it was practical as well. They loved being up and about, especially the boys at that age. I think having a book in front of them and reading, you know yourself, it is boring. I think it is just because it is stuff that is going on in their life and we made it very clear that it is happening in their life and all the stuff that is happening that they are learning about now is going to be their history and it is their legacy and it is what they are growing up with. I think it made them way more interested in it because even when we brought them out on trips and stuff, they were able to spot things that we had talked about in class, so they were able to relate it back to the real world. What's that word? Contextualise. They were able to relate to it and talk to their parents about it. I think they were all really interested in it as well”.

O.5.9 Conclusion

The qualitative and quantitative data provided a rich source of evidence pertaining to the impact of the SSIPSC intervention on Case B students’ scientific literacy competencies. Data revealed that pre and post-intervention, the majority of students had positive attitudes towards school. The students had similarly high positive attitudes towards school science at the initial and exit stages of the study with no statistical significant difference reported between the pre and post-intervention scale data. However, post-intervention the students demonstrated more accurate perceptions of school science and had had more frequent experience of school science. For example, pre-intervention the students often described lessons that were non-science lessons (e.g. geography or art) when describing their favourite science lessons whereas post-intervention students described lessons that were hands-on, engaging and relevant to their everyday lives. The quantitative scale data revealed that the students had limited experience of IBSE pre-intervention and statistical significant more frequent experience of IBSE post-intervention with a large effect size reported (Cohen, 1988). Qualitative data corroborated these findings as students described greater opportunity to ask inquiry questions, conduct fair-test investigations and described how they were recording and communicating their findings when they were discussed their favourite science lessons. Quantification of the qualitative focus group data revealed that the students’ enhanced experience of IBSE resulted in developments of their science skills as outlined by the primary science curriculum (DES, 1999a). Students demonstrated informed understanding of NoS pre-intervention, this improved post-intervention but was not statistically significant. However, post-intervention the qualitative data revealed that the students were able to apply their understanding of NoS to the negotiation of the SSI scenarios, a themes that did not emerge pre-intervention. More advanced argumentation skills and socioscientific reasoning ability were also provided with both pupils and teachers indicating that they enjoyed engaging in discussion and debate as part of the SSIPSC intervention. Finally, student-led citizenship emerged as a prominent theme as students described action they took at a personal and school level in response to the SSI, something which they found meaningful and important in their everyday lives. These results will be compared to the findings in the other cases in the cross-case analysis.

Appendix P SPSS Codebook

Variable Information

Variable	Label	Measurement Level	Role	Missing Values
STUDID	Student ID	Nominal	Input	99
SCHID	School ID	Nominal	Input	99
Gender	Student Gender	Nominal	Input	99
Class	Class	Nominal	Input	99
LikeSchool	I like school	Ordinal	Input	99
POSTLikeSchool	Post I like school	Ordinal	Input	99
SchoolInterest	I find school interesting	Ordinal	Input	99
POSTSchoolInteresting	Post I find school interesting	Ordinal	Input	99
IEnjoySWrk	I enjoy school work	Ordinal	Input	99
POSTIEnjoySWrk	Post I enjoy school work	Ordinal	Input	99
TOTAttSch	TOTAL attitude towards School	Scale	Input	99
POSTAttSch	POST attitude towards School	Scale	Input	99
SchSciInt	School science is interesting	Ordinal	Input	99
POSTSchSciInt	Post School science is interesting	Ordinal	Input	99
SciOtherSub	School science is better than other subjects	Ordinal	Input	99
POSTSciOtherSub	Post School science is better than other subjects	Ordinal	Input	99
LookForwardSci	I look forward to science	Ordinal	Input	99
POSTLookForwardSci	Post I look forward to science	Ordinal	Input	99
LookFSecSci	I look forward to secondary school science	Ordinal	Input	99
POSTLookSecSci	Post I look forward to secondary school science	Ordinal	Input	99
TOTAttSchScience	Total Attitude towards School Science	Scale	Input	
PostAttSchScience	Post Total Attitude towards School Science	Scale	Input	
SciGroup	In science we work in groups	Ordinal	Input	99
POSTSciGroup	Post In science we work in groups	Ordinal	Input	99
ActSciCreatvity	In science we do activities that show us how scientists use their creativity in their work	Ordinal	Input	99
POSTActSciCreatvity	Post In science we do activities that show us how scientists use their creativity in their work	Ordinal	Input	99
SciInvOurselves	In school we carry out science investigations ourselves	Ordinal	Input	99
POSTSciInvOurselves	Post In school we carry out science investigations ourselves	Ordinal	Input	99
SciPlanInvest	In school we plan how we are going to carry out science investigations ourselves	Ordinal	Input	99

POSTSciPlanInvest	Post In school we plan how we are going to carry out science investigations ourselves	Ordinal	Input	99
SciFairTest	In science we talk about whether we are carrying out a fair test	Ordinal	Input	99
POSTSciFairTest	Post In science we talk about whether we are carrying out a fair test	Ordinal	Input	99
Prediction	In school we make predications before we carry out science investigations	Ordinal	Input	99
POSTPrediction	Post In school we make predications before we carry out science investigations	Ordinal	Input	99
Record	In school we record what happens when we are doing investigations	Ordinal	Input	99
POSTPecord	Post In school we record what happens when we are doing investigations	Ordinal	Input	99
RecordDiff	In school we record the results of our investigations in different ways	Ordinal	Input	99
POSTRecordDiff	Post In school we record the results of our investigations in different ways	Ordinal	Input	99
DiscussRes	In school we discuss the results of our investigations in science class	Ordinal	Input	99
POSTDiscussRes	Post In school we discuss the results of our investigations in science class	Ordinal	Input	99
TOTIBSE	Total IBSE scale	Scale	Input	99
POSTIBSE	Post IBSE scale	Scale	Input	99
ContentKnowledge	Content Knowledge Results	Scale	Input	99
POSTContentKnowledge	Post Content Knowledge Results	Scale	Input	99
WindEnergy	3 disadvantages of wind energy	Scale	Input	99
POSTWindEnergy	Post 3 disadvantages of wind energy	Scale	Input	99
BeesImp	Why are bees important?	Scale	Input	99
POSTBeesImp	Post Why are bees important?	Scale	Input	99
Absorbent	Material most absorbent	Scale	Input	99
POSTAbsorbent	Post Material most absorbent	Scale	Input	99
Seperation	Separating Materials	Scale	Input	99
POSTSeperation	Post Separating Materials	Scale	Input	99
Nonrenewable	3 non-renewable sources	Scale	Input	99
POSTNonrenewable	Post 3 non-renewable sources	Scale	Input	99
Worker	Worker Bee	Scale	Input	99
POSTWorker	Post Worker Bee	Scale	Input	99
Water	Water home come from?	Scale	Input	99
POSTWater	Post Water home come from?	Scale	Input	99
Microplastics	Microplastics	Scale	Input	99
POSTMicroplastics	Post Microplastics	Scale	Input	99
Digestive	3 parts digestive system	Scale	Input	99
POSTDigestive	Post 3 parts digestive system	Scale	Input	99

FairTest	Keep the same fair test	Scale	Input	99
POSTFairTest	Post Keep the same fair test	Scale	Input	99
NoisePoll	Sources of Noise Poll	Scale	Input	99
POSTNoisePoll	Post Sources of Noise Poll	Scale	Input	99
ScientCreat	Scientists use their creativity when they plan and carry out investigations	Ordinal	Input	99
POSTScientCreat	Post Scientists use their creativity when they plan and carry out investigations	Ordinal	Input	99
DiffAns	Scientists can have different answers to the same Q	Ordinal	Input	99
POSTDiffAns	Post Scientists can have different answers to the same Q	Ordinal	Input	99
SciOpinions	Scientists use their opinions when they are explaining things	Ordinal	Input	99
POSTSciOpinions	Post Scientists use their opinions when they are explaining things	Ordinal	Input	99
BookChange	Ideas in books sometimes change	Ordinal	Input	99
POSTBookChange	Post Ideas in books sometimes change	Ordinal	Input	99
GoodAns	Good answers are based on results from different science experiments	Ordinal	Input	99
POSTGoodAns	Post Good answers are based on results from different science experiments	Ordinal	Input	99
ChangeMind	Scientists sometimes change their mind about what is true	Ordinal	Input	99
POSTChangeMind	Post Scientists sometimes change their mind about what is true	Ordinal	Input	99
TOTNoS	Total NoS Scale	Scale	Input	99
POSTNoS	Post Total NoS Scale	Scale	Input	99

Appendix Q Effect Size Calculation

Attitudes Towards School

Case	Z	N	N*2	Square Root N	Effect Size	Cohen's 1988 Criteria Interpretation
Case A	0.65	25	50	7.1	0.09	Small
Case B	1.51	32	64	8	0.19	Small
Case C	0.68	22	44	6.63	0.10	Small
Case D	0.38	9	18	4.24	0.09	Small
Case E	0.11	23	46	6.78	0.02	-------
Case F	2.29	13	26	5.10	0.45	Medium
Case G	0.29	20	40	6.32	0.04	-------

Attitudes towards School Science

Case	Z	N	N*2	Square Root N	Effect Size	Cohen's 1988 Criteria Interpretation
Case A	1.02	23	46	6.78	0.15	Small
Case B	1.07	32	64	8.00	0.13	Small
Case C	1.82	22	44	6.63	0.27	Medium
Case D	1.23	8	16	4.00	0.31	Medium
Case E	0.24	23	46	6.78	0.04	----------
Case F	0.81	12	24	4.90	0.17	Small
Case G	0.17	18	36	6.00	0.03	---------

Experience of IBSE

Case	Z	N	N*2	Square Root N	Effect Size	Cohen's 1988 Criteria Interpretation
Case A	3.66	24	48	6.93	0.53	Large
Case B	4.57	28	56	7.48	0.61	Large
Case C	4.02	21	42	6.48	0.62	Large
Case D	1.59	9	18	4.24	0.37	Medium
Case E	3.64	22	44	6.63	0.55	Large
Case F	0.15	11	22	4.69	0.03	---------
Case G	1.02	20	40	6.32	0.16	Small

Nature of Science

Case	Z	N	N*2	Square Root N	Effect Size	Cohen's 1988 Criteria Interpretation
Case A	1.61	24	48	6.93	0.23	Small
Case B	1.21	28	56	7.48	0.16	Small
Case C	1.59	21	42	6.48	0.25	Small
Case D	1.87	9	18	4.24	0.44	Medium
Case E	0.73	23	46	6.78	0.11	Small
Case F	0.92	12	24	4.90	0.19	Small
Case G	1.56	20	40	6.32	0.25	Small

Content Knowledge

Case	Z	N	N*2	Square Root N	Effect Size	Cohen's 1988 Criteria Interpretation
Case A	3.56	27	54	7.35	0.48	Medium
Case B	4.68	32	64	8	0.59	Large
Case C	4.11	22	44	6.63	0.62	Large
Case D	2.67	9	18	4.24	0.63	Large
Case E	4.16	23	46	6.78	0.61	Large
Case F	3.08	13	26	5.10	0.60	Large
Case G	3.88	**22**	44	6.63	0.58	Large

Appendix R Sample SPSS Output

N.1 Sample: Checking the reliability of a scale

Attitudes towards school scale

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.796	.798	3

Attitudes towards school science scale

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.723	.721	4

Conceptions of NoS Scale

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.706	.712	6

Experience of IBSE

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.862	.863	9

N.2 SPSS Wilcoxon Signed Rank Test

Case A

Test Statistics[a,b]

	POST Attitude towards School - TOTAL Attitude towards School	Post Total Attitude towards School Science - Total Attitude towards School Science	Post IBSE scale - Total IBSE scale	Post Content Knowledge Results - Content Knowledge Results	Post Total NoS Scale - Total NoS Scale
Z	-.652[c]	-1.021[c]	-3.659[c]	-3.559[d]	-1.605[c]
Asymp. Sig. (2-tailed)	.514	.307	.000	.000	.109

a. School ID = School A

b. Wilcoxon Signed Ranks Test

c. Based on positive ranks.

d. Based on negative ranks.

Case B

Test Statistics[a,b]

	POST Attitude towards School - TOTAL Attitude towards School	Post Total Attitude towards School Science - Total Attitude towards School Science	Post IBSE scale - Total IBSE scale	Post Content Knowledge Results - Content Knowledge Results	Post Total NoS Scale - Total NoS Scale
Z	-1.505[c]	-1.074[c]	-4.592[c]	-4.680[d]	-1.208[c]
Asymp. Sig. (2-tailed)	.132	.283	.000	.000	.227

a. School ID = School B

b. Wilcoxon Signed Ranks Test

c. Based on positive ranks.

d. Based on negative ranks.

Case C

Test Statistics[a,b]

	POST Attitude towards School - TOTAL Attitude towards School	Post Total Attitude towards School Science - Total Attitude towards School Science	Post IBSE scale - Total IBSE scale	Post Content Knowledge Results - Content Knowledge Results	Post Total NoS Scale - Total NoS Scale
Z	-.667[c]	-1.823[c]	-4.021[d]	-4.113[c]	-1.594[d]
Asymp. Sig. (2-tailed)	.505	.068	.000	.000	.111

a. School ID = School C

b. Wilcoxon Signed Ranks Test

c. Based on negative ranks.

d. Based on positive ranks.

Case D

Test Statistics[a,b]

	POST Attitude towards School - TOTAL Attitude towards School	Post Total Attitude towards School Science - Total Attitude towards School Science	Post IBSE scale - Total IBSE scale	Post Content Knowledge Results - Content Knowledge Results	Post Total NoS Scale - Total NoS Scale
Z	-.378[c]	-1.225[d]	-1.590[c]	-2.670[d]	-1.866[c]
Asymp. Sig. (2-tailed)	.705	.221	.112	.008	.062

a. School ID = School D

b. Wilcoxon Signed Ranks Test

c. Based on positive ranks.

d. Based on negative ranks.

Case E

Test Statistics[a,b]

	POST Attitude towards School - TOTAL Attitude towards School	Post Total Attitude towards School Science - Total Attitude towards School Science	Post IBSE scale - Total IBSE scale	Post Content Knowledge Results - Content Knowledge Results	Post Total NoS Scale - Total NoS Scale
Z	-.108[c]	-.243[c]	-3.644[c]	-4.156[d]	-.732[c]
Asymp. Sig. (2-tailed)	.914	.808	.000	.000	.464

a. School ID = School E

b. Wilcoxon Signed Ranks Test

c. Based on positive ranks.

d. Based on negative ranks.

Case F

Test Statistics[a,b]

	POST Atttude towards School - TOTAL Attitude towards School	Post Total Attitude towards School Science - Total Attitude towards School Science	Post IBSE scale - Total IBSE scale	Post Content Knowledge Results - Content Knowledge Results	Post Total NoS Scale - Total NoS Scale
Z	-2.287[c]	-.810[d]	-.154[c]	-3.08[c]	-.917[c]
Asymp. Sig. (2-tailed)	.022	.418	.878	.002	.359

a. School ID = School F

b. Wilcoxon Signed Ranks Test

c. Based on positive ranks.

d. Based on negative ranks.

Case G

Test Statistics[a,b]

	POST Attitude towards School - TOTAL Attitude towards School	Post Total Attitude towards School Science - Total Attitude towards School Science	Post IBSE scale - Total IBSE scale	Post Content Knowledge Results - Content Knowledge Results	Post Total NoS Scale - Total NoS Scale
Z	-.288[c]	-.168[c]	-1.023[c]	-3.88[c]	-1.562[c]
Asymp. Sig. (2-tailed)	.774	.867	.306	.000	.118

a. School ID = School G

b. Wilcoxon Signed Ranks Test

c. Based on positive ranks.

d. Based on negative ranks.

Appendix S Sample Argumentation Analysis

Extract from Focus Group Interview Case E (6th class)

Pre-Intervention

Note Scenario was read to the students. Students recalled scenario clarifying that they understood the content of it.

Perfect, yes XXX do you want to start?

Code: Claim and warrant

I think we should kill the grey squirrel because it is carrying a disease that will kill the grey squirrel in two weeks (Student B).

What I disagree. There could be other reasons causing it. It's not fair to kill one animal to save another (Student C).

I still think we should save our native animal. America has loads (Student B)

Code: Counter argument and warrant

Okay XXX what do you think?

Well then I think if you find any grey squirrels maybe capture them and bring them to a different place like a squirrel sanctuary to stop the spread of the disease (Student D)

Code: Claim and warrant

Note: Seeks clarification

That's not fair. The grey squirrel doesn't know what it's doing (Student C)

Code: Rebuttal

Code: Counter claim and warrant

I get what you're saying but the red squirrels are close to extinction and it would give them time to reproduce (Student D)

Note: Acknowledges an alternative perspective

XXX [Student C), go for it. Thank you, XXX.
Why do you think that?

Post-Intervention

Note Scenario was read to the students. Students recalled scenario clarifying that they understood the content of it.

Code: Claim and warrant

Okay XXX who wants to start?

I feel like they should have grey squirrels, like kind of have a little pen type thing, have a grey squirrel and a red squirrel and then maybe see which one would survive longer and if the red squirrel dies within like 2 weeks of it being there or something or interacting with the grey squirrel then they could like probably know better at least (Student B).

Note: recognises need for inquiry

Yeah, it would be like see what happens like, how it affects the red squirrel (Student C).

Note: More student directed discourse

Like is there a big like reason we need the red squirrels? Like do they… They look better? (Student E)

But like you can't just be like, oh yeah it doesn't matter if they go extinct (Student B).

Code: Counter argument and warrant; rebuttal

Yeah maybe I get that. (Student E)

Like, we're only helping the bees now because people didn't do anything (Student B).

Code: Backing

So, you're comparing it to the bees? Yeah, I understand.

Like it took a while for people to actually start noticing climate change. It took a while for people to start noticing the bees and stuff (Student C).

Code: Backing

Note: Connection to SSIPSC

Well, like I don't really think it but if we got rid of the grey squirrels and then found out that like they weren't even the cause like then we would have no squirrels and it wouldn't work (Stu... E)

Note: Speculating. Recognises the need for inquiry?
Code: Claim and warrant

Okay, really interesting, anyone else?
Well that's good because like, humans could be causing the red squirrels to go because we're already killing our…
Because we're humans, we're…

Code: Claim and warrant

We're already killing, sorry?
Like, already killing our earth because like all the gases we have been using and stuff like that (Student C).
What do you think XXX?
Well, maybe it might be because of humans as well because they're putting like weed-killer and stuff in the forests maybe and like mushroom killer that's poisonous and that could be like, killing the squirrels like the fumes and stuff.
Very good, what do you think XXXX?
I don't think that we should kill anything because there is like, they don't mean to kill the red squirrels and they, it wouldn't be fair if we just killed all of the grey squirrels.

Code: Claim and warrant

So, you don't agree with what the…
No.
Okay. Is it an easy problem to solve?
No. It can be for some people, but then it can't be for some other people.
Can you explain that further, why might it be easy for some and not for others?
Because like some people might be like, 'No, don't kill any animals' and some people are vegetarians maybe, they might be like, 'That's not really fair on the grey squirrels' and then some people might be like, 'Well then, red squirrels are going to be extinct' so then they would be like, 'Yeah, kill the grey squirrels' but then some people would be like, 'I don't know.'

Code: Claim and warrant

Note: Multiple perspectives

It's still taking loads of people…I think it's just taking too long.
They only notice when it affects them (Student B).

Note: Citizenship

They do it with this, well then, they're going to go extinct because if it doesn't affect them then they're never going to notice it (Student C).

Yeah like we might as well do something now (Student A).

Code: Claim and warrant

Then what do you suggest happens?
It's not fair to like lock them up in a small place I think because they don't know what they're doing, they didn't do anything (Student E).

It's really hard, I don't know (Student B).

What more information would you like to have before making this decision?
Do they 100% kill the red squirrels, like 100%?

Note: Recognises the need for additional information

Okay, anybody else?
Is there anything that we can do about it without hurting the animals?
They should kind of look into more what they do. Like, their habitat and see if they can like figure anything out from that.

Code: Counter argument Claim and warrant

Very good.
Wait they said the red squirrel is dying because the grey squirrels can eat unripe acorns too?

Note: Recognises the need for additional inquiries. Suggest plan of inquiry

Yes
Could there be a substitute that just doesn't grow in the wild that you could, if you took in red squirrels could you feed them and get them used to it and then see if you could plant it.

That sounds like a great idea. Do you think everyone would agree with your suggestion?

Good and just what you have said there, some people have different opinions. So, what do you think the next step should be, so before we decide anything what should we do?

> *Note:* Recognises need for inquiry. Correlate with SSR scenario data

I think maybe scientists should take action and do an experiment about like what both species carry and like if, what's causing it.

Okay, sticking with the two of you, what do you propose should happen then?

It's a hard one because you don't want the red squirrels to like...

To die.

To die, but like you don't want to kill grey squirrels when they don't know what they're actually doing. They're only animals.

They're minding their own business.

> *Code:* Claim and warrant

> *Note:* Considers both side of scenario

Okay, anyone agree or disagree? Different opinion?

It's a hard one.

I agree with XXX idea, just like capture, like not even all of the grey squirrels but like most of them and see if that works and then if that doesn't work you just have to leave it because you can't just kill them (Student A).

> *Note:* Recognises need for inquiry.

Yeah like, I was thinking if you did capture them...

Like, if I was the person that was organising this, I wouldn't make them be killed, I would like make them have food and water and stuff.

And then at least just until the red squirrels get like, bigger I guess in the family or something (Student C).

> *Code:* Claim and warrant

Yes XXX, what do you think?

I think that maybe like a couple of parks or something should be cleared out of the grey, like captured and then they could let the red squirrels in there and then bring the grey squirrels to a different park and then where there are like no red squirrels.

Well, like people would care because it's a species but like some people wouldn't really care because like they don't... (Student A)

> *Code:* Claim and warrant

They're a native species (Student B).

They probably just don't care about them because it doesn't affect them (Student A).

They're probably not educated as well as they should be (Student B).

Okay, can you explain that a bit further?

Like, people just think, 'Oh well, it doesn't really affect us and...'

People make decisions so fast when they're not investigating it more. They just make the decision.

> *Note:* Looking at the issue from multiple perspectives.

> *Note:* Highlights the importance of evidence based informed decisions.

Okay

They don't take the time to see what like, why this is a problem, they're just like, 'Oh, the squirrels are dying, I don't mind.' It doesn't affect me.

Very good so we're discussing the red and the grey squirrel now. Can you think of any other issues that you have discussed like similar to this?

The bees.

Well if it's like choosing I guess which one then I can kind of think of the sugar tax.

> *Note:* Connection to discussion and debate in the teacher interview; student-led citizenship

Very good.

Technically everything because it's all being world debates and it's all, we have all had to make, come up with a plan to solve it, then execute that on a smaller scale.

Very good.

And then try and do it on a bigger scale ourselves.

That's really interesting

Do you think it's going to be easy for them to catch the grey squirrels? No. they're so fast. I'd say you probably have to lure them in. **Yeah.**	

Extract from Focus Group Interview Case A (4th class)

Pre-Intervention	Post-Intervention
Note Scenario was read to the students. Students recalled scenario clarifying that they understood the content of it. I think we should do; you know the way how they said that the, how the grey squirrel carries the disease and it take its nuts? Like even if it just touched the nuts then it could carry the disease to that squirrel, so I think that we should like say get nuts in forests and like people could trap them and then they should kill them, because… **Kill the grey squirrel?** *Code:* Claim and warrant Yeah, because I think if the grey squirrel gets killed then it will be better for the red squirrel to live, and as you said the red squirrel was the one that was found in Ireland. So that's why. **Okay, what do you think? Now before you start, you don't have to agree with everybody, so you can have a different opinion or idea if you want.** Well I think we should torch the grey squirrel, because it's very, very mean. They're stealing their… *Code:* Claim and warrant *Note:* Negative emotional response **Okay, so get rid of all the grey squirrels?** Yeah. From Ireland. **Why?** Because the grey squirrel… I know the grey squirrel doesn't know what it's doing, but it shouldn't be doing that.	***Note Scenario was read to the students. Students recalled scenario clarifying that they understood the content of it.*** **Okay XXX what do you think?** *Code:* Claim and warrant I think we should leave it and it might sort itself out. There are other red squirrels in other parts of the world so they are not actually going extinct. Ya I agree. If you kill the grey squirrel, they might go extinct. Nature should be left to sort it out. *Code:* Claim and warrant I think that we should take the grey squirrel to a different country because it is affecting the red squirrel and it's not like, like people are actually using – well not stupid ideas but, can they think, just bring them to a different country because what's it going to do in a different country, do they have red squirrels in different country? *Note:* Clarifying prior to making a decision. **They have yeah.** They have yeah but we don't care about their squirrels so just take the grey squirrel – it doesn't matter then if those red squirrels die in the other country, just take the grey squirrel to another country. *Code:* Claim and warrant. *Note:* Emotional response. **Do you think that would be easy to do?** Yeah (Student A). No (Student A). *Note:* Rebuttal with no supporting argument

Okay. What do you think XXX?
Well I think we could just build some sort of habitat for the grey squirrel to live in and then just give it some food, and if that doesn't work, we can just ask America if they'd like it, if they'd like them back! And if that doesn't work, well then, we just trap them in a cage and feed them nuts.
And feed them nuts, so don't kill them?
Yeah, because we don't want them to go extinct.

Code: Claim and warrant

Yeah, okay.
I mean all creatures are part of the life.

Code: Claim and warrant

And what do you think XXX? You look like thinking very carefully there.
I'd say just leave it because there'll still be other squirrels all over the world

Code: Claim and warrant

You were thinking that as well XXX?
I was like thinking, I like XXX idea and I like Tadgh's XXX and like XXXX, because then XXXX said that we can like get, like we could try get an antidote to make sure that like they stay, like they don't spread the disease, but then like, as XXXX said, then we can just trap them somewhere else, like we could keep the red squirrels one place and then the grey squirrels another place and then…(Student A)

Note: Takes into consideration other students' ideas. Synthesises these ideas into a possible solution.

Well what I meant was like, you know, enclosure. Maybe a zoo enclosure or something? (Student B)

Note: Illogical solution – link to SSR scenarios

Good, thank you.
Or just we build something and then they can keep together and then they can even make friends!

Brilliant. They could make friends?

Because you just trap it in a cage – oh a bit easy no a bit hard but just trap it in a cage, then put it on a plane and wherever you're going just (Student A).

And do you think that's the best solution to the problem?
No but it's my opinion.

Code: Counter argument: Claim and warrant.

That's your solution, okay. Let's listen to other opinions. XXXX.
You see it wouldn't be easy as XXX, well it's actually not – it wouldn't be easy to catch all the grey squirrels in Ireland, you'd have to check all over the country but here's my plan, it's a bit like XXXX, I'm sure it'll be hard but try to find forests that have more grey squirrels than others and then move the red squirrels to different fo… so just try to put red squirrels in d… even if grey squirrels do come there if someone notices one while they're in the forest they can just note the workers there, there was a grey squirrel somewhere in the forest.

Note: Puts forward possible solution to SSI

And how would you keep the red squirrels in one forest and the grey squirrels in another forest?
Well find different forests around Ireland.

Code: Claim and warrant

And how would you keep them in it?
Well it's not as if they're just going to move out of a forest into the open because they're going to need the forests with trees for nuts, so they will need it. Or I guess you could borrow off some forests or maybe just make a gate in so that you can enter when you want. I've seen lots of red squirrels that go up a tree. I think I've seen a few grey squirrels too.

Note: Connection to students' everyday lives

Okay.
I've seen squirrels run across in Dublin Zoo. You actually see them run across you in Dublin Zoo. It's as if they don't have an enclosure (Student A).

Loads of friends! There could be about 101 spots and then all of them could be friends.	Yeah, I have seen more red squirrels because like there's usually more red squirrels down the country and the grey squirrels are bit more like in Dublin, Kildare (Student B). I've seen lots of grey squirrels like in Tipperary because my granny lives in Tipperary, Galway (Student E). *Code:* Claim and warrant. *Note:* Take into account other student's perspective **Okay thank you XXX what do you think of the two boys' opinion?** I definitely not agree with XXX solution because I think they're hardly going to…he's hardly going to let's say you're hardly going to find every single squirrel in Ireland, you're hardly going to see every single grey squirrel in Ireland and then bring it over to a different country but then XXX opinion is kind of changing because he said that he doesn't want any squirrels to get hurt but then he's saying, bring them to another country.

Appreciation of the complexity of the SSI (C)	yellow
Approaching the SSI from multiple perspectives (P)	green
The value of ongoing inquiry (I)	blue

Appendix T Sample Socioscientific Reasoning Analysis

Sample analysis of student focus group (Case D) scenarios pertaining to the SSI Bee scenarios

Pre-Intervention	**Post-Intervention**
Okay. I think that they should ban the spray because we need to care about the animals because God make them and because they're like humans and it's not really nice to kill them because…the animals don't kill us or do nothing to us. (Student A). P2 Assess issue from a single perspective I1 Does not recognise the need for inquiry **Okay. What do you think?** Well personally I think they should ban it but I mean you could also just like move his vegetables inside maybe…so the bees can't get in. C1 Offers an illogical solution P1 Fails to carefully examine the issue Note: student lacks content knowledge on the role of bees in society. **So you disagree?** … Well I think that bees are very important because they make honey and it's actually good for you if you have a cough. They also get pollen but I'm not exactly sure what it helps with but I know that it helps (Student B). **Okay, so you think you can keep them separated?** *Student nods head* **Okay, very good, thank you.** What's the point if we have like insects and animals in real life when we have to kill them (Student C). **Okay.**	Well I'm not too sure but I would stop using it and then just try to find other ways of stopping the insects from getting in. Like the bees pollinate…if he doesn't have bees, his vegetables won't get pollinated, meaning that he will still lose his crops. I2 Recognises the need for inquiry C3 Perceives the problem as relatively complex **And what do you think? Should John continue to spray his fruits and vegetables?** I'm just like in my head like bee, vegetables, bee, vegetables. I don't know because I say we need bees –bees make our vegetables but then we need to get the vegetables to eat so that we stay alive so I'd say it's kind of both we need because we need like say to keep insects off so we can get our food. We should get a spray like that does not kill any bees. C3 Perceives the problem as relatively complex P3 recognises the issue from different perspectives without being probed I2 Recognises the need for inquiry **Yeah.** Ya, he's using pesticide to get rid of them which I don't think is a good thing because they could experiment and maybe they could find something else that you can use and they will go and they will just leave it alone. But it won't kill anybody. I3 Suggests a plan for inquiry focused on the collection of scientific data C3 Perceives the problem as relatively complex **Okay thank you. Yes.**

You can trap them to take them [insects] away, you can't kill them.

And would you be worried about insects on your fruit and vegetables?

Yeah...

> C1 Offers an illogical solution
> P1 Fails to examine the issue carefully

I think I'd rather kill the bugs than die myself (Student C).

Now, it would be that the farmer can't sell his fruit and vegetables anymore at the market.

Oh. Well then like you could just like get rid of the animal [insect] spray and then like you could maybe like put a fence or something around [the fruit and vegetables] something that'll make the bugs stop (Student C).

> C1 Offers an illogical solution
> *Note:* Lack of student content knowledge

Okay. What do we think over here?

I disagree because whenever you, bees are important for the planet, they help the plants grow actually and if we kill them, they'll be like, just going to be the same as using killing all the, keeping all the insects. Because the bees will need to pollinate the plants and that helps them grow and without them, we won't have trees and flowers which give us oxygen. And if a fruit is not organic it doesn't have all its important vitamins or chemicals inside (Student E).

> *Note:* Informed content knowledge
> C3 Considers the issue to be relatively complex
> I1 Does not recognise the need for inquiry

Okay. And what do you think? Do you agree or disagree?

Well I have a solution (Student E).

Okay. Great.

They can probably make a bee friendly pesticide (Student E).
That's what I just said [whispered].

> I2 Suggests a vague plan for inquiry.
> *Note:* Inquiry coming to the fore. Students not as willing to make a decision in comparison to pre-intervention.

Okay. And why would you come up with that solution?

..... So, it'll be even worse for him if he goes around killing the bees. Because then the bees cannot pollinate the tree or perhaps the flower to produce the fruit or veg and then he will run out of money (Student E).

Very good, okay.

> C3 Offers an illogical solution
> P4 Assess the issue from multiple perspectives: the farmer and the bee keeper.
> *Note:* Considers the economics associated with the issue. Considers an alternative solution in light of this.

And he won't survive.
(Student E).
.....

Okay. Why John is spraying his fruit and vegetables?

Yeah, because he doesn't want the insects to eat it and then he'll be left with no food and he won't be able to sell it. And one more thing it also affects the food chain (Student B).

Yeah.

> P3 Can examine an issue from a unique perspective when asked to do so

something could eat those insects. So, if those insects die then something can't eat it like maybe a bee if they can fly, some insets

I disagree. If you want to save the fruit and vegetables I think you can put something on top of it and you can build up a fence and to prevent the insects I think you need to grow some flowers around, they will go and sit in the flowers (Student B).

C3 Considers the issue to be relatively complex
I1 Does not recognise the need for inquiry

Okay.

You can make a protective glasshouse to keep all your vegetables and fruit inside it so no bugs come in (Student B).

Okay, good suggestion.

C3 Considers the issue to be relatively complex
I1 Does not recognise the need for inquiry
P1 Examines the issue from a single perspective

…………

And what do you think John should do now? So, John is the farmer, what advice would you give John?

Make a greenhouse and store all your vegetables and all your fruit in there and then you won't need to kill any insects or anything (Student A).

C1 Illogical solution
I1 Does not recognise the need for inquiry
P3 Can examine an issue from unique perspective when asked to do so

That's a good suggestion

…..

I don't think he should build a greenhouse because greenhouses hold gasses called greenhouse gasses and those are very bad for the flowers which are used to growing in areas which aren't very hot and the tropical ones will be used to it but I don't think we have such a tropical weather here in Ireland. So then, in Europe so the greenhouse gasses will affect all the flowers (Student C).

Note: Inaccurate science conceptions

can fly. Like a bee can't eat it and then spiders or whatever they can't eat their food and then whatever eats the spider can't get the food and that upsets the food chain.
(Student B)

Very good.

C3 Recognises the complexity of the issue
Note: Making connections outside the context of the SSIPSC intervention

Okay, what Is your opinion?

Well we need the bees and the bees need the plants…they want to get all the pollen and the sacks? (Student C).

Yeah. The sacks?

The pollen sacks like (Student C).

Note: Development of content knowledge pertaining to the role of the bees

Very good, what do they do with the pollen sacks?

They suck up nectar and then the pollen sacks is where they keep all their pollen. Yeah, it's like having a bag on your leg.
I actually saw one (Student C).

Note: student making connection between SSIPSC programme and everyday lives

You saw one?

Yeah, in my back garden there is some wild flowers and I don't know what type of bees they are and when they fly, I see pollen sack.
We have like a big bush and it's blue and for some reason every time I walk out there on a sunny day, I see a bee.
You know bees are in danger? (Student C)

………

Do you think this is an easy problem to solve?

I3 Suggests a plan for inquiry focused on the collection of scientific data.

Okay. And what do you think Tom should do right now? Tom is the beekeeper.

C1 Illogical solution
I1 Does not recognise the need for inquiry
P3 Can examine an issue from unique perspective when asked to do so *Note: Economic considerations*

Maybe he could move, but that would cost money as well. But maybe he could make like a little cage and put them in there and maybe like a little, like a small little wooden house (Student C).

C2 Considers pro and cons
I2 Presents vague suggestion for inquiry

……

What do you think? Should insect spray be banned?
Maybe, I don't know because sometimes it can prove useful and sometimes it can prove not so useful. They can make this type of spray, like this insect spray which only affects like insects except for the bees (Student E).

C1 Illogical solution
P3 Examine the issue from different perspectives e.g. the farmer and bee, however illogical argument presented.

Good, well done. What do you think?

I think they should, they can ban but they need to still sell the insect spray in some of the shops.
Maybe they could sell it somewhere else like maybe in the countryside where like people, where there's not that many insects like if you don't, like if there's an insect in your house they probably could use it (Student A).

No. We need to investigate like what is the source.
What is the spray doing to the people, the insects, the bees.
They can make a new type of spray and try that (Student A).

Okay, what do you think? Do you think insect spray should be banned?

Well we could all have organic fruit and vegetables then (Student C).

But they cost more than normal fruit and veg (Student D).

Yeah, it costs like more money to buy organic than normal (Student C).

P3 Can examine an issue from multiple perspective. *Note: Economic considerations*
C3 considers the problem as relatively complex

Okay. So is that a solution to the problem?

A little bit.

It's a solution for these two [famer and bee keeper], but it's not really a solution for us, because then really we're paying more money just to help them two (Student D).

Yes, you have your hand up
…people will have like different opinions on it, because they'll be like 'But we need…' Like the Farmers, the Farmers will have no business and then all the poor Farmers will have no jobs, but then other people will be like 'Oh, but like the bees are dying and loads of bees are getting extinct' and it's … ht B).

C4 perceives the general complexity of the issue based on different stakeholders' interests and opinions.
P4 Examine the issue from multiple perspectives without being probed.

Sample analysis of student focus group (Case F) scenarios pertaining to the Energy scenario

Pre-Intervention	Post-Intervention
So, does anyone know why they want to reduce it carbon dioxide? If you breathe out whatever it is… Maybe other people will take it and make you sick. *Researcher Note:* Inaccurate understanding of carbon dioxide **Okay so anyone have any idea of why they might want to reduce it or bring it down?** Because they think it's bad for your body. **Yeah, they think it's, okay, bad, any other reason why you think?** For tall people. **Okay, any other reason why they think that carbon dioxide might not be good for us?** It's not good for the environment and things around us. **Why do you think it's not good for the environment?** Because things won't grow and it'll just stay the way it is and… **Yes?** I don't know. *Researcher Note:* Some awareness of climate change but unable to elaborate **Okay, and is there any way you can think of that we can reduce the carbon dioxide?** By getting bags of it and keeping it (Student A). Bags of it, you can't see it (Student B). You can't catch air (Student A). C1 Illogical	**So does Ireland need to reduce carbon dioxide?** Because carbon dioxide is something that you breathe out after you breathe in your breath, and carbon dioxide goes out and we give it to tree and the trees make it cleaner and you can breathe it back in. So do not cut down trees and…And we'll be fine. *Researcher Note:* Development of content knowledge pertaining to respiration **Very good. Is there anything else that makes carbon dioxide?** Your breath (student C). On very hot days, elderly people can get very sick (Student B). **Well done. Thank you. Can you tell me more that?** That it is smoke? Out of a car, out of the engine (Student A). The smoke, the dirty smoke from the factories. The factories and car engines. That is bad (Student E). *Researcher Note:* Evidence of development of content knowledge regarding courses of Co2. **And what's that making?** Carbon dioxide. **Carbon dioxide, okay. So how can we reduce our carbon dioxide? How can we bring it down?** Don't stop breathing, okay. C1 Illogical solution to the issue presented. **Okay** Look, then you'll die.

Any other idea?....No? That's okay. Why do you think the government are going to build wind farms to try and reduce carbon dioxide?

Maybe the wind will take it.

What do you mean will take it?
When they spin.
Oh yeah, then we'll take it into things and just go [pinging noise]

And what will it do with it?
Probably stay in there forever.
Reduce it.

Researcher Note: Difficult to assess from a SSR perspective. Students lack content knowledge and do not understand the issue.

Okay they could reduce it by what, doing what?
Putting it into air.

By putting it into?
Air.

Air. Okay, anyone have any other reasons why they might? Yes?
If you blow a whistle it breathes out the air.

Any other reason why they might be using wind turbines?
I have no idea.
I don't even know what wind turbines are, I don't know that much.

Good, so why do you think the government are recommending to build wind farms?
So there will be more electricity and more...I don't know, no idea.

Researcher Note: Demonstrates a lack of understanding of wind energy. Lack of development of content knowledge as a result of SSIPSC?

Anything else?
Carbon dioxide is bad for your body and lungs.

Okay, very good.
Well you have to breathe in

Okay so before the government make a decision on this, is there any other information they require?

No (Student E)
Don't think so (Student A)

I1 Does not recognise the need for inquiry

Okay thank you.

Appendix U Sample Teacher Interview Data

<u>Case E Extract from Teacher Interview</u>

Ok David, Tell me about your experience of teaching science?

Yeah. I really enjoyed science in SESE in college but what I found was then when I tried to translate it into a classroom it wasn't so easy because it was very difficult to plan for it in the way that we had done it in college. Where you were prepared for a teaching practice, you were prepared for your three weeks or four weeks, or whatever it was going to be rather than looking more long term and how you can develop science or any other subjects in SESE over the course of a whole year or throughout the school. Up until this year it has been very much textbook based, supplemented with bits from other resources that have come in rather than being directed by what I have been most interested in or taking cues from the children and things like that. Sometimes science was just blitzed kind of in science week; it was a fun scien thing to do for like two weeks.

Code: History of experience with professional development courses

Code: Previous teaching of science; text-book dedicated approach to teaching science; lack of child-led approach

Have you engaged other in any professional learning courses in science since you left college?

I did the outdoor classroom, one with Paddy Madden in Marino a couple of years ago which would have been science but then it was more just the plants and animals side of it rather than anything to do with engineering - but that would have been the only one since.

Code: Children's attitudes towards the programme

Code: Hands-on investigations.
Researcher Note: Movement away from textbook dominated approach to the teaching of science

In terms of the programme and the children's learning. Did the children enjoy the lessons?

Yes, definitely, they loved it. Anytime I said, get into your science groups, it was up, quick as flash, moving tables. I didn't have to do anythin Once I had established, I suppose, the groundwork with them in the first topic and how we were going to break our science lessons up, how we were going to work in groups, what is group work, what is individual, what is whole class. They absolutely loved it particularly anything t was practical and because there were so many more practical activities, they didn't open a textbook once for science this year. I just think t that was - they really liked that but also then because of the level of the class that there were, being sixth class, and also, they were a very articulate class. They had very good discussion skills and the fact that then it was really bringing it into real life, really brought it home to them and they would very rarely bring their parent into the classroom but they were bringing them in if we had a science display on or when we were doing a sugar tax. For example, we had the sugar out and parents were being dragged upstairs to come and look at them. They were really bringing the messages home.

Code: Parental Involvement;
Researcher Note: School science bridging the boundary of school into home environment.

Code: Real-life science; discussion
Researcher Note: Consider link to argumentation

In terms of development of their scientific skills like for example questioning, predicting and investigating, do you think the programme was effective at developing those type of skills?

I think it was really good. I spent a lot of time early on doing that Sellotape observation that we had done with you and just finding the difference between what is a scientific observation and what is just opinion and how, I suppose, as the topics were going on, you could overhear the children when they were discussing in little groups, asking each other 'Well, how do you know that? What evidence do you have? while they were doing their investigating. If it was a fair test investigation that they were supposed to be doing, they were pulling each other up and saying, 'Actually no, you can't do that, you have just ruined our experiment'. But nicely with each other as well. So, I think that all those kind of skills did really improve. It took time but they were getting more and more confident with them as everything went on. Even when they were dissecting lilies, it was 'Are we allowed to touch them with our fingers, or do we have to use our tweezers?'. But they were looking to see if that was going to change what they were going to see. So, that kind of thing; they were looking for it a little bit more.

Code: Nature of science, observation skills.

Code: Fair test investigation; group discussion; Argumentation
Researcher Note: Use of evidence to support claims emerging.

Code: Scientific Inquiry skills; observation skills

Can you tell me a bit more about their investigation skills please?

At the beginning it felt like things at times, from my point of view, it felt like they are going out of control because, I think, as a teacher, it is much easier as a teacher to say, 'This is the question that you are going to investigate and this is how you are going to figure it out.' So, it did take me a little bit of time to adjust to that and just to let them at it knowing that they are not really going to do any damage. I do think that the fact that they could ask a question and if we didn't know the answer and if we couldn't find out the answer through investigation, we would try and figure a way that we could or figure out someone we could go and ask. And I think the fact they got answers to their questions brought them into the topics a lot more than if I was just saying 'this is what we are going to do'.

Code: Teacher dominated investigations
Research Note: Little evidence of child-led investigations prior to SSIPSC in terms planning and conducting investigations.

Code: Inquiry approach; skill development; child-led questioning.
Research Note: Evidence of real child-led inquiry and impact it had on children's learning.

In terms of developing their content knowledge. Do you feel it was effective developing content knowledge aligned with the science curriculum?

Definitely. We found that we actually were hitting across a lot of strands and strand units of the curriculum with just one topic of the SSIPSC programme. So yes it was mapped to the curriculum really well but, I think, just in a different way and I suppose, it made me think a little bit more outside the box. I think that it was allowing them time to show their outside knowledge as well because everything was so topical. They were hearing things on the news. They were hearing their parents talking about things and that was all coming into it at once. So they were getting a much broader, well rounded, knowledge or opinion of science, rather than just abstract or individual topics presented in their books. I definitely think it was much more well–rounded

Researcher Note: Individual topics could be as a result of text based approach? Consider follow-up question here?

Code: Development of content knowledge; Real-world science.
Research Note: Evidence of connection between school science and science in the students' everyday lives

You mentioned the children engaged in discussion earlier, is that something that you would have brought into science before this?

It would have been more discussion and opinion gathering rather than debating, I suppose. Whereas, I think because it was so based in real life, it gave that opportunity to have proper debates and this particular class love a debate. I actually think it improved their debating skills because they were much better at drawing on evidence rather than having an argument essentially. So, I think it improved that but it was because they were getting the articles and because they were reading the headlines in the papers, because they were watching the news and little clips, I think that was all that allowed them to really discuss and debate the science topics at the same time as learning other skills without really realising they are developing them, I suppose.

Code: Relevant to students' everyday lives; discussion; argumentation.
Research Note: Evidence-based discussions emerged.

Brilliant, and do you think their attitude towards school science have changed as a result of the programme?

I think here that the children have always really liked science but I do think it has stepped up another level this year. And I think that their attitude towards science in secondary school is more positive where they are looking forward to it and they are talking about their subjects that they are choosing for next year and every single one of them has talked about science or has talked about going into science later on and it is a real interest. They really are looking at the world around them and how things work. And then the odd time they are coming in and they are saying, 'Oh, I saw this on the news the other day and it kind of reminded me of...' and they pick up something from some topic that we had been covering. But yeah, I think that they are certainly more open to being confident to ask questions and trying to figure it out themselves and not expecting the teacher to know everything.

Code: Previous attitudes towards science
Research Note: Connection to focus group data and students' attitudes towards science scale. Improved attitudes towards science post SSIPSC intervention.

Code: Attitudes towards science; attitudes towards secondary school science;
Research Note: Connection to attitude towards science scale.

Code: Child-led inquiry; scientific inquiry skills, real world-science.
Research Note: Illustrative of development of scientific literacy. Correlate with questionnaire and focus group data.

<u>**Case C Extract from Teacher Interview**</u>

Can you start off by telling me very quick background about your teaching, your history of teaching, how many years you're teaching.

> ***Researcher Note:*** Include this as contextual information for case

Yeah, so this is my ninth-year teaching, I did a bachelor in Pat's. And then I did the… I did my masters in science …., and then I did a postgrad in English as an additional language. And I've been teaching in XXX now for XXXX years.

Okay, and in terms of the programme, I'm just going to ask you about the children's learning in it, and what you thought of the children's learning. So did the children enjoy the lessons, first of all?

> ***Code:*** children's attitudes towards the SSIPSC programme.

Yeah, they loved it, they absolutely loved it.

And what do you think they enjoyed about them, maybe in comparison to other lessons?

> ***Code:*** Child-led investigation; discussion and debate; positive attitudes towards the SSIPSC programme.

> ***Code:*** Previous teaching of science
> **Researcher Note:** Teacher highlights the importance of connecting school science to their everyday lives

That they were very hands-on, that there was a good background set up, so they knew, I suppose, what the experiment… the context of the different experiments and investigations that they were conducting. I think sometimes there's a tendency to kind of like, oh, pick these great experiments off Primary Science or whatever. But there's no contextualisation for it. So, they do the experiment, they learn something on that day, but that's it, it's not kind of brought forward in any meaningful way. So, we really liked that… well, they really enjoyed, there was a lot of debate with it and language arts. So, there were hitting it across different lessons over a longer period of time. But then everything was integrated. So, I think that that made them a little bit more motivated, because they were… they could see where they were going. Like, I've picked this question, I can investigate it, this is the end product, if that makes sense.

Brilliant. And in terms of the way you taught science before then and now are there any differences?

> ***Code:*** Relevant nature of science
> **Researcher Note:** Illustrates teacher's confidence with teacher science through SSIs (current issues). Interesting quote – "It was light to a light bulb.

Yeah, I think that the main difference is putting in the current… like, I felt like I would have had the framework to about, like, okay we should be doing the current issues, and we would have done them in the Learn Together curriculum – but we wouldn't have connected to the science. So, I think that that has changed the way that I would look at a theme. And so, trying to take a theme in science, and then also across the curriculum. So, I think that is integrating the science part throughout, as opposed to like, science is just something we do on Mondays for an hour, or whatever the timetable says. So, for me, I think it's more of looking at science, like it's everywhere, it's everything that we're doing. So yeah, the current issues is a big thing, because I kind of linked it, it was light a light bulb. Do you know what I mean? It was like, oh, why didn't we do this before? We've been talking about this and we were doing debate writing, we're doing persuasive writing, we're doing letter writing, but we never connected them altogether. And I think that that's a big… that's a lot of work. So, when it's given to you, it makes it so much easier. Because if you're to start from scratch yourself, like, I could probably do it now with a new current issue, because I've had the experience of teaching throughout the whole year, whatever the five or six big ones that we did. So, I think I could do it now, but I wouldn't have been able to take the current issue and develop it to that extent beforehand, if that makes sense.

Code: Discussion; argumentation; real-world science
Researcher Note: Cross-curriculum approach.

Code: Argumentation; different perspectives; Nature of Science
Researcher Note: Connection to the appreciation of the complexity of the SSI.

So you mentioned debate writing and persuasive writing. Can you tell me about the connection between that and the science lessons?

Yes. So, we do… so, persuasive writing and the persuasive oral language is the core for fourth class. In our school anyway, persuasive writing is the overarching thing that they should be learning in fourth class. So, we would have done units on persuasive writing, in previous years. But would have been just related on what was in the book or what we… I don't know, we kind of picked a topic maybe to do for that month. But whereas this, it [SSIPSC intervention] kind of gave them more of a meaning behind the discussion, as opposed to just saying, okay, you're for or against this motion, go and write me a debate…whereas this, they were able to discuss and then kind of like argue or debate against each other about the same issue… And that was good because it's not just black and white. Whereas, sometimes when you're just teaching persuasive writing it's very like, you're either yes or no, or, today we're going to write for and tomorrow we're writing against. And this is how you write it and this is how you lay it out. Whereas, that gave them an opportunity to see it in a real context

What scientific skills do you think the programme helped to develop, if any?

Code: Scientific skills: Design and Make.

Code: Investigating and experimenting; Fair test investigation.

Analysing and then… design and making, because they were really thinking of, okay, well we'll need to have something that the wind can push.
Yeah, the problem solving was a big thing. Because like, oh it doesn't work… like, especially I suppose with the wind turbine, but even with the paper towel, letting them make the mistake and then be like, is that really a fair test? Are you sure? And then they're like, oh no, because this piece is bigger than the other piece, and so we're emerging the whole piece in the water….so we need to make them all the same size. It was important to give them the freedom maybe to go back and doing it again, if they made the mistake, like I suppose the problem solving. Because it was interesting with the skills assessment how many of them were not aware what a fair test was, and they would be very much aware now about what a fair test is. And that's a really good take away, I suppose that's a scientific skill, identifying a fair test, designing a fair test, conducting a fair test. And particularly when we were doing to temperature in the cups, really, they go so involved in that. Like some… we were recording time and they were asking for timers, others were measuring the amount of water in it. Or when we had enough boiled water, so this one was at this time starting and that one was like, at this time. So, we had to… really taking it very seriously.

Code: Hands-on investigation; Fair test investigation; Measurement

Code: questioning; child-led inquiry
Researcher Note: Teacher provides examples of the different investigations the students conducted as part of the SSIPSC programme.

Great thank you.
And I think the inquiry question, the questioning inquiry base, as in like, the students were like, oh, are we allowed investigate this, or, can we do this, coming up with their own questions to investigate that they were able to design themselves … like even for the paper towel or the cups or whatever it was,

whether it was like, the reusable cups or the lids or not the lids, or the paper towels, you know, what was absorbency of strength or whatever it was, that they were able to design it themselves. So that does come back to like, them having ownership over it.

Code: Positive attitudes towards school science both prior to and post the SSIPSC programme
Researcher Note: This correlates with students' attitudes towards science in the student focus groups and questionnaire data.

Yes, very good. And in terms of their attitudes towards science as a subject, do you see that has changed from before [the SSIPSC programme] and after [the SSIPSC programme]?

I think they're more enthusiastic about it. Like, when you're like, science, they're like, 'Yes!' Like, mine are very like, enthusiastic, in general … but like, a lot of them got more… I would say I got more enthusiastic. They have had such a positive experience of science. Like, there's a girl in my class like, 'I definitely want to be an entomologist now, that's definitely it, that's what I want to do'. She loved the programme…and she's really like gung-ho about it now and she's serious, she's not just like, I want to be a scientist when I grow up, she's like, I want to be an entomologist. So, I think that … you need to get them young to get that positive experience with it and the world.

And in terms of developing their content knowledge, aligning it with the curriculum, do you think it was effective at developing their scientific content knowledge?

Code: *Science content knowledge*
Researcher Note: Cross strand approach to the teaching of science

Yes, I think it was. When we sat down and looked at that green thing, remember you sent us the list of the scientific skills and then the over plan, and then when we sat down and did the long-term plan we found out we actually were hitting across… we were hitting a lot of strands of the curriculum with just one topic of the programme. Now, we did find it… geography was easy enough to integrate, English was… literacy was easy enough to integrate. The history then kind of was left on its own, because like, we had… prior to that, I suppose we had done like I suppose SESE planning, and some of them linked across the three. But like, history is the most difficult one to bring into what we were doing. Which is fine too, but then it needs to really like hit the language arts.

Researcher Note: Evidence of cross curricular approach. Could this be linked to the new primary curriculum framework and a thematic approach?

Code: Teacher directed approach; child-led inquiry; questioning skills
Researcher Note: Change of pedagogical approach from teacher-directed to child led.

In terms of the way you have taught science prior to this programme, can you describe the similarities and differences

I would have come from very prescribed science; this is what we're doing in science and this is how we're going to do it. I found it [the SSIPSC intervention] helped me to make it more child-led and get them more involved in inquiry-based learning…Now instead of just waiting for a teacher to tell them everything… it gave them more independence to question and find the answer themselves

Appendix V Sample Focus Group Data

Case E Extract from Focus Group [Section A]

Pre-Intervention	**Post-Intervention**
Think about science in school, you're in 6th class now and you're nearly going into secondary school. So, what do you like about school science? I like experiments. **What kind of experiments?** Explosions. Yeah. **Have you done any explosions in school?** Not yet. No. **No, so think about school science.** Well, we did an after-school club, and we did a chemical reaction called 'elephant's toothpaste'. And it was like… It was meant to shoot into the air but it didn't. Yeah, we used like 5% of the chemical agent instead of 20%. It's like, basically acid. **Okay, very good.** So, it was a chemical reaction. **A chemical reaction, very interesting. So, we won't talk about after school, if we just think about school science, okay?** I feel like it's really good but I don't feel like we do enough experiments. **Like, we usually just like look in our books and then like talk about it, I don't feel like we actually like try the stuff we actually learn about.** **Okay, good. XXX what do you think, do you agree with XXX?** Yeah, I like it, it sometimes gets a bit boring when we just read the exact same stuff just in different books but I like doing experiments. It's fun because we don't really do much [science] so then it's like kind of a treat for us. Some parts are like fun and oral and other parts are like, you have to do research and work. **Okay. So, thank you XXXX can you think of your favourite science lesson in school?**	**Can you tell me what you like about science in school and why? So, I don't know if anyone wants to begin?** I liked doing about bees. **Okay, good, tell me why did you like it?** Just because people actually need to start knowing more about that they're going to be extinct and how they help us and stuff. **Good, can you tell me, how do bees help us?** They pollinate flowers and stuff and like they give us honey. **Very good, and we'll just speak about pollination first of all. Why is that important XXX?** It keeps flowers alive and it keeps nature alive. **Very good XXX and how about bees and honey?** They go back with nectar; they go back to their hive. The bees throw up basically in other bees' mouths. And then eventually it gets put into the hexagon of the honeycomb and they seal it over with wax. **Well done. And why did you like that, the bees lesson?** Because it was interesting. **Okay, very good. Okay, we'll move on. What do you like about school science XXX?** I loved the climate change one. **Okay, so tell me about that?** Yeah and we did this critical thing, but it was really interesting to learn about climate change because we don't really do that in school. **Very good.** So, it was nice to do something different. **Brilliant.** And like, all the activities that we did with like the bees, all of those are so different to normal science we used to do, so it's really nice to do it.

That we’ve done already?

That you’ve done already, yes.
Last year we got three eggs and we put one in vinegar, one in water and one in Fanta and then the one in Fanta started growing mould, and the one with vinegar it was all bouncy.
Very good. Why did you enjoy it?
It was actually really fun and we got to see like what effect like the protein and the keratin had on the egg.
Thank you. That was your favourite as well XXX? anyone have anything different? Yes, XXX, can you think of your favourite science lesson?
Well, it depends on the topic of the science and research.
Okay, good, what do you mean?
We don’t really get much writing but if you do then it’s not, it doesn’t make it as fun. Yeah, like we often have to write [in science] and it would literally be the thing that we just talked about and then we’re just repeating it in writing
Okay, anything else you don’t like about science.
How little of it we do. Like, we do way more Irish and Maths in a month than we would do science.
Yeah, because like in one day we’d only do like maths, English and Irish and then like there would be a certain day that we do science but then like all the teachers like would sometimes forget where like some things would come up.
Can I just ask, how much science around do you do? Say a week.
We’ve only done one lesson I think since the start of the year. We did a workshop, that was really fun (Student B).
Yeah, that was fun (Student C).
We did a science, forensic workshop (Student B).
Tell me about the forensic science?
A guy came in to do it (Student C).
It was like a treat for us (Student B).

When you say normal science XXX, what do you mean by that?
Yeah, we just used to like get our books out and like read a page of science and then like talk about like just human body, just…

Like it would be science, it would still be fun but it would be less fun than what we’re doing now. Than what we’re doing. It’s more like kind of interactive and like into groups.
Very good anyone else?
Oh like I liked the paper towel investigation. We saw how many layers there were and like how much water had been poured on it. And then there was the wind turbines as well where we got to make our own ones in groups. So, that was really fun as well and different.
That’s interesting XXX, what do you mean different?
It was more…We just…It was more like books and reading pages. We didn’t really… It was writing stuff down. Read a book for like 15 minutes, kind of talk about it and then it would be… (Student A)
We did do the human body and like she got some, it wasn’t really like, I don’t know but she got these bodies and like you could take them apart. But like she just put them in the class and like we wouldn’t actually like look at it as a class. We just would sit at the back of the classroom and go and look if you want. (Student B)
How was that different to the science you have been learning about with XXX?
It’s more like you’re up and moving and doing different things rather than just reading about it.
Very good, anything else?
It’s way better now because we get to learn about like problems in the world, you get to share your opinion on how it can be changed, whereas looking in the book isn’t going to do anything
Kind of like nowadays problems like the book might be made quite a while ago as well.
And what did you like doing about the bees XXX?
I think it’s cool because we got to dissect a lily. That was fun because we don’t do anything like that.

Okay pretend I'm going to teach you for science this year. What kind of things would you want me to do? What kind of things would you not want me to do with you?

Like, more experiments definitely.

Yeah.

Yeah.

Yeah, experiments.

Maybe things that would actually be useful in our life.

Okay, like what do you mean useful XXX?

Maybe well it wouldn't be like, well if you were going to study mini-beasts when you were older maybe but maybe like biology or something, I don't know.

Right.

Yeah like more, usually the main thing that we would learn is like biology but it's really fun to learn physics.

Good well done.

Chemistry.

Chemistry, yeah.

Like, there are two types of science I really like, geology and cosmology.

Very good.

Because I love space and stuff.

Okay I am going to write all that down.

Oh yeah, that was so fun.

And what was the point of dissecting a lily?

To see like the pollen. Yeah, the different parts of like how the bees help with the pollen and like…

And like we tied the bees in with our art as well.

I saw them, they're amazing.

It's really fun just learning about them. Like in the garden you like look up close and like see them pollinating and you could see like what you learned in school. You could see their pollen sacs.

I also thought it was cool that there was like a load of species of like bumblebee and solitary bee but there's only one of the honey bee.

Thank you XXX, yes XXX?

We also did what cup could keep the water hot for the longest.

Very good. Did you all do this question?

No, Different questions.

Lots of different questions. Like value for money.

Who decides how you're going to investigate your question?

That was ourselves. When we do science, we go off in our science groups that we do all our experiments with.

Very good. And can you think of doing any investigations like that prior to this where you had to decide your question and you got to decide how to investigate it?

No. We never had to do any of that.

It was kind of like we're going to do this experiment except I'm going to show you and you're going to watch it and then you're going to read about it and then you're going to write stuff down.

I remember one experiment we did, we all just crowded around a table and XXX [teacher] just did the experiment and we were just all, 'yeah'. It was like science wasn't enjoyable.

Case B Extract from focus group interview [Section A].

Pre-Intervention	Post-Intervention
Very good. Okay, do you like science in school? Yeah, sometimes, because I like learning new stuff in science and it's very fun. **Okay like what?** Well my favourite kind would definitely be learning about space. I know loads about space…. And other stuff…. Well I can't really think of the other stuff. **Great thank you, yes XXX.** I like science, because like you can learn different things like, like really different things, like say different ingredients for science and you can learn all about education and all like, all around the world. **Can you tell me more about that?** it's like the volcano thing where you put salt and everything in it and then it comes out. **Brilliant!** And it's like real. **Okay, so XXX is after telling me his favourite science lesson. Anyone else think of their favourite science lesson?** Wait, I want to ask XXX something. **Okay.** So, did you actually make one of those volcano things? (Student A) I done one with my Dad (Student B) **Did you do it in school or with your Dad?** With my Dad only. We made it with blue clay. **Very good! So, can you think about your science *in school?* Okay, in school?** Well sometime, I think we might make slime and I like to make slime. **Did you make slime?** No.	**Okay. We will start off with you XXX, what do you like about school science?** Well you see it's interesting because well you get to do fun experiments; you get to learn about all sort of stuff and this year – we even have to learn about stuff that adults would be doing stuff about. **Like what?** Well global warming and should we kill the red squirrel – should we kill the grey squirrel to save the red squirrel? **Very good.** But I have a plan that doesn't actually require to kill anything. **Well we won't – I'm going to ask you that after this.** Okay **And when you said you like fun experiments, what kind of fun experiments did you like?** Well the ones where we have to test what material slows a car down the most. Experimenting a car on a ramp and some other stuff like the wind turbines or bees, which I'd say everybody loved. **Good. Brilliant. And XXX, what do you like about school science?** What I love about school science is that it's very interesting. And it's very fun and it's also you're learning a lot and I just like it because well it's – it's better than – I think science is better than like maths. **Why do you think that?** Because maths is very boring and science is very fun. **And what's – when you say it's fun, what's fun about it?** Like when we get to test the stuff, it's like – and like all the different type of things like you need to do the science project, it's really fun like playing with – not playing with them sorry – working with them. **Very good well done. And XXXX, what do you like or not like about school science?**

Okay, so I want you to think of something that you *have* done in science, Maybe, think of your favourite science lesson
In school?
In school.
Well I don't think this is science, but it was Halloween last year, we carved out a pumpkin and it was…
Okay.
Well it's like history science.
Kind of. What about XXX, can you think of your favourite science lesson?
In school?
Yeah, in school.
My favourite one was when we were learning about space and all that kind of stuff, because like I said earlier…I love space
Very good.
Well my favourite science lesson was when once we did this where we had a piece of paper and then we were writing down all the different like little insects that we could find outside and what they do and stuff like that. How many legs and like how slimy and stuff they were like that.
Very good.
My favourite bit about science is that like, the same as XXX, when we went outside and looked at all the different animals and stuff.
Very good. And XXX, what was your favourite thing about *school* science?
It was when we were in XXX [teacher's] class we done the plant thing where one plant was out in the sun and one plant was in the cupboard and…
And what happened?
And the one in the cupboard turned orange and the one along the window just turned green.
Very good!
I remember a science lesson now; I know something…
We were doing this thing that; I think it was like an egg and a banana. I think the egg, when we put the egg in… no, it was an orange, sorry. When we put the whole orange in it didn't float, it sunk, but then when we took off a bit it then floated and then we did a thing with a banana. We put the

Like I like it because it's really interesting and I don't know like it's better than history. I don't like history.
And what do you find interesting about it?
Like climate change and all like.
Why did you like that?
Because there's loads of stuff that I didn't know about and all like.
X, tell me, do you like school science?
Yes.
I think science is the fourth best subject because I think that it's maths, then I think it's Irish, then PE, then science.
Very good and what do you like about science?
I like learning about different things like say the body. Say I like learning about the body because if there's something wrong with you then they know what part of the body and then let's say making antidotes say I forgot who discovered antidotes but someone, let's say if you're sick then you could take an antidote let's say for your leg or something and then or let's say if you're on drugs you could take an antidote.
Very good. Well done. What was the science you learned this year, what did you think of that?
Let's say, well we didn't really do science that much let's say in other years but we did science this year. So then other years it might have been a bit different because like there are different things going on like say and like in other classes they might want like say in junior or senior they might want to make science a little bit easier because we're just learning and then let's say this year it was probably a bit harder but not too much.
Very good. Brilliant. XXX, you have something to say?
Well this year you see we you see we never went on science trips any other year but this year we got to go on them. And that's one different thing about science because then we were on science trips and we've also been learning about world crisis's which are different and I think we've done a bit more – and I think we might do well not much I think we might have done a few more experiments.
Okay that's interesting, can you tell me about your favourite science lesson?

whole banana in and it sunk and then we took off the banana skin and then it floated.

Oh! brilliant, thank you. XXX yes what do you think about school science?

I don't like science, because like you write down stuff in your copies and it takes ages.

Okay

Like I like science, all like when we do it at home and stuff like that, but I don't really like it when I do it in school, because we don't really do any like real science. Like we don't really like put potions together and stuff like that and we, it's… like it's really easy to do and we don't like really do anything really hard or anything that's really cool or like sort of like that.

Thanks you XXX, yes XXX.

Well when I heard XXX saying about writing, it reminded me of one of my least favourite things about school – writing. [Laughter]

Writing?

Yeah, well just writing in general anyways, but it would be my least favourite part.

I don't like when we learn about science when we talk about animals, because I just don't really like… because it takes forever.

Okay, thank you very much.

Like, I would like if we did experiments on animals, like different kinds, like ants and all and bees.

The global warming.

Oh interesting. Why did you enjoy that one the most XXX?

Because I thought it was really interesting because I didn't know anything like that before. I didn't know burning coal and stuff was bad for the earth or anything.

Why is it bad for the earth?

it sends all this gas up into the air, called greenhouse gasses. It makes a big huge blanket.

Yes, and what does the blanket do?

It makes the whole world get warmer.

Is that a good thing? I mean I like warm weather, I like the summer.

No. it's not a good thing because it causes more floods from the ice melting in other places. And the polar bears they lose their homes and all

Thank you. XXX what were your favourite science lessons?

Well I have two I liked. Our trip to XXX Park to learn about the bees and global warming like XXXX.

Very good. Why did you like learning about the bees?

Well you see, they're dying off because of insect spray and stuff. The insect spray it's supposed to kill the insects but it also kills off the bees which is what makes it very bad.

Why is it bad?

Because they pollinate, making us new flowers and trees to get rid of the CO_2 for global warming. I planted, my family planted flowers outside our house, lavender and other stuff and in the back garden so that they can get more flowers, meaning that they can pollinate more.

Brilliant.

They're amazing creatures. They way how they speak with body language is amazing and how they make honey, you don't want to know.

Appendix V.1 Sample Focus Group Coding

Case E Extract of coding from focus group interview [Section A].

Sample Coding (for details of codes, see codebook Appendix _)

Previous experience of school science	child-led investigation
Inaccurate perception of school science	Positive attitudes towards science
Real world science	Negative attitude towards science
Scientific inquiry skills	Didactic approaches to science
Outside of school science	Science content knowledge
Limited school science	

Pre-Intervention	Post-Intervention
Think about science in school, you're in 6th class now and you're nearly going into secondary school. So, what do you like about school science? I like experiments. **What kind of experiments?** Explosions. Yeah. **Have you done any explosions in school?** Not yet. No. **No, so think about school science.** Well, we did an after-school club, and we did a chemical reaction called 'elephant's toothpaste'. And it was like… It was meant to shoot into the air but it didn't. Yeah, we used like 5% of the chemical agent instead of 20%. It's like, basically acid. **Okay, very good.** So, it was a chemical reaction. **A chemical reaction, very interesting. So, we won't talk about after school, if we just think about school science, okay?** I feel like it's really good but I don't feel like we do enough experiments. Like, we usually just like look in our books and then like talk about it, I don't feel like we actually like try the stuff we actually learn about. **Okay, good. XXX what do you think, do you agree with XXX?** Yeah, I like it, it sometimes gets a bit boring when we just read the exac same stuff just in different books but I like doing experiments. **Researcher Note:** Conception of science as explosions. Link to previous studies **Multiple codes**	**Can you tell me what you like about science in school and why? So, I don't know if anyone wants to begin?** I liked doing about bees. **Okay, good, tell me why did you like it?** Just because people actually need to start knowing more about that they're going to be extinct and how they help us and stuff. **Good, can you tell me, how do bees help us?** They pollinate flowers and stuff and like they give us honey. **Very good, and we'll just speak about pollination first of all. Why is that important XXX?** It keeps flowers alive and it keeps nature alive. **Very good XXX and how about bees and honey?** They go back with nectar; they go back to their hive. The bees throw up basically in other bees' mouths. And then eventually it gets put into the hexagon of the honeycomb and they seal it over with wax. **Well done. And why did you like that, the bees lesson?** Because it was interesting. **Okay, very good. Okay, we'll move on. What do you like about school science XXX?** I loved the climate change one. **Okay, so tell me about that?** Yeah and we did this critical thing, but it was really interesting to learn about climate change because we don't really do that in school. **Very good.** **Researcher Note:** Part of SSIPSC programme

It's fun because we don't really do much [science] so then it's like kind of a treat for us. Some parts are like fun and oral and other parts are like, you have to do research and work.

Okay. So, thank you XXXX can you think of your favourite science lesson in school?

That we've done already?

That you've done already, yes.

Last year we got three eggs and we put one in vinegar, one in water and one in Fanta and then the one in Fanta started growing mould, and the one with vinegar it was all bouncy.

Very good. Why did you enjoy it?

It was actually really fun and we got to see like what effect like the protein and the keratin had on the egg.

Thank you. That was your favourite as well XXX? anyone have anything different? Yes, XXX, can you think of your favourite science lesson?

Well, it depends on the topic of the science and research.

Okay, good, what do you mean?

We don't really get much writing but if you do then it's not, it doesn't make it as fun. **Yeah, like we often have to write [in science] and it would literally be the thing that we just talked about and then we're just repeating it in writing.**

Okay, anything else you don't like about science.

How little of it we do. Like, we do way more Irish and Maths in a month than we would do science.

Yeah, because like in one day we'd only do like maths, English and Irish and then like there would be a certain day that we do science but then like all the teachers like would sometimes forget where like some things would come up.

Can I just ask, how much science around do you do? Say a week.

We've only done one lesson I think since the start of the year. **We did a workshop, that was really fun (Student B).**

Yeah, that was fun (Student C).

We did a science, forensic workshop (Student B).

Tell me about the forensic science?

> **Researcher Note:** Outside of school teacher

So, it was nice to do something different.

Brilliant.

And like, all the activities that we did with like the bees, all of those are so different to normal science we used to do, so it's really nice to do it.

When you say normal science XXX, what do you mean by that?

Yeah, we just used to like get our books out and like read a page of science and then like talk about like just human body, just…

Like it would be science, it would still be fun but it would be less fun than what we're doing now. Than what we're doing. It's more like kind of interactive and like into groups.

> **Additional Codes:** Hands on science; group work

Very good anyone else?

> SSIPSC Intervention

Oh like I liked the paper towel investigation. We saw how many layers there were and like how much water had been poured on it. And then there was the wind turbines as well where we got to make our own ones in groups. So, that was really fun as well and different.

That's interesting XXX, how was it different?

It was more…We just…It was more like books and reading pages. We didn't really… It was writing stuff down. Read a book for like 15 minutes, kind of talk about it and then it would be… (Student A)

We did do the human body and like she got some, it wasn't really like, I don't know but she got these bodies and like you could take them apart. But like she just put them in the class and like we wouldn't actually like look at it as a class. We just would sit at the back of the classroom and go and look if you want. (Student B)

Ya this science, It's more like you're up and moving and doing different things rather than just reading about it (Student A).

> **Researcher note:** Correlate with teacher interview

Very good, anything else?

It's way better now because we get to learn about like problems in the world, you get to share your opinion on how it can be changed, whereas looking in the book isn't going to do anything

A guy came in to do it (Student C).
It was like a treat for us (Student B).
Okay pretend I'm going to teach you for science this year. What kind of things would you want me to do? What kind of things would you not want me to do with you?
Like, more experiments definitely (Student E).
Yeah (Student B).
Yeah (Student C).
Yeah, experiments (Student D).
Maybe things that would actually be useful in our life (Student A).
Okay, like what do you mean useful XXX?
Maybe well it wouldn't be like, well if you were going to study mini-beasts when you were older maybe but maybe like biology or something, I don't know.
Right.
Yeah like more, usually the main thing that we would learn is like biology **but it's really fun to learn physics.**
Good well done.
Chemistry.
Chemistry, yeah.
Like, there are two types of science I really like, geology and cosmology.
Very good.
Because I love space and stuff.
Okay I am going to write all that down.

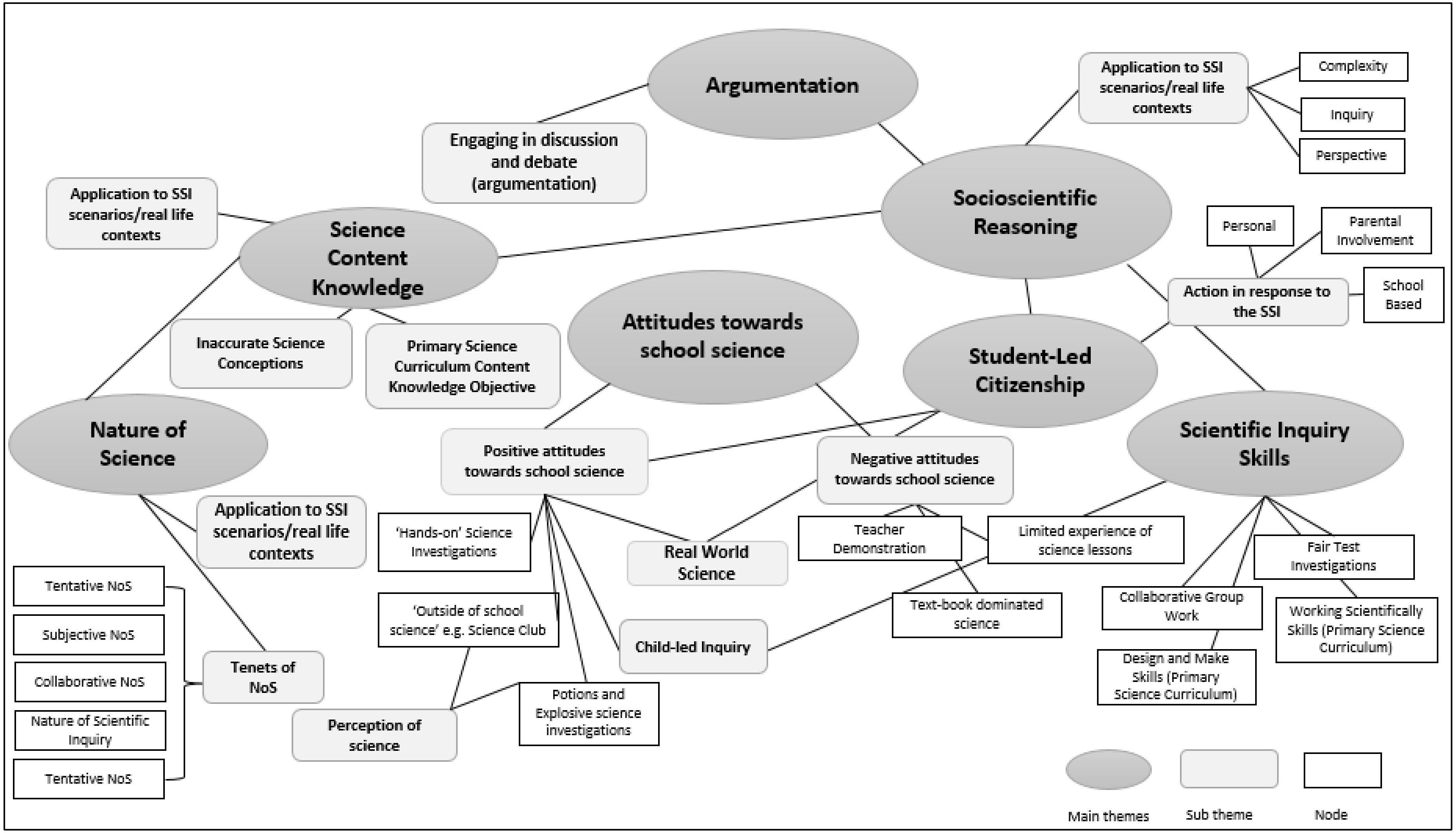
Researcher Note:
Teacher data corroborates this child-led approach

. Kind of like nowadays problems like the book might be made quite a while ago as well. Like the bees isn't in our book.
And what did you like doing about the bees XXX?
I think it's cool because we got to dissect a lily. That was fun because we don't do anything like that (Student D).
Oh yeah, that was so fun (Student E).
And what was the point of dissecting a lily?

Researcher note:
Cross curricular

To see like the pollen. Yeah, the different parts of like how the bees help with the pollen and like...And like we tied the bees in with our art as well.
I saw them, they're amazing.
It's really fun just learning about them. Like in the garden you like look up close and like see them pollinating and you could see like what you learned in school. You could see their pollen sacs.
I also thought it was cool that there was like a load of species of like bumblebee and solitary bee but there's only one of the honey bee.
Thank you XXX, yes XXX?
We also did what cup could keep the water hot for the longest.
Very good. Did you all do this question?
No, Different questions.
Lots of different questions. Like value for money.
Who decides how you're going to investigate your question?
That was ourselves. When we do science, we go off in our science groups that we do all our experiments with.
Very good. And can you think of doing any investigations like that prior to this where you had to decide your question and you got to decide how to investigate it?
No. We never had to do any of that.
It was kind of like we're going to do this experiment except I'm going to show you and you're going to watch it and then you're going to read about it and then you're going to write stuff down.
I remember one experiment we did, we all just crowded around a table and XXX [teacher] just did the experiment and we were just all, 'yeah'. It was like science wasn't enjoyable.

Appendix W Thematic Analysis Map



Appendix X NVivo Codebook

Phase 2: Generating Initial Codes

Phase 2: Generating initial codes	Code Definitions for Coding Consistency (Rules for Inclusion)	No. of Sources	Units of Meaning Coded
Inaccurate perceptions of school science	Inaccurate perceptions of what school science is including references to science at home, science in after school clubs, explosions.	7	18
Attitudes towards school	Evidence of student attitudes towards school.	16	20
Positive Attitudes towards school science	Student(s)/teacher(s) make reference to the positive aspects of school science (content and pedagogies).	20	92
'Easy' science lessons	Students would like science lessons that are more challenging.	3	8
Field trip	Reference students made to going outside of school grounds on a science related field trip.	1	4
Non-science lesson	Lessons that are not science lessons (e.g. Carving pumpkins, geography lessons).	3	6
Limited experience of science	Students make reference to a lack of science lessons.	5	10
SSIPSC lessons	Description of science lessons associated with the SSIPSC intervention.	13	29
Collaborative group work	Sharing ideas and working collaboratively during science lessons.	7	10
Student questioning	Asking questions that can be answered using a scientific inquiry.	8	35
Design and make Skills	Reference to a lesson where students engaged in a design and make activity. Design and make as defined by the Irish primary science curriculum (DES, 1999a).	9	32
Estimating and measuring	Use measuring equipment to make estimations and take measurements in an inquiry/investigation.	6	15
Fair test investigations	Ensuring the investigation is carried out in a fair and reliable manner.	6	28
Analysing	Using the information from the data collected in an investigation/research activity to make deductions	3	4
Investigating and experimenting	Deciding on the method and equipment to use when carrying out an inquiry/investigation/experiment.	8	55
Observation	Using the senses to make observations of an inquiry.	7	12

Phase 2: Generating initial codes	Code Definitions for Coding Consistency (Rules for Inclusion)	No. of Sources	Units of Meaning Coded
Prediction	Using prior knowledge to suggest what will happen in an inquiry/investigation/experiment.	4	6
Recording and communicating	Using tables/notes/graphs and other means to record and communicate findings.	7	14
Bees and economic	Students consider the economic perspective the of bee SSI scenario.	4	6
Bees informed conceptions	Student demonstrates Informed conception of the role of bees (e.g. pollination and honey).	8	16
Bees limited understanding	Student demonstrates limited understanding of the purpose of bees related to the production of honey.	7	8
Bees additional evidence	Student request for additional evidence pertaining to the SSI bee scenario.	8	10
Bees possible solution	Students consider alternative solutions to the bee scenario.	3	11
Sources of carbon emissions	Students make reference to sources of carbon emissions.	10	28
Solution carbon emissions	Suggestions to reduce carbon emissions provided.	8	18
Climate change additional evidence	Student request for additional evidence pertaining to SSI scenario on energy and climate change.	5	7
Wind farms	Construction of wind farms suggested as a solution to reducing carbon emission production in Ireland.	6	11
Disadvantages wind farm	Reference to disadvantages associated with wind energy including location, noise pollution, environmental impact.	5	8
Development of scientific content knowledge	Student and/or teacher discussions of SSI scenarios and science lessons that made reference to accurate scientific content knowledge.	12	84
Inaccurate science conceptions	Students make reference to inaccurate scientific content knowledge.	15	114
Discussion	Students/teachers describe how they engaged in discussions pertaining to science related issues.	11	22
Collaborative NoS	Scientists work collaboratively; share ideas and results.	10	7
Scientists DO NOT work collaboratively	Scientists work individually; do not share ideas or results.	6	8
Creativity	Students/scientists use their creativity when devising a hypothesis/investigation.	10	32
No one scientific method	There is no single investigation procedure to answer investigation questions.	8	23

Phase 2: Generating initial codes	Code Definitions for Coding Consistency (Rules for Inclusion)	No. of Sources	Units of Meaning Coded
Subjective NoS	Scientists' work and beliefs are impacted by previous knowledge and experience. Observations are affected by social factors.	6	11
Tentative NoS	Scientific knowledge is tentative/developmental and subject to change.	8	16
Parental involvement	Parental involvement in school science e.g. communicating findings.	8	10
Relevance to students' everyday lives	Students/teachers make reference to the connection of school science to their everyday lives and/or make reference to the importance of science in their everyday lives.	10	42
Connection to role of scientist	Reference made between school science and the role of scientists.	3	4
Child-led Investigations	Students make reference to science lessons where they devised investigation question and/or devised the investigation method (child-led inquiry).	13	57
Completion of worksheets/workbooks	Students complete workbooks; recall, question and answer, fill in the blanks.	10	21
Hands on activities prescribed by the teacher	Teacher directs the science lesson and the students follow the teachers' directions.	17	32
Teacher demonstration	Teachers conduct the investigation and students observe.	5	12
Teacher explaining facts	Teacher explains information to the students.	7	13
Taking action	Students take action in response to a socioscientific issue.	14	20

Phase 3 Searching for Themes (Developing Categories)

Phase 3: Searching for Themes	Code Definitions for Coding Consistency (Rules for Inclusion)	No. of Sources	Units of Meaning Coded
Science content knowledge	**Student reference to accurate and inaccurate science content knowledge.**	**19**	**198**
Development of scientific content knowledge	Student discussions of SSI scenarios and science lessons that made reference to accurate scientific content knowledge.	12	84
Inaccurate science conceptions	Students make reference to inaccurate scientific content knowledge.	15	114
Science skills	**Student/teacher description of science lessons where students explicitly referred to a broad range of**	**18**	**211**

Phase 3: Searching for Themes	Code Definitions for Coding Consistency (Rules for Inclusion)	No. of Sources	Units of Meaning Coded
	scientific skills; e.g. questioning, observing, predicting, communicating.		
Collaborative Group Work	Sharing ideas and working collaboratively during science lessons.	7	10
Student Questioning	Asking questions that can be answered using a scientific inquiry.	8	35
Design and Make Skills	Reference to a lesson where students engaged in a design and make activity. Design and make as defined by the Irish primary science curriculum (DES, 1999a).	9	32
Estimating and Measuring	Using senses and measuring equipment to make observations about the inquiry/investigation.	6	15
Fair test investigations	Ensuring the investigation is carried out in a fair and reliable manner.	6	28
Analysing	Using the information from the data collected in an investigation/research activity to say what you found out.	3	4
Investigating and Experimenting	Deciding on the method and equipment to use when carrying out and inquiry.	8	55
Observation	Using the senses to make observations of an inquiry.	7	12
Prediction	Using prior knowledge to suggest what will happen in an inquiry/investigation/experiment.	4	6
Recording & Communicating	Using tables/notes/graphs and other means to record and communicate findings.	7	14
Nature of Science	**Student reference to tenets of NoS including**	**10**	**101**
Collaborative NoS	Students/scientists work collaboratively; share ideas and results.	10	7
Scientists DO NOT work collaboratively	Scientists work individually; do not share ideas or results.	6	8
Creativity	Students/scientists use their creativity when devising hypothesis/investigations.	10	32
No one scientific method	There is no single investigation procedure to answer investigation questions.	8	23
Subjective NoS	Scientists work and beliefs are impacted by previous knowledge and experience. Observations are affected by social factors.	6	11

Phase 3: Searching for Themes	Code Definitions for Coding Consistency (Rules for Inclusion)	No. of Sources	Units of Meaning Coded
Tentative NoS	Scientific knowledge is tentative and subject to change.	8	16
Connection to role of scientist	Reference made between school science and the role of scientists.	3	4
Argumentation	**Student/teacher attitudes towards engaging in argumentation pertaining to socioscientific issues.**	**11**	**22**
Attitudes towards school	**Evidence of student attitudes towards school.**	**16**	**20**
Attitudes towards school science	**Student/teacher reference to student attitude towards school science.**	**20**	**344**
Inaccurate perceptions of school science	Inaccurate perceptions of what school science is including references to science at home, science in after school clubs, explosions.	7	18
'Easy' science lessons	Students would like science lessons that are more challenging.	3	8
Field trip	Reference students made to going outside of school grounds on a science related field trip.	1	4
Non-science lesson	Lessons that are not science lessons (e.g. Carving pumpkins, geography lessons).	3	6
Limited experience of science	Students make reference to limited number of science lessons.	5	10
Teacher demonstration	Teachers conduct the investigation and students observe.	5	12
Teacher explaining facts	Teacher explains information to the students.	7	13
Completion of worksheets/workbooks	Students complete workbooks; recall, question and answer, fill in the blanks.	10	21
Positive Attitudes towards school science	Student(s)/teacher(s) make reference to the positive aspects of school science (content and pedagogies).	20	92
SSIPSC lessons	Description of science lessons associated with the SSIPSC intervention.	13	29
Child-led Investigations	Students make reference to science lessons where they devised investigation question and/or devised the investigation procedure.	13	57
Hands on activities prescribed by the teacher	Teacher directs the science lesson and the students follow the teachers' directions.	17	32
Relevance to students' everyday lives	Students/teachers make reference to the connection of school science to their everyday lives and/or recognise the importance of science in their everyday lives.	10	42

Phase 3: Searching for Themes	Code Definitions for Coding Consistency (Rules for Inclusion)	No. of Sources	Units of Meaning Coded
Bee SSI Scenario	**Reference student made to the bee SSI scenario in terms of socioscientific reasoning competencies.**	**13**	**51**
Bees and economic	Students consider the economic perspective the bee scenario.	4	6
Bees informed conceptions	Student demonstrates Informed conception of the role of bees (e.g. pollination and honey).	8	16
Bees limited understanding	Student demonstrates limited understanding of the purpose of bees related to the production of honey.	7	8
Bees additional evidence	Student request or additional evidence pertaining to the SSI bee scenario.	8	10
Bees possible solution	Students consider alternative solutions to the bee scenario.	3	11
Climate Change	**Reference student made to the climate change SSI scenario in terms of socioscientific reasoning competencies.**	**12**	**65**
Causes of climate change	Students make reference to carbon emissions and climate change including source of carbon emissions. This includes inaccurate concepts of what causes climate change.	10	28
Solution carbon emissions	Suggestions to reduce carbon emissions provided.	8	18
Wind farms	Construction of wind farms suggested as a solution to reducing carbon emission in Ireland.	6	11
Disadvantages wind farm	Reference to disadvantages associated with wind energy including location, noise pollution, environmental impact.	5	8
Taking Action	**Taking action in responses to the SSI.**	**14**	**30**
Parental involvement	Parental involvement in science lessons e.g. communicating findings.	8	10
Taking Action	Students take action in response to a socioscientific issue.	14	20

Phase 4 Reviewing Themes (Drilling Down)

Phase 4: Coding (Drilling down)	Description	No. of Sources	Units of Meaning Coded
Science content knowledge	**Student/teacher reference to accurate and inaccurate science content knowledge.**	**19**	**198**
Development of Science Content Knowledge	Evidence of student development of scientific content knowledge. References made by	12	84

Phase 4: Coding (Drilling down)	Description	No. of Sources	Units of Meaning Coded
	teacher/s regarding development of student scientific content knowledge also included.		
Inaccurate Science Conceptions	Student/teacher reference to inaccurate science conceptions in the context of describing science lessons and discussing the SSI scenarios.	15	114
Development of NoS Conceptions	**Student/teacher reference to the tenets of Nos including (i) Tentative NoS, (ii) Creative NoS, (iii) Subjective NoS, (iv) Nature of Scientific Inquiry, (v) Collaborative NoS.**	**10**	**101**
Student experience and impact of Inquiry Based Science Education (IBSE)	**Evidence of student experience of IBSE. Student descriptions of science lessons analysed in terms of an inquiry based approach namely student-directed investigations, student devising investigation question and investigative procedure.**	**13**	**94**
Scientific inquiry skill development	**Reference to student development of scientific skills when discussing and describing science lessons. Skills include those in the Irish Primary Science Curriculum (DES, 1999a): Observation, questioning, prediction, investigating and experimenting, estimating and measuring, analysing, recording and communicating.**	**18**	**211**
Argumentation	**Reference to student/teacher experience of argumentation as a science pedagogy.**	**11**	**22**
Socioscientific Reasoning Competencies	**Evidence of relationships between the Socioscientific Reasoning constructs ('appreciation of the complexity of the SSI', 'approaching the SSI from multiple perspectives', and 'the value of ongoing inquiry') and the other scientific literacy constructs.**	**14**	**94**
'Appreciation of the complexity of the SSI' and science content knowledge	Reference to science content knowledge when discussing the complexity of the SSI scenarios of (i) Bees and Biodiversity and (ii) Wind energy. The relationship between accurate/inaccurate science content knowledge and the 'appreciation of the complexity of the SSI' sub-construct also included here.	14	52
'Approaching the SSI from multiple perspective' and argumentation	Reference to different perspectives (e.g. social, environmental, economic) of the SSI scenarios, (i) Bees and Biodiversity and (ii) Wind Energy.	9	25

Phase 4: Coding (Drilling down)	Description	No. of Sources	Units of Meaning Coded
Value of ongoing inquiry and IBSE	Reference to the necessity of inquiry to gather further evidence (social and/or scientific) evidence in relation to the SSI scenario (i) Bees and Biodiversity and (ii) Wind energy. Includes reference students make to inquiry skills, for example the need to gather fair and reliable evidence prior to making a decision pertaining to a SSI.	8	17
Student-Led Citizenship	**Evidence of action the student-led action undertaken by the students in response to the SSI.**	**12**	**32**
Personal student-led action	Action the students took in response to a SSI at a personal level.	8	14
School level action	Action the students took in response to a SSI at school level.	6	6
Community level action	Action the students took at home and in their community in response to the SSI. This includes parental/guardian involvement.	12	12
Student attitudes towards school science	**Evidence of student attitudes towards school science.**	**20**	**238**
Positive attitudes towards school science	Teacher/student evidence of and reference to enjoyment/engagement of school science.	20	121
Negative attitudes towards science	Reference to content/pedagogies that the students do not enjoy. Includes for example teacher demonstration, completion of worksheets, limited experience of school science.	9	51
Perception of school science	Evidence of student perception of school science in terms of relevance to their lives/future careers. Also includes inaccurate perceptions of school science, for examples 'potions' and 'explosions' and student confusion between 'school science' and 'outside of school science'.	20	66
Student attitudes towards school	**Positive/negative reference students make regarding school.**	**16**	**20**

Phase 5 Defining and Naming Themes (Data Reduction)

Phase 5: Defining and naming themes	Description	No. of Sources	Units of Meaning Coded
1. Development of Student Science Content Knowledge	**Student/teacher reference to the development of science content knowledge in the context of describing science lessons and discussing the SSI scenarios. Included here is reference to accurate/inaccurate science conceptions.**	**19**	**198**
2. Development of Student Conceptions of NoS Understanding	**Student/teacher reference to, and application of, the tenets of Nos including (i) Tentative NoS, (ii) Creative NoS, (iii) Subjective NoS, (iv) Nature of Scientific Inquiry, (v) Collaborative NoS when discussing and negotiating the SSI scenarios.**	**10**	**101**
3. Student experience of Inquiry Based Science Education (IBSE) and development of Scientific Inquiry Skills.	**Evidence of student experience of IBSE including teachers experience of teaching through IBSE. Reference to student development of scientific skills when discussing and describing science lessons. Skills include those in the Irish Primary Science Curriculum (DES, 1999a): Observation, questioning, prediction, investigating and experimenting, estimating and measuring, analysing, recording and communicating.**	**18**	**305**
4. Student and teacher attitudes towards Argumentation	**Students' and teachers' attitudes towards argumentation as a pedagogical approach in science lessons.**	**11**	**22**
5. Development of Student Socioscientific Reasoning Competencies	**Evidence of relationships between the Socioscientific Reasoning constructs ('appreciation of the complexity of the SSI', 'approaching the SSI from multiple perspectives', and 'the value of ongoing inquiry') and the other scientific literacy constructs when discussing the SSI scenarios of (i) Bees and Biodiversity and (ii) Wind energy.**	**14**	**94**
6. Student-Led Citizenship	**Evidence of the student-led action undertaken by the students in response to the SSI at a personal, school and community level.**	**12**	**32**
7. Student attitudes towards school and school science	**Teacher/student reference to school and school science including the content/pedagogies that the students enjoy/do not enjoy. Evidence of student perceptions of school science included here.**	**20**	**258**

Appendix Y DCU Ethical Approval

Ollscoil Chathair Bhaile Átha Cliath
Dublin City University

Ms Nicola Broderick

School of STEM Education, Innovation and Global Studies

27th November 2018

REC Reference: **DCUREC/2018/184**

Proposal Title: **Developing children's scientific literacy through real world science**

Applicant(s): **Ms Nicola Broderick, Dr Cliona Murphy**

Dear Nicola,

Further to expedited review, the DCU Research Ethics Committee approves this research proposal.

Materials used to recruit participants should note that ethical approval for this project has been obtained from the Dublin City University Research Ethics Committee.

Should substantial modifications to the research protocol be required at a later stage, a further amendment submission should be made to the REC.

Yours sincerely,

Donal O' Gorman

Dr Dónal O'Gorman

Chairperson

DCU Research Ethics Committee

DCU Research & Innovation

Appendix Z Plain Language Statement and Informed Consent Form (Principal/Board of Management)

School of STEM Education, Innovation and Global Studies,

Institute of Education,

Dublin City University,

St. Patrick's Campus,

Dublin 9.

Dear _______________,

My name is Nicola Broderick and I am completing a research project as part of my Doctorate of Education, under the supervision of Dr. Cliona Murphy, lecturer in primary science education, DCU. This research project will explore whether the teaching of primary science through everyday science-related issues has an impact on children's understanding of science, their development of scientific inquiry skills, and their attitudes towards science. This research project will explore the effects of teaching the primary science curriculum through science-related issues, over a six-month period from November 2018 to April 2019. It is hoped that that this project will have a positive impact on children's learning and interest in science.

Pending Principal/Board of Management consent, information for this research will be gathered via children's questionnaires and focus group interviews which the children will be invited to complete/take part in. Having sought parent/guardian consent and child assent, the teachers will be asked to administer the questionnaires to the children in their classes in November 2018 and again in April 2019. These questionnaires will be in paper format and will take no longer than twenty minutes to complete. The teacher will also be asked to administer a practical science skill assessment to five randomly selected children which will take no longer than 20 minutes. Having sought parent/guardian consent and child assent, four/five children will be randomly invited to participate in a group interview in XXXX N.S. in November 2018 and again in April 2019. In this group interview, I will ask the children questions about their interest in science and their opinions on different every day scientific issues.

The teachers will be given the option to complete a reflective journal throughout the six-month period. They will be invited to give me the reflective journal, for research purposes, at the end of the research project. Teachers will also be invited to participate in an interview in XXXX N.S. in April 2019 to elicit their perceptions of the impact of the science-related issues on children's learning and interest in science.

Children's questionnaires will be anonymous. Teacher reflective journals will be anonymised. Both the children's focus group interviews and teacher interviews will be audio recorded and once the conversations are transcribed and anonymised, these recordings will be deleted. The questionnaires, transcripts and teacher reflective journals will be stored safely in my office in DCU and will be used for research purposes only. You are welcome to receive feedback on the project on its completion. In any reports of the project, individual children's names, teacher's names or the school's name will not be used to safeguard anonymity.

Involvement in this research is voluntary. Teachers may volunteer to participate in the interview, or complete a reflective journal but are under no obligation to do so. Furthermore, teachers may withdraw from the research project at any point. Pending parent/guardian consent and prior to the research being carried out, the participating children will be provided with full details about the research and will be informed that participation in the research is voluntary. Each child will then be asked to give their oral assent to participate in the research. As the research is exploring classroom practice, there is no risk anticipated as a result of participation in this study.

If you wish to ask further questions about the research, please contact the principal investigator: Nicola Broderick, School of STEM Education, Innovation and Global Studies, Institute of Education, Dublin City University, Dublin 9. **Tel:** 01 884 2213 **Mob:** 0861018150 **Email:** nicola.broderick@dcu.ie

If participants have concerns about this study and wish to contact an independent person, they can contact: The Secretary, Dublin City University Research Ethics Committee, c/o Research and Innovation Support, Dublin City University, Dublin 9. Tel 01-7008000, e-mail rec@dcu.ie

If participants have concerns about Data Protection, they can contact: Mr. Martin Ward, Dublin City University Data Protection Officer. Tel 01-7005118/01-7008257. Email data.protection@dcu.ie

If you are happy for XXX and her class to participate in this research project, please complete the attached Informed Consent Form and return in the SAE. I will then arrange a time to meet with XXXX to discuss the project further.

Best wishes,

Nicola Broderick

DUBLIN CITY UNIVERSITY

Informed Consent Form for Principal/Board of Management

- **Research Study Title:** Developing children's learning and interest in science through science-related issues.
  University: Institute of Education, Dublin City University.

  Investigator: Nicola Broderick

II. Clarification of the purpose of the research

To explore whether the teaching of primary science through everyday science-related issues has an impact on their children's learning and interest in science.

III. Confirmation of particular requirements as highlighted in the Plain Language Statement

Participant – please complete the following (Circle Yes or No for each question)

I have read the Plain Language Statement. Yes/No
I understand the information provided. Yes/No
I have had an opportunity to ask questions and discuss this study. Yes/No
I have received satisfactory answers to all my questions. Yes/No
I am happy for my school to participate in this research Yes/No
I am aware that children's focus group interviews will be conducted on the school grounds. Yes/No
I am aware that the teacher interview will be conducted on the school grounds. Yes/No

IV. Confirmation that involvement in the Research Study is voluntary

Participating school, teachers and children may withdraw from the Research Study at any point without penalty.

V. Advice as to arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations

Only the investigator and her supervisor will have access to the data, which will be password-protected and stored securely on-site in DCU St. Patrick's Campus. The identity of the school, teacher/s and children will be protected; they will not be identified in any write up of the research. All information gathered will be safely disposed of five years after the completion of the project.

VII. Signature:

Name of School: ____

Name of teacher who is participating in this research project:

DCU
Ollscoil Chathair
Bhaile Átha Cliath
Dublin City University

Appendix AA Plain Language Statement and Informed Consent Form (Teacher)

Dear Teacher,

My name is Nicola Broderick and I am completing a research project as part of my Doctorate of Education, under the supervision of Dr. Cliona Murphy, lecturer in primary science education, DCU. This research project will explore whether the teaching of primary science through everyday science-related issues has an impact on children's understanding of science, their development of scientific inquiry skills, and their attitudes towards science. This research project will explore the effects of teaching the primary science curriculum through science-related issues, over a six-month period from November 2018 to April 2019. It is hoped that that this project will have a positive impact on children's learning and interest in science.

Information for this research will be gathered via children's questionnaires, practical science skill assessment and focus group interviews which the children will be invited to complete/take part in. Having sought and granted parent/guardian consent and child assent, the teachers will be asked to administer the questionnaires to the children in their classes in November 2018 and again in April 2019. These questionnaires will be in paper format and will take no longer than twenty minutes to complete. Teachers will also be asked to administer a practical science skill assessment to five randomly selected children which will take no longer than thirty minutes to complete in November 2018 and again in April. Having sought and granted parent/guardian consent and child assent, four/five children will be randomly invited to participate in a group interview, in November 2018 and again in April 2019. In this group interview, I will ask the children questions about their interest in science and their opinions on different every day scientific issues.

The teachers will be given the option to complete a reflective journal throughout the six-month period. They will be invited to give me the reflective journal, for research purposes, at the end of the research project. Teachers will also be invited to participate in an interview in April 2019 to elicit their perceptions of the impact of the science-related issues on children's learning and interest in science.

Children's questionnaires will be anonymous. Teacher reflective journals will be anonymised. Both the children's focus group interviews and teacher interviews will be audio recorded and once conversations have been transcribed and anonymised, these recordings will be deleted. The questionnaires, transcripts and teacher reflective journals will be stored safely in my office in DCU and will be used for research purposes only. You are welcome to receive feedback on the project on its completion. In any reports of the project, individual children's names, teacher's names or the school's name will not be used to safeguard anonymity.

Involvement in this research is voluntary. Teachers may volunteer to participate in the interview, or complete a reflective journal but are under no obligation to do so. Furthermore, teachers may withdraw from the research project at any point. Pending parent/guardian consent and prior to the research being carried out, the participating children will be provided with full details about the research and will be informed that participation in the research is voluntary. Each child will then be asked to give their oral assent to participate in the research. As the research is exploring classroom practice, there is no risk anticipated as a result of participation in this study.

If you wish to ask further questions about the research, please contact the principal investigator: Nicola Broderick, School of STEM Education, Innovation and Global Studies, Institute of Education, Dublin City University, Dublin 9. **Tel:** 01 884 2213 **Mob:** 0861018150 **Email:** nicola.broderick@dcu.ie

If you have concerns about this study and wish to contact an independent person, you can contact: The Secretary, Dublin City University Research Ethics Committee, c/o Dublin City University, Dublin 9. Tel 01-7008000, e-mail rec@dcu.ie

If you have concerns about data protection, you can contact: Mr. Martin Ward, Dublin City University Data Protection Officer. Tel 01-7005118/01-7008257. Email data.protection@dcu.ie

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DUBLIN CITY UNIVERSITY

Informed Consent Form (Teachers)

I Research Study Title: Developing children's learning and interest in science through science related issues

University: Institute of Education, Dublin City University.

Investigator: Nicola Broderick

II. Clarification of the purpose of the research

To explore whether the teaching of primary science through everyday science-related issues has an impact on children's learning and interest in science.

III. Confirmation of particular requirements as highlighted in the Plain Language Statement

Participant – please complete the following (Circle Yes or No for each question)

I have read the Plain Language Statement (or had it read to me).	Yes/No
I understand the information provided.	Yes/No
I have had an opportunity to ask questions and discuss this study.	Yes/No
I have received satisfactory answers to all my questions.	Yes/No
I am happy to take part in this research project.	Yes/No
I agree to participate in a teacher interview in April 2019.	Yes/No
I am aware that this interview will be audio recorded.	Yes/No

IV. Confirmation that involvement in the Research Study is voluntary

I may withdraw from the Research Study at any point without penalty.

V. Advice as to arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations

Only the investigator and her supervisor will have access to the data, which will be password-protected and stored securely on-site in DCU St. Patrick's Campus. The identity of the school, teacher and the children will be protected; they will not be identified in any write up of the research. I am aware that the confidentiality of information provided can only be protected within the limitations of the law. All information gathered will be safely disposed of five years after the completion of the project.

VII. Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project

Participant's Signature: ________________________Date: ________

Appendix BB Plain Language Statement and Informed Consent Form (Parent)

Dear Parent/Guardian,

My Name is Nicola Broderick and I work in Primary Science Education in the Institute of Education, DCU. I am planning a research project under the supervision of Dr. Cliona Murphy, lecturer in primary science education DCU, and I am seeking the support of you and your child. The aim of this project is to improve children's learning and interest in science by teaching the primary science curriculum through everyday science-related issues that are relevant to the children's lives.

The class teacher will teach the primary science curriculum through everyday science-related issues, over a six-month period from November 2018 to April 2019. As part of this study the class teacher will distribute a questionnaire to the children in her/his class in November 2018 and again in April 2019, pending parent/guardian consent and child assent. The teacher will also administer a practical skill assessment to a random group of five children in November 2018 and again in April 2019, pending parent/guardian consent and child assent. The teacher will randomly invite a group of four/five children to participate in a group interview at the beginning of this project, November 2018 and at the end of the project, April 2019, pending parent/guardian consent and child assent. In this group interview, I will ask the children questions about their interest in science and their opinions on different every day scientific issues. I will record the interview so that it is easy to type up the interview afterwards. I will keep the questionnaires and transcripts safely in my office in DCU and the information will be used for research purposes only.

We hope that the children's learning and interest in science will improve as a result of participating in this study. You are welcome to receive feedback on the project on its completion. In any reports of the project, individual children's names or the school names will not be used to safeguard anonymity.

Involvement in this research is voluntary. Your child may volunteer to complete the questionnaire and to participate in the practical skill assessment and group interview but is under no obligation to do so. Furthermore, your child may withdraw from the research at any point. If your child choses to opt out of the research this will have no impact on their relationship with their teacher and /or school. Prior to the research being carried out your child will be provided with full details about the research and will be asked to complete an informed assent form. As the research is exploring classroom practice, there is no risk anticipated as a result of participation in this study.

If you wish to ask further questions about the research, please contact the principal investigator: Nicola Broderick, School of STEM Education, Innovation and Global Studies, Institute of Education, Dublin City University, Dublin 9. **Tel:** 01 884 2213 **Mob:** 0861018150 **Email:** nicola.broderick@dcu.ie

1. Your child does not have to participate in the group interview or questionnaire.
2. Your child can choose to withdraw from the interview at any time.
3. You can request that your child/ your child's data be withdrawn from the study at any time.

If you have concerns about this study and wish to contact an independent person, you can contact: The Secretary, Dublin City University Research Ethics Committee, c/o Research and Innovation Support, Dublin City University, Dublin 9. Tel 01-7008000, e-mail rec@dcu.ie

If you have concerns about Data Protection, you can contact: Mr. Martin Ward, Dublin City University Data Protection Officer. Tel 01-7005118/01-7008257. Email data.protection@dcu.ie

DUBLIN CITY UNIVERSITY

Informed Consent Form (Parent/Guardian)

Research Study Title: Developing children's learning and interest in science through science-related issues.
University: Institute of Education, Dublin City University. **Investigator:** Nicola Broderick

II. Clarification of the purpose of the research

To explore whether the teaching of primary science through everyday science-related issues has an impact on children's learning and interest in science.

III. Confirmation of particular requirements as highlighted in the Plain Language Statement

Participant – please complete the following (Circle Yes or No for each question)

I have read the Plain Language Statement (or had it read to me). Yes/No
I understand the information provided. Yes/No
I have had an opportunity to ask questions and discuss this study. Yes/No
I have received satisfactory answers to all my questions. Yes/No
I consent for my child to complete a questionnaire in school about his/her science lessons Yes/No
I consent for my child to participate in a group interview in school about his/her science lessons Yes/No
I consent for my child to complete a science practical skill assessment. Yes/No
I am aware that my child's interview will be audiotaped. Yes/No

IV. Confirmation that involvement in the Research Study is voluntary

Your child may withdraw from the Research Study at any point without penalty.

V. Advice as to arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations

Only the investigator and her supervisor will have access to the data, which will be password-protected and stored securely on-site in DCU St. Patrick's Campus. The identity of the school, teachers and children will be protected; they will not be identified in any write up of the research. I am aware that the confidentiality of information provided can only be protected within the limitations of the law. All information gathered will be safely disposed within five years of completion of the project.

VII. Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent for my child to take part in this research project

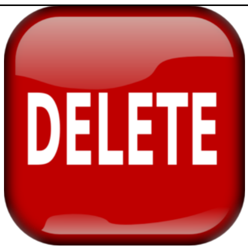
Participant's Signature: _____________**Name in Block Capitals:**_________________

Date: _____________

Appendix CC Plain Language Statement and Informed Consent Form (Child)

Plain Language Statement for the participating children (This will be read with the target participants) We would like to do some research about science in school but we need your permission to do this.

	Research helps us find out new things and test new ideas. First we ask a question and then we try to find the answer.
	We are looking for 3^{rd}, 4^{th}, 5^{th} & 6^{th} class children to take part in this research. Would you like to take part in this research where you will get a chance to tell me what you think about science in school?
	To find out what you think about science, you will be asked to fill out a questionnaire. This will take about 20 minutes to do. There are two questionnaires, one in November 2018 and one in April 2019. Your teacher will help you read the questions.
	To find out what you think about the project, you will be asked to join in a group interview with four other children in your class. It will last about 15 – 20 minutes. During this group interview, I will ask you questions about your experience of learning science in school. This is not a test! You may also be asked to complete a science investigation, one in November 2018 and one in April 2019.

	To help us remember what you say we will record the group discussion. This recording will only be used for our research.
	If you do not feel comfortable taking part in this research, you do not have to. It is completely up to you. If you start the group interview but do not want to continue, I will stop straight away. You will be allowed to return to class and you won't have to take part after that.
	We will write about the results from this research but we will never use your name.
	We will keep the questionnaires in a locked cabinet in my office in DCU. We will keep all electronic information in a folder on a computer in DCU which is password protected.
	We will keep the information for five years. After this we will safely destroy the information.

DUBLIN CITY UNIVERSITY

Informed Assent Form (Participating Children)

What is the aim of this research?

The aim of this research is to find out what children learn about science in school.

What will I have to do for this research?

This research involves me filling in two questionnaires, completing two science investigations and taking part in a group interview with four other children in my class about what I think about school science.

What happens to the information I give?

All the information will only be used for this research. I know that my name will not be used in any of the research. All the information will be kept safely in DCU by the researchers.

If I change my mind:

I know that I do not have to take part in this study and that if I do, I can change my mind and decide not to take part in this research at any time. It is okay if I do not want to take part in the research.

Please complete the following: (Circle Yes or No for each question)

I read or my teacher read to me the information about the research.	Yes/No
I understand what the teacher explained to me.	Yes/No
I could ask the teacher questions about the research.	Yes/No
I am happy with the answers the teacher gave me.	Yes/No
I would like to take part in this research project.	Yes/No
I know that I can stop at any time.	Yes/No

Children's Signature: ____

Name in Block Capitals: ____

Witness: ____