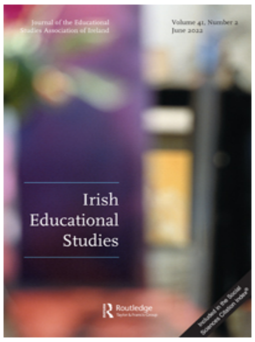

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Teachers' experience of inquiry into socioscientific issues in the Irish lower secondary science curriculum

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The Irish lower secondary science curriculum emphasises the development of scientific literacy through the use of inquiry teaching and learning approaches. The Science in Society Investigation assessment in this curriculum requires students to carry out inquiry into socioscientific issues (SSI). This research presents two case studies exploring how teachers used inquiry in the context of SSI for the development of students' skills and knowledge. There were differences in the pedagogical approach adopted by the two teachers, including the level and type of inquiry and the SSI context chosen. In Clover Field School, the teacher facilitated open, experimental and discussion-based inquiry. The students developed skills of experimentation, with little focus on scientific knowledge in SSI contexts. In Daisy Park School, the teacher facilitated guided, research and discussion-based inquiry, placing a central focus on authentic SSI contexts. Students developed skills relating to research and critical evaluation of scientific evidence and scientific knowledge was demonstrated while considering societal implications. The two different pedagogical approaches led to the development of a range of skills and knowledge. Open and guided inquiry pedagogical approaches, experimental, discussion and research-based inquiry, were shown to complement each other in achieving the outcomes of the Irish lower secondary science curriculum.

Keywords: inquiry; socioscientific issues; junior cycle; science; assessment

Introduction

Development of scientific literacy is a key aim of science education across the globe and research suggests that this can be achieved through student inquiry into socio-scientific issues (SSI), more recently known as socioscientific inquiry-based learning (SSIBL) (Colburn 2000; OECD 2013; Levinson 2018; Zeidler, Herman, and Sadler 2019). Recent changes to the second-level (secondary) science curriculum in Ireland promote the use of inquiry into SSI for the development and assessment of the skills and knowledge of scientific literacy, including the addition of a new class-room based assessment, the *Science in Society Investigation*. This assessment requires

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students to carry out an inquiry into SSI, with support and guidance from the teacher (NCCA 2018, 2015). While there has been an increased focus on the use of inquiry based science education (IBSE) in Europe, research exploring the combination of the use of inquiry teaching approaches and SSI contexts is only emerging (Levinson 2018; Rundgren and Chang Rundgren 2018). Very little of this research has been set within the context of the Irish education system and this study aims to examine teachers' experiences of implementing inquiry into SSI teaching approaches within the Irish context.

Inquiry in science education

Inquiry is often lauded as an effective means of developing the skills and knowledge of science (Colburn 2000; Jerrim, Oliver, and Sims 2020; Hmelo-Silver, Duncan, and Chinn 2007). Broadly speaking, inquiry pedagogical approaches are 'hands-on' activities with students involved in the active construction of knowledge and the teacher acting as a facilitator of learning (Colburn 2000).

Inquiry in the classroom often follows a step-by-step process where students formulate a problem or question for investigation, state an expected outcome, perform an experimental investigation, analyse the gathered data and draw final conclusions based on their findings (Wenning 2005). However, in practice this simplified version of inquiry is unlikely to be reflective of the complex processes involved in real-world scientific inquiry (Bybee 2002). Some researchers regard authentic classroom inquiry approaches to focus more on finding, interpreting and evaluating data and evidence, and carefully scaffolded, teacher-mediated student interaction and discussion (Levinson 2018; Linn, Davis, and Eylon 2013; Zeidler et al. 2009). In these inquiry-based science lessons students are encouraged to listen to, analyse and build upon a range of viewpoints and ideas from their own secondary research and from peer discussion (Linn, Davis, and Eylon 2013). These inquiry approaches are more akin to the discourse that takes place in real-life science situations (Bybee 2002).

Inquiry teaching is often described as a hierarchy of levels of increasing student autonomy and cognitive demand (Colburn 2000; Wenning 2005). These levels vary according to whether the teacher or student takes control of the inquiry. Colburn (2000) describes *structured*, *guided* and *open* levels of inquiry. In a structured inquiry, the teacher is in control of most of the decision making and the level of intellectual sophistication for the students is low. In guided level inquiry, the teacher provides the problem for students to explore. The onus is on the students to devise their own methods to solve the given problem. In open level inquiry, the student chooses the question to be investigated and the methods used to explore this question. The students have control over their investigation and the level of intellectual sophistication is high. The teacher acts as a facilitator to guide students and ask probing questions (Colburn 2000).

However, there is much debate around the effectiveness and appropriate use of inquiry approaches in the classroom. Open level inquiry, in particular, has been dismissed as ineffective by some researchers. Kirschner, Sweller, and Clark (2006) state that the minimally guided teaching approach of open inquiry 'ignores the structures that constitute human cognitive architecture' (76). In addition, frequent use of open inquiry by teachers has been shown to decrease achievement in standardised science tests (Jiang and McComas 2015). While these criticisms appear to point towards the use of more structured 'cookbook' approaches to inquiry, these approaches have been shown to decrease student interest and engagement with classroom science (Jiang and McComas 2015).

Researchers suggest that teachers facilitating inquiry approaches with students who are not yet experienced in classroom inquiry should heavily scaffold student learning. This can be achieved through explicit guidance and instruction, to support learners' active construction of scientific knowledge and development of skills (Bao and Koenig 2019; Lazonder and Harmsen 2016; Levinson 2018). Progressing from teacher-led to more student-led inquiry approaches has been shown to facilitate the progressive development of students' scientific knowledge and skills (Colburn 2000; Hmelo-Silver, Duncan, and Chinn 2007; Kirschner, Sweller, and Clark 2006). In this way students are afforded the opportunity to develop an understanding of the processes of inquiry, decrease their reliance on teacher scaffolding and enable them to progress to open inquiry (Kirschner, Sweller, and Clark 2006).

Therefore, teachers are required to carefully plan for how they use inquiry approaches depending on the students' prior experience of inquiry (Colburn 2000; Jiang and McComas 2015). However, research suggests that many teachers lack confidence using inquiry approaches (Capps, Shemwell, and Young 2016; Fitzgerald, Danaia, and McKinnon 2019). This may arise from teachers having tried out open inquiry approaches, without adequate awareness of the different levels (Fitzgerald, Danaia, and McKinnon 2019; Wenning 2005), and found the results to be ineffective in terms of the acquisition of scientific knowledge (shown by an exam or test result) (Jiang and McComas 2015; Kirschner, Sweller, and Clark 2006). There may also be a mismatch between the use of inquiry approaches and assessment of learning. Inquiry approaches are often recommended in curricular documentation, while student performance may still be judged through a final written exam (e.g. NCCA 2015; OECD 2013). Teachers also raise concerns about the lack of time within the science curriculum to focus on inquiry-based approaches (Fitzgerald, Danaia, and McKinnon 2019). As a result, teachers often resort to more direct instructional methods or pay 'lip-service' to inquiry approaches (Fitzgerald, Danaia, and McKinnon 2019; Kirschner, Sweller, and Clark 2006).

Socioscientific issues as the context for inquiry

Socioscientific issues (SSI) are described as scientific topics which have implications for society and these issues can be used as the context for inquiry in the classroom (Levinson 2018; Sadler 2009).

An important aspect of SSI is that they are controversial. This means that there are a range of possible viewpoints on the issue due to the differing interpretations of evidence by those with opposing views (Oulton, Dillon, and Grace 2004). Student discourse is often used during an inquiry into SSI, to allow students to explore and build their understanding of the range of ideas and viewpoints held by their peers on such issues and compare these to their own. Secondary research into SSI exposes students to viewpoints from a wide range of sources (Zeidler, Herman, and Sadler 2019). Exploration of SSI develops skills relating to reasoning and argumentation, perspective-taking, recognition of the contributions and limitations of science, and skepticism relating to the basis of viewpoints and arguments, encouraging students to consider whether arguments are based on scientific evidence or other considerations (Linn, Davis, and Eylon 2013; OECD 2013; Zeidler, Herman, and Sadler 2019). Furthermore, students may be provoked to engage in socially responsible activism, taking action on the SSI not just within the classroom but more widely in their communities (Zeidler, Herman, and Sadler 2019; Bencze and Sperling 2012).

The choice of the SSI context is an important consideration for the development of students' scientific skills and knowledge. Discussion of SSI allows students to combine the use of curricular and everyday knowledge through the use of scientific and everyday language during discourse. This highlights the relevance of the SSI for students (Åkerblom and Lindahl 2017). Tasks are perceived by students as meaningful only when they are familiar to the students. Teachers may choose local issues and problems in an attempt to increase students' familiarity and relevance with the SSI (Åkerblom and Lindahl 2017). Conducting inquiry using SSI as the context presents additional challenges for the teacher in terms of choice of contexts and managing the classroom. Teachers may find choosing a topic for SSI challenging. Research suggests that the most successful SSI topics should align with the curriculum, students' interests and the personal interests of the teacher (Bayram-Jacobs et al. 2009). However, due to differing student backgrounds and prior experience, not all students will view the relevance and familiarity of the SSI equally. Some students may view the inquiry into SSI as less relevant and like a traditional school assignment. Students that view the task in this way may be at greater risk of losing interest and motivation (Åkerblom and Lindahl 2017).

The use of inquiry into SSI contexts to develop a range of skills and knowledge has received growing attention in the literature (Levinson 2018). However, studies indicate that taking part in limited and one-off exploration of SSI may not have a transformative impact on students' understanding and skills. Studies show that students involved in short-term SSI-based activities (e.g. a two-week project) develop scientific knowledge but do not show improvements in SSI related skills such as reasoning and argumentation, perspective-taking, recognition of the contributions and limitations of science, and scepticism (Zeidler, Herman, and Sadler 2019). However, these skills may be developed through longer-term, sustained engagement with SSI learning experiences (Zeidler, Herman, and Sadler 2019).

SSI contexts are generally considered to be based on controversial topics. Therefore, there is a risk of conflict between students during discussion of controversial topics. Teachers must preempt possible sources of conflict and have the pedagogical knowledge and skills to deal with any that arise (McCully, Smyth, and O'Doherty 1999). Teachers must also choose the stance that they take when facilitating student inquiry into SSI contexts. Teachers may choose to present a balanced view of the SSI. This perceived neutrality may serve to prevent accusations, from parents or management, of indoctrination of students towards one stance over another (Oulton, Dillon, and Grace 2004). However, this false neutrality may threaten the rapport teachers have with students. Alternatively, teachers may provide a range of conflicting views related to the SSI but also share their personal views (Oulton, Dillon, and Grace 2004).

These planning considerations and classroom management challenges are likely to require considerable commitment on the part of the teacher, as well as willingness to take risks in the classroom (Balgopal 2020; McCully, Smyth, and O'Doherty 1999).

This is likely to prove particularly challenging for teachers who are still developing their role as facilitators of inquiry (Fitzgerald, Danaia, and McKinnon 2019; Kelly and Erduran 2019). Therefore, there is a need to provide teacher professional learning and enhance their knowledge of inquiry into SSI alongside changes to the curriculum (Rundgren and Chang Rundgren 2018).

Inquiry into SSI in lower secondary science curricula

Within Europe, science education has increasingly focused on the use of inquiry-based learning as a way of promoting student engagement and motivation. Inquiry approaches have also been promoted as a way of increasing achievement in international tests, such as PISA and TIMSS (Rundgren 2018). However, due to the differing cultural, social and economic contexts across Europe, there is no common framework for science curricula, which are decided at the national level (Rundgren 2018). These cultural and educational variations challenge the widespread use of inquiry, and SSI, in school science curricula. The range of knowledge and skills associated with student inquiry into SSI needs to be valued in the school environment, examinations and progression routes and this is not always the case. For example, university admission criteria are likely to rely on achievement in high-stakes examinations based on recall of scientific knowledge (Kara 2012). Recent studies highlight the need for changes to curricula that involve modifying overall priorities and embedding formative and summative assessment approaches based on inquiry into SSI (Kara 2012; Rundgren and Chang Rundgren 2018).

A review of the Irish lower secondary science curriculum recommended moving away from a previously content-knowledge focused curriculum, where topics were often presented as disconnected, arbitrary facts to be memorised (Erduran and Dagher 2014). These studies recommended that students should be given the opportunity to develop the skills and knowledge of scientific literacy through discussion of relevant, connected, social contexts, including formally embedding the exploration of controversial issues within the curriculum (Erduran and Dagher 2014; McCully, Smyth, and O'Doherty 1999; NCCA 2013). In response to this, the *Junior Cycle science specification* was introduced, and placed emphasis on developing understanding of the aims and values of science, investigative approaches, communicating scientifically and appreciating the role of science and scientists for society (Kelly and Erduran 2019; NCCA 2015).

The Science in Society Investigation was also included in the Junior Cycle science specification. This classroom-based assessment centres around inquiry into SSI and aims to develop and assess a range of scientific skills and knowledge (NCCA 2018, 2015). Students are expected to research SSI, analyse the gathered information, evaluate the claims and opinions found, and draw conclusions in the form of personal opinions informed by their research. The NCCA (2018) briefly describes SSI as scientific topics which impact society and/or the environment and recommends that students choose their own personally relevant SSI for investigation. Students are expected to conduct inquiry into SSI, at varying levels, during the first and second year of the Junior Cycle, developing a range of scientific skills and knowledge. The formal assessment is undertaken by students in their third year of the Junior Cycle (NCCA 2018).

Given the planning and classroom management challenges that teachers are likely to face when facilitating inquiry into SSI, it is of note that the NCCA (2018) gave little detail on the pedagogical approach teachers should adopt. The NCCA (2018) guidelines briefly state that teachers should 'guide and supervise' students and provide 'reasonable support' (8). Reasonable support is described as teachers clarifying the requirements of the task, providing exemplars, providing instructions and providing supports for students with Special Educational Needs (SEN), while also encouraging students to show a 'level of initiative' (NCCA 2018, 9). This lack of detail enables teacher agency in terms of their capacity to act on their beliefs and to adopt and sustain new pedagogical approaches (Balgopal 2020; Erduran and Dagher 2014). However, it also challenges the teacher to carefully plan and scaffold student learning in the science classroom. Professional development opportunities, as well as initial teacher education, can provide support to teachers to develop effective pedagogical strategies for inquiry into SSI in the Junior Cycle science specification (Kelly and Erduran 2019; Erduran and Dagher 2014).

This research examines how two experienced in-service science teachers implemented inquiry approaches using SSI contexts to develop students' skills and knowledge as part of the lower secondary Irish science curriculum. The research question for this study was:

> What are teachers' experiences of facilitating inquiry into socioscientific issues in the Irish Junior Cycle science specification?

Theoretical basis

Inquiry approaches aim to facilitate students to follow a process of questioning, hypothesising, designing, carrying out and evaluating experimental and secondary research based investigations, data analysis and interpretation, and drawing final conclusions (Wenning 2005). The terms *structured*, *guided* and *open* are used to describe different levels of inquiry (Colburn 2000). Structured inquiry refers to inquiry in which the teacher makes most of the decisions and the student interprets information and draws conclusions. Guided inquiry is where the student is given a question for investigation and they choose how to investigate this question followed by data collection, analysis and conclusions. Open inquiry is where the student chooses a question for investigation, although the teacher may have given the topic. The student designs the method for investigation, gathers and analyses data and draws conclusions (Colburn 2000; Wenning 2005). Facilitated discussion is a type of inquiry but it does not follow the set process of experimental and secondary research-based inquiry (Linn, Davis, and Eylon 2013).

Socio-Scientific Issues (SSI) are scientific topics with moral, ethical and/or societal implications (Zeidler, Herman, and Sadler 2019). They are controversial, meaning they can be viewed from a range of viewpoints and cannot be easily concluded even through examination of available evidence. They are contemporary, based on current events and encourage activism (Bencze and Sperling 2012; Oulton, Dillon, and Grace 2004). SSI can be used as the context to support the development of students' scientific skills and knowledge at second level (Levinson 2018).

More recently, SSI have been used as the context for students to conduct inquiry at the different levels – open, guided and structured (Colburn 2000; Levinson 2018).

This approach enables teachers to use different pedagogical approaches, including experimentation, secondary research and discussion-based inquiry (Linn, Davis, and Eylon 2013; Zeidler, Herman, and Sadler 2019). Students develop a wide variety of skills and knowledge situated within an appreciation of the implications for society (Levinson 2018; OECD 2013). This research presents two case studies examining teachers' use of inquiry into SSI contexts with lower secondary level students (aged 12-15). The study reports on the teachers' pedagogical approach to inquiry, authenticity of the SSI contexts selected and the skills and knowledge developed by students.

Methodology

Case study approach

This research presents two qualitative case studies, set in Irish second-level (secondary) schools. Case studies were chosen because they can be used to explore phenomena in real-life contexts in a context specific, flexible way (Denzin and Lincoln 2011; Luck, Jackson, and Usher 2006; Stake 1995). A criticism of qualitative case studies is the perceived inability to generalise findings due to the limited number of participants. However, this misses the point of case study research where the focus is on describing the particulars of the situation and the uniqueness of each case (Stake 1995). In this study, the researchers are experienced qualitative researchers with knowledge of teaching and the Irish education system. The role of the researcher was to observe lessons, interview teachers about their experience and examine a range of records and documents (Stake 1995). The researcher aimed to be as passive and objective an observer as possible.

The case studies presented in this paper followed a series of stages, including: identifying the issue; asking research questions and drawing up ethical guidelines; gathering and storing data; generating, interpreting and explaining findings; writing and publishing the conclusions in a report (Bassey 1999). The research focussed on gaining an understanding of teachers' experiences of carrying out inquiry into SSI, as part of the Junior Cycle science specification. The aim of the research was to report observations from the two case studies which will inform classroom practice in relation to the use of inquiry into SSI within the Irish Junior Cycle science specification and in wider European contexts.

Ethical approval was obtained from the researchers' University Research Ethics Committee. Participants were contacted directly by email and invited to participate in this study. They were chosen because they indicated that they were using inquiry-based approaches focused on developing skills related to the Junior Cycle Science in Society Investigation. Written consent was obtained from participants prior to the research commencing.

The level of risk to participants in this study was low-moderate. Findings are presented anonymously and participants and schools were given pseudonyms. The participants in the study were teachers who contributed in their professional roles, so this aspect was considered low risk. Secondary documents were provided pre-anonymised. Observation of lessons focused on the actions of the teachers and not the students. The presence of students under the age of 18 during lesson observations meant that this aspect was considered moderate risk. Data was stored as per the university's GDPR and data protection guidelines.

The first case study presented is the Clover Field School case study. This study followed Sam, a biology and science teacher, over seven lessons with a second-year class of 19 students (aged 13-15). The second case study presented is the Daisy Park School case study, which followed Joe, a biology and science teacher, through six lessons with a first-year class of 20 students (aged 12-14). Both schools were mixed-gender. In both case studies the teachers were very experienced and both had been teaching science at the second level for over 15 years.

Design and implementation of data collection instruments and methods

In these case studies, data was collected through standard qualitative data collection methods (Creswell and Plano Clark 2011):

(1) Lesson observations and field-notes: open written notes detailing the actions of the teacher.
(2) Teacher interview: Semi-structured interview
(3) Secondary documentation: Teacher lesson plans, student work and student questionnaires

Interviews took place three months after the final lesson observation allowing time for the researcher to complete initial analysis of the data to inform the interview questions. The semi-structured interview asked about the teacher's experience and background, the class-group, the teacher's view of the observed lessons and what the students had learnt. The interview also gave an opportunity to discuss initial analysis with the participants in a process known as member checking. This validation method allows the researcher to discuss the findings with the participants, to check whether they are an accurate representation of their experience, before finalising the analysis (Creswell and Plano Clark 2011).

Student work provided by the teacher included audio-visual material and written reports. Student questionnaires were students' written response to 'state three things you learnt in these lessons'.

Analytical framework: thematic analysis

Qualitative data analysis methods, such as thematic analysis, value the researcher's skills and expertise while promoting trustworthiness of findings and conclusions. These methods use coding to sort and classify researcher observations and other data into representative categories or themes (Braun and Clarke 2006; Creswell and Plano Clark 2011; Stake 1995). Thematic analysis involves in-depth coding of data, often using software (e.g. NVIVO), to identify, analyse and report patterns from a wide range of data by following standardised procedures (Braun and Clarke 2006).

The process of thematic analysis is represented for the two case studies in Figures 1 and 2. The final sub-themes are displayed in order of relative emphasis or focus from highest number of coded references to lowest. The same three final themes were identified in both case studies, namely *skills*, *knowledge* and *pedagogical approach*. The sub-themes, however, varied between the two case studies.

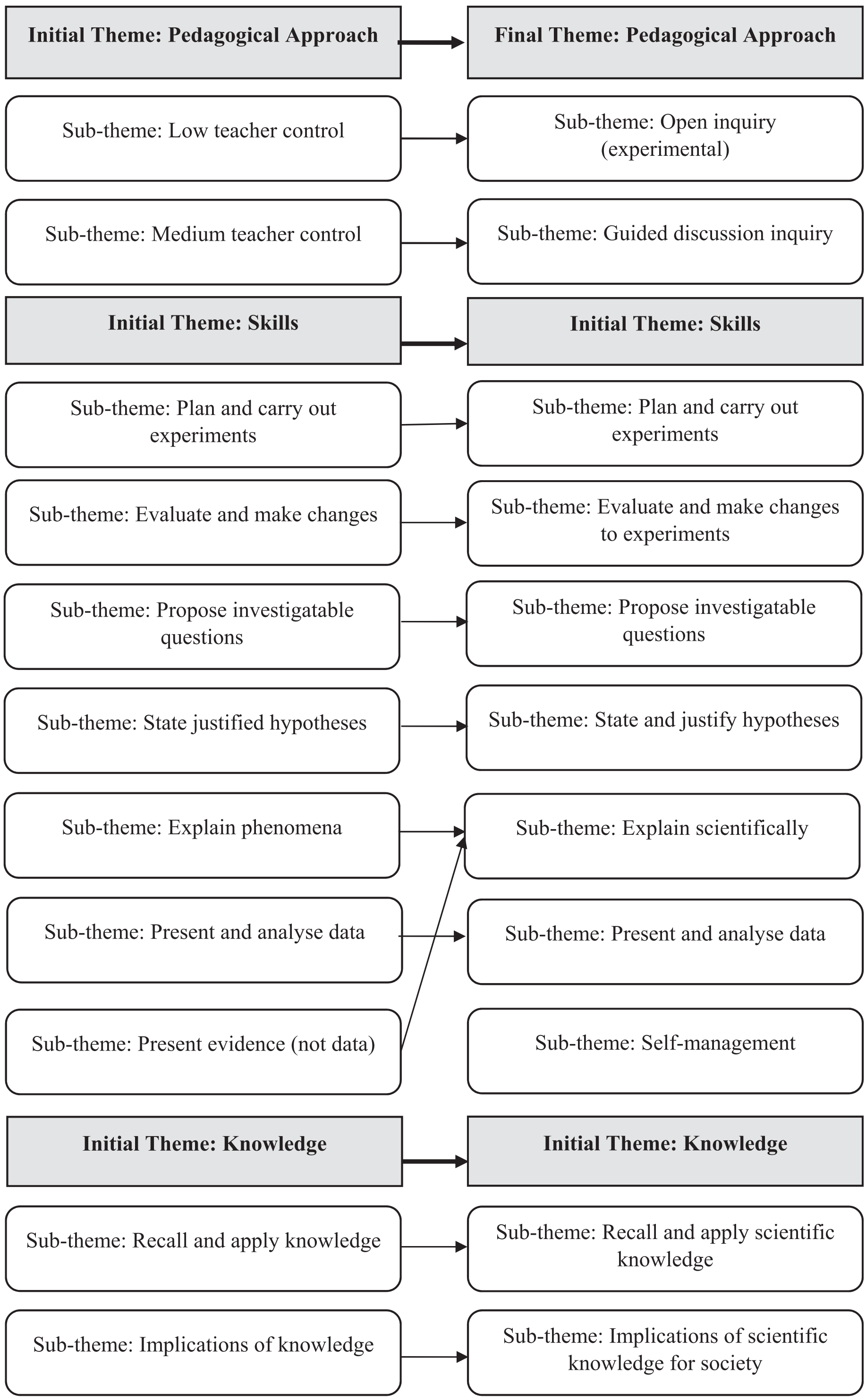

Figure 1. Initial to final themes for Clover Field School case study.

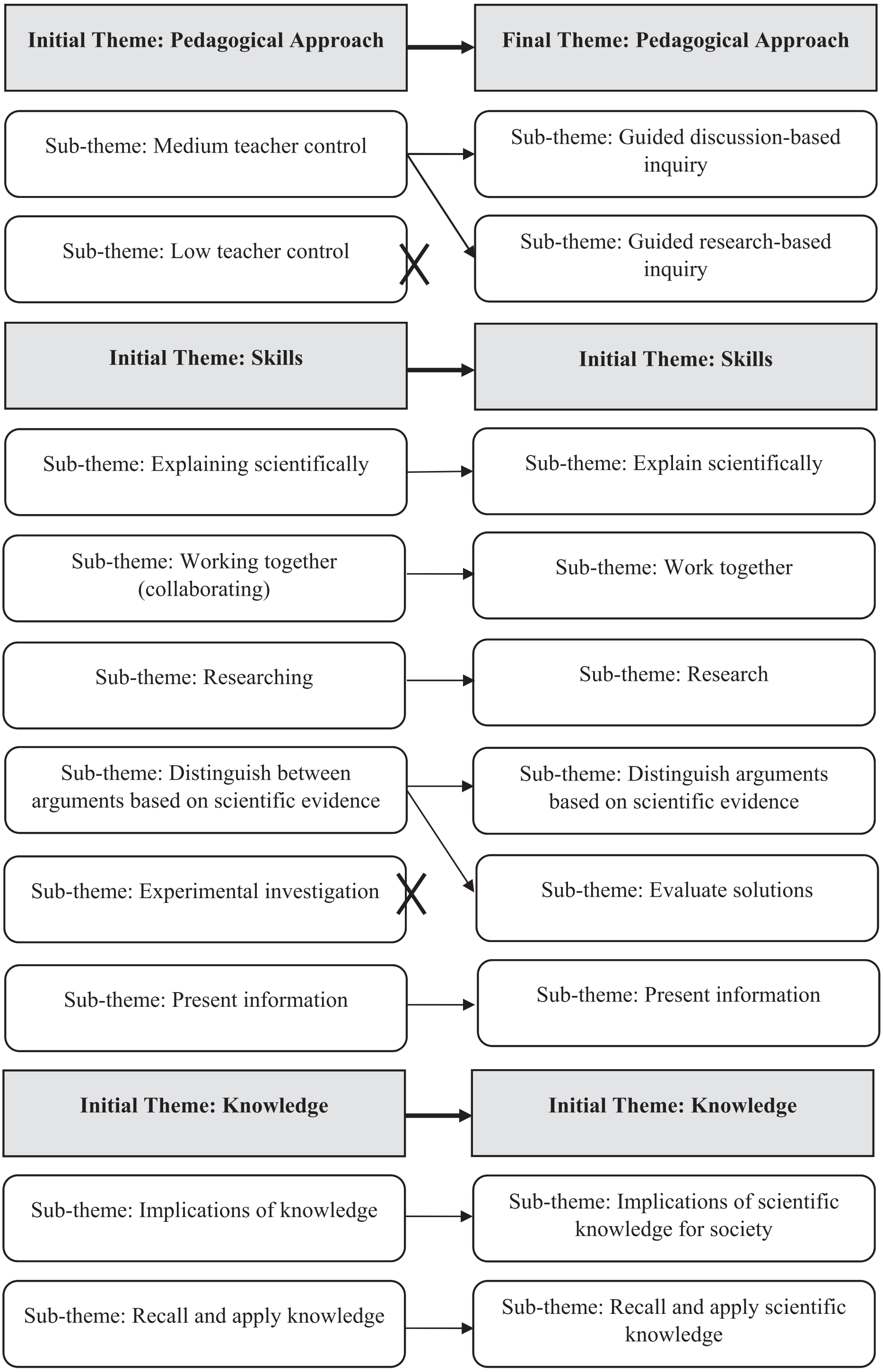

Figure 2. Initial to final themes for Daisy Park School case study.

The procedures of thematic analysis aim to increase reliability and validity of findings, decreasing reliance on the researcher's direct observations. Validity relates to accurate representation of the situation while reliability relates to the consistency of coding (Creswell and Plano Clark 2011). Triangulation, where different data sources are compared for evidence of convergence and corroboration, and member checking can be used to increase the validity of findings (Creswell and Plano Clark 2011). In these case studies, validity was increased through the comparison of different sources of data (researcher observations, interview data, student work) and member checking. Reliability was increased through rigorous and consistent coding based on standard thematic analysis procedures (Braun and Clarke 2006).

Findings and discussion

Sam, the teacher in Clover Field School, took a *pedagogical approach* combining open level, experimental inquiry and guided level, discussion-based inquiry (Figure 1). Students developed a range of *skills* and *knowledg*e (Figure 1). Joe, in Daisy Park School, took a *pedagogical approach* that included guided level, discussion-based inquiry and guided level, research-based inquiry (Figure 2). A range of *skills* and *knowledge* were developed (Figure 2). The order of the themes indicates the relative emphasis, according to the number of coded references, on each skill or knowledge sub-theme (Figures 1 and 2).

Clover Field School case study

An overview of the Clover Field School case study is shown in Figure 3. Sam's pedagogical approach was mainly open level, experimental inquiry followed by guided level, discussion-based inquiry into SSI.

Pedagogical approach

Sam facilitated an experimental investigation with his students over six 40-minute lessons. During these lessons Sam's *pedagogical approach* was to facilitate an *open inquiry*. The students were given responsibility for planning, carrying out and evaluating their experiments. Although the topic or theme was chosen by the teacher, the question for investigation was chosen by the students. This is a key distinction between open and guided levels of inquiry (Colburn 2000). Sam described his approach to inquiry:

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

He also described his role as a facilitator of inquiry:

> Some of them had more complicated designs which I tried to steer them away from. They were to draw me some schematic diagrams, tell me what equipment they were going to need, answer my questions as I went around the room. If it was in any way practical, I

> would say 'OK brilliant! Let's do it' … Rather than giving them advice I would always just ask questions (Sam – teacher interview)

Sam wanted to say 'Brilliant! Let's do it.' but at times his role as the facilitator was to 'steer' and guide students away from one path and towards a more fruitful path. With less emphasis on the teacher as the knowledge provider, there was more emphasis on the students' role.

Only one lesson was dedicated to *guided discussion inquiry.* During this lesson, Sam facilitated student discussion of SSI by posing a variety of questions to the

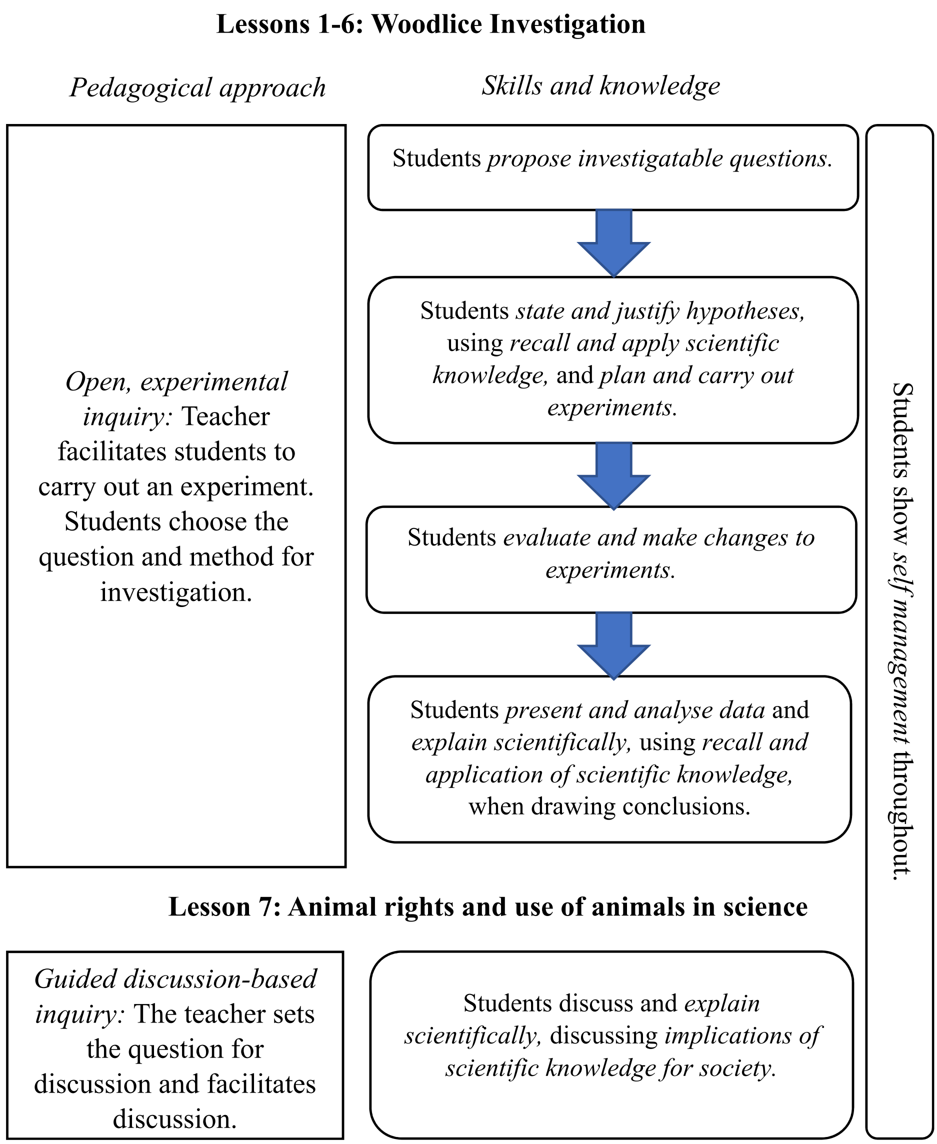

Figure 3. Overview of Clover Field School case study.

students regarding the ethical issues surrounding the use of animals in science. The level of inquiry was guided because Sam posed questions to the students and directed the discussion and did not pass over full control to the students during this discussion (Colburn 2000). He conducted a whole class 'discussion' in which students raised their hands and made points in turn, meaning students were exposed to a range of viewpoints within the class. However, he maintained a neutral stance by avoiding giving his own opinions (McCully, Smyth, and O'Doherty 1999; Oulton, Dillon, and Grace 2004).

SSI context

Sam described the SSI as 'the ethics of animal experimentation' (Sam – email communication to the researcher). Explicit discussion of the SSI context was limited to one lesson involving *guided discussion inquiry* of these issues. Sam acknowledged that the focus on the SSI context during the preceding experimental inquiry had not been made explicit:

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

There was evidence that the students considered the welfare of the woodlice during their experimental investigations. In oral presentations of their experiments, they described a 'hotel' to keep the woodlice 'happy' and considered their role and responsibility in ensuring the welfare of the animals:

> 'For the moment all the woodlice have gone into a little hotel. So the woodlice are happy now just munching on some leaves … During our experiment, 2 or 3 of the woodlice died doing it. Maybe because of us dropping them in. So, yeah, R.I.P woodlice.' (student work sample two); 'Unfortunately, two of the woodlice in our experiment died.' (student work sample seven).

While the words used appear flippant, there was a nervous laughter and awkwardness in the student's voice, indicating that they took the issue seriously.

In following the *guided discussion inquiry*, the SSI context was dealt with explicitly. The teacher facilitated a whole class discussion of animal rights and the ethics of the use of animals in science: 'Why don't animals have the same rights as humans? Why do we as humans have more rights?' (Sam – Researcher field notes from lesson observation). Sam described the 'diversity of views' that emerged during the discussion (Sam – Researcher field notes from lesson observation): 'Some people were like 'ah they're only woodlice, it doesn't matter'. And other kids obviously from the outset had felt really uncomfortable … they didn't feel comfortable that the woodlice were being 'put out' even if they weren't harmed.' (Sam – interview). During the discussion there was evidence of opposing viewpoints within the class: 'We're more developed, when every human has equal rights and we fix our own problems, then we work on their [animal] rights.' (student one – researcher field notes), 'Animals have so much to offer, we should respect their rights.' (student two – researcher field notes). This highlights the controversial nature of the chosen SSI, with conflicting points of view even between students in the same class (Oulton, Dillon, and Grace 2004).

Skills and knowledge developed and assessed

Sam's chosen pedagogical approach aimed to develop and assess a range of inquiry skills: 'So, for a particular investigation I pick out maybe one or two inquiry skills, such as developing hypotheses or presenting data' (Sam – interview). There was evidence, from analysis of the teacher interview, lesson observation field notes and secondary documentation, of the development and assessment of a range of skills (Figure 1). In line with Sam's pedagogical approach of mainly open experimental inquiry, the skills developed mainly related to experimental procedures and processes. The skills developed included: proposing investigatable questions and stating hypotheses; planning, carrying out and evaluating experiments; presenting data gathered through experimentation; and drawing and justifying conclusions. Sam's students also devised their own experimental method, engaged in evaluation of their procedures and made changes as they carried out their experiments. Students considered practical constraints, such as 'woodlice escaping', 'daylight getting through the box', availability of equipment and feasibility of their designs. Students presented and analysed the data they gathered through experimentation. Students stated final conclusions, justified with scientific knowledge, but not linked back to the SSI. Sam's students demonstrated their scientific knowledge mainly as fragments of scientific terminology or fact, given without consideration of context.

Sam's open inquiry approach promoted the development of a range of skills relating to student inquiry and scientific literacy (OECD 2013). However, there was little focus on the development of scientific knowledge, as evidenced by the lower number of references to knowledge compared to skills during thematic analysis. The choice of SSI was authentic (moral, ethical and/or societal implications, controversial, contemporary). However, in line with critique of inquiry into SSI approaches, this one-off activity showed little evidence of transformation of student thinking in terms of the SSI, and there was no evidence that students engaged in socio-political activism (Bencze and Sperling 2012; Zeidler, Herman, and Sadler 2019). This may, however, be achieved through continued engagement with throughout the three years of Junior Cycle as recommended in the Junior Cycle science specification.

Daisy Park School case study

An overview of the Daisy Park School case study is shown in Figure 4. The Transport Problem took place over five 40-minute lessons. This was followed by Letters to Trump which was carried out over one 40-minute lesson of class time with additional research carried out by students at home.

Pedagogical approach

In the Transport Problem lessons Joe's pedagogical approach was *guided discussion inquiry*. The discussion focussed on traffic congestion in the local community. The level of inquiry was guided because Joe provided students with the topic of discussion and steered the discussion by asking probing questions (Colburn 2000). After this initial discussion, Joe asked the students to propose solutions. He facilitated the students to present their solutions to the rest of the class and encouraged their peers to provide feedback on the proposed solutions. Finally, the students worked in small

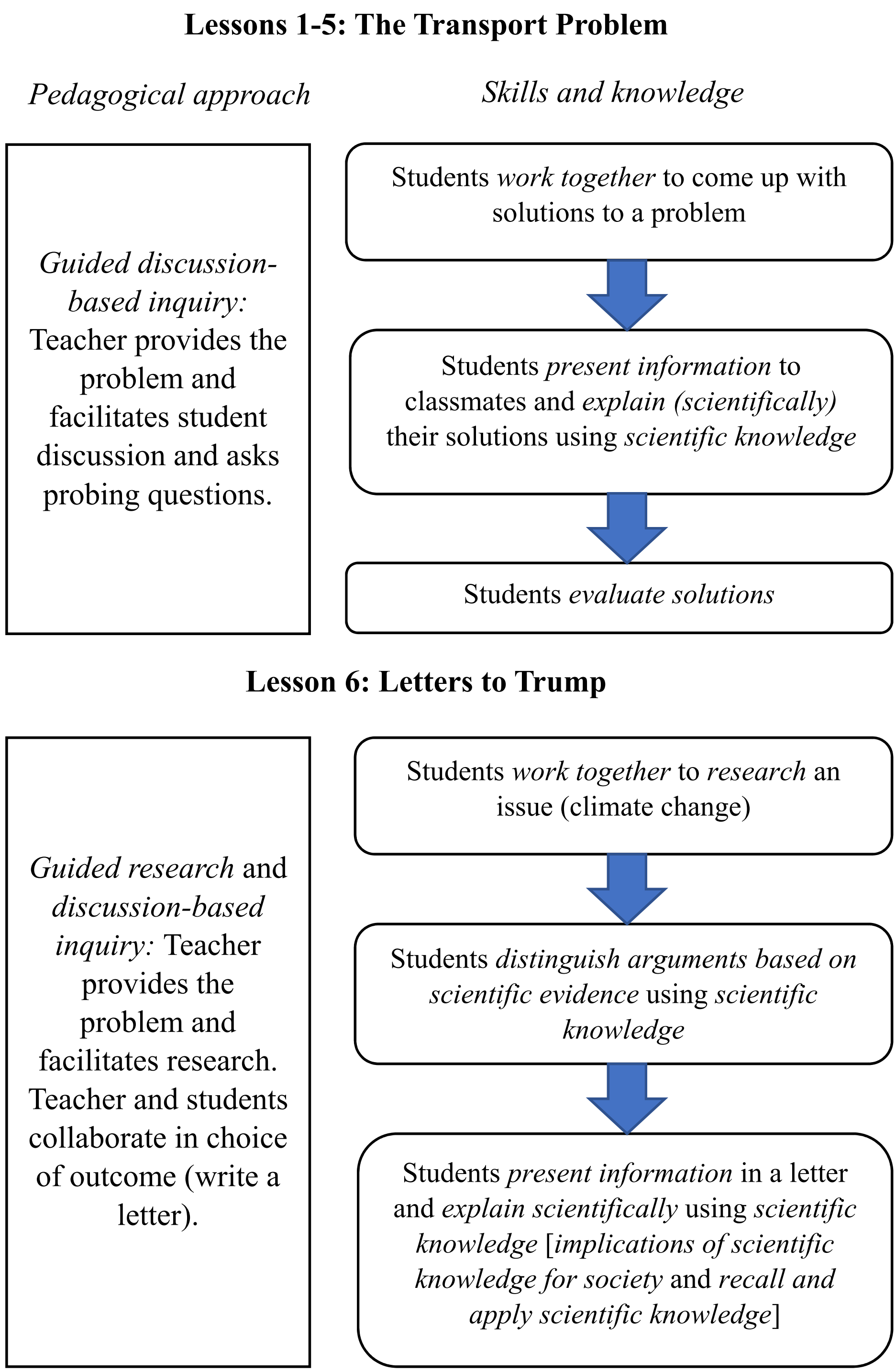

Figure 4. Overview of Daisy Park School case study.

groups to evaluate their proposed solutions by discussing the 'pros and cons' of each while Joe circulated between the groups asking questions.

In the final lesson, Letters to Trump, Joe's pedagogical approach was *guided discussion* and *guided research inquiry*. The level of inquiry was guided because Joe chose the question to be discussed (Colburn 2000). Firstly, Joe facilitated a whole class discussion about climate change and highlighted relevant news stories. He introduced the idea of 'climate change denial' by reading a series of climate change denying 'tweets' from the President of the USA, President Trump.

> Joe takes out a sheet of paper and reads aloud to students. Students whispering: 'Trump', 'Donald Trump'- very current topic linking global politics and global science. Joe reveals that the statements are made by president elect Donald Trump. Students are asked to complete a letter to Donald Trump to 'inform him of the difference between climate change and global warming'. The best ones will be sent to the whitehouse. (Researcher field notes showing introduction of the SSI climate change denial)

Joe facilitated students to conduct research on the science of climate change, in pairs, using i-pads and present their findings in the form of a letter to President Trump.

Joe described his pedagogical approach to inquiry as he recommended it to other teachers:

> Stand back. Stop talking. One thing that really shocks me is the noise that you hear, more than anything else, is the constant teacher talk. It doesn't matter where you go around the school, you hear the same thing. You have this directed learning. If you are doing something like this [SSI based inquiry] the learning comes from the students' discovery and interaction. They are talking with their peers, engaging in constructive arguments, discussing the pros and cons. This is where true construction takes place. (Joe – interview)

Joe's guided discussion inquiry approach utilised teacher scaffolded student interaction and discussion. This encouraged students to listen to and evaluate a range of viewpoints as well as express their own (Linn, Davis, and Eylon 2013). Furthermore, by using a guided, research inquiry pedagogical approach students were encouraged to explore varied points of view from a wide range of sources (Zeidler et al. 2009).

SSI context

Students explored two SSI contexts which were chosen by the teacher due to their relevance to the students:

> '[The Transport Problem] was looking at an issue that would be relevant to the students that they could tap into fairly rapidly, and it was the idea of local congestion when getting into school in the morning. Many of them would be familiar with this because they come from the local community and towns.' (Joe - interview)

> 'There are three things to remember in education: Motivation, motivation, motivation. They were motivated because they were incensed by the, as they put it, "stupidity of the man" [President Trump]. When you have students motivated they overcome the challenges and difficulties' (Joe - interview)

Students explored the Transport Problem from a socioscientific perspective. They discussed the science of fuels, pollution and climate change, and considered the societal implications (e.g. economic, political and social factors) relating to transport in the local area.

There were a range of conflicting viewpoints within the class, highlighting the controversial nature of the chosen SSI. Students expressed: 'not everyone will agree with you', 'you have to respect people's opinions' (student questionnaire – The Transport Problem). This range of viewpoints, from their research and within the class, meant that the students found it difficult to reach a definitive conclusion, even after research and discussion. Instead the students had to 'think about the pros and cons of each idea and [understand] that no solution is going to be perfect' (student questionnaire – The Transport Problem). This is typical of authentic SSI which encourage students to reflect on the range of viewpoints and therefore the basis of their own views (Oulton, Dillon, and Grace 2004).

Letters to Trump explored a contemporary, global SSI:

> 'It was fortunate at the time and it just tied in nicely that Trump had just released a series of tweets about global warming and climate change, saying that the whole thing was a very expensive hoax … The circumstances that set up the lesson were unique in that it happened at a time when Trump had been very vocal on a particular topic.' (Joe - interview)

The SSI was centred around climate change and the range of possible viewpoints on the topic due to differing economic, political and environmental concerns (Oulton, Dillon, and Grace 2004). However, within the class there was a consensus, and all the students supported the existence of climate change: 'Some people think it's not real and that's their opinion … but scientists have proven it to be real.' (student questionnaire – Letters to Trump). Research suggests that what constitutes a controversial topic in one setting may not cause any disagreement in another and so could not be considered SSI (Zeidler, Herman, and Sadler 2019). The lack of diversity of views within the class calls into question the authenticity of the chosen SSI, in terms of whether it can be considered controversial. In addition, Joe chose to take a neutral stance regarding this SSI, putting him at odds with the consensus of the class. Research suggests that this strategy of enforced neutrality risks the teacher's relationship with the students (Oulton, Dillon, and Grace 2004). The chosen SSI was a powerful motivator for the students who were incited to take wider socio-political action on the issue by writing letters to President Trump explaining the science behind climate change (Bencze and Sperling 2012).

Skills and knowledge developed and assessed

Joe's chosen guided level inquiry pedagogical approach to inquiry enabled students in Daisy Park School to develop a range of skills relating to evaluating and explaining scientific evidence, researching and collaborating (Figure 2). Joe described students 'ability to work as part of a group, listen to others and present your own opinion' (Joe – interview).

Joe described the students carrying out *research*: 'analysing information, looking for bias, selecting information that was appropriate for communication … the interrogation of information.' (Joe – interview).

Students in Daisy Park School developed their ability to *distinguish arguments based on scientific evidence* and *evaluate solutions,* which are skills particularly associated with an inquiry into SSI and the development of scientific literacy (OECD 2013). Kelly and Erduran (2019) describe how students completing the Junior Cycle science specification should be afforded opportunities to consider and evaluate a range of evidence. Evidence from these sub-themes highlighted instances where students evaluated the researched information, considering whether arguments were based on science or other considerations such as economics or politics. As part of the Transport Problem lessons, students evaluated their own and their classmates' solutions to a local congestion issue in terms of the range of conflicting societal and economic considerations, highlighting the controversial nature of the issue (Oulton, Dillon, and Grace 2004). They did not attempt to form concrete conclusions but instead they discussed the 'pros and cons' of each group's 'idea' or 'solution'. In Letters to Trump the view presented to them conflicted with their current understanding and this led them to consider the basis for the argument:

> I learned that a lot of the things President Donald trump says is not fact. There is a lot of evidence of climate change everywhere. Most websites have hard facts about climate change that contradict Donald Trump. (student questionnaire – Letters to Trump)

> Donald Trump is very ignorant and has done no scientific research on the matter. (student questionnaire – Letters to Trump)

> I learned that sometimes people in power are there because they have negative views on things that people don't want to make an effort about. I learned that there is a difference between global warming and climate change I learned that the whole class has an educated view on the whole thing. (student questionnaire – Letters to Trump)

The students indicated that they considered President Trump's view on climate change to be due to considerations other than scientific evidence, such as lack of political will or 'effort'. This shows evidence that students engaged in argumentation and interrogation of the basis of the viewpoints they found through their research, considering whether arguments were based on scientific evidence or other motivations (Linn, Davis, and Eylon 2013; OECD 2013).

The students used their scientific knowledge to present and explain the underlying science. They presented information using PowerPoints and oral presentations (The Transport Problem) and wrote letters to President Trump. The students' explanations demonstrated their scientific knowledge and discussed the implications for society:

> I learned the different types of power sources for cars to not necessarily reduce the traffic amount but to reduce the amount of pollution coming from all the cars! (student questionnaire – The Transport Problem)

> I learned that he [President Trump] thinks that global warming is a Chinese hoax to Make U.S manufacturing non-competitive. I learned that hurricanes and storms are to become stronger as a result of global warming. I learned that diseases like malaria are spreading as a result of the Earth becoming warmer!?? (student questionnaire – Letters to Trump)

> The Earth will become too warm for humans at some point. Or it will melt enough ice to raise the sea levels and decrease land space and cause overpopulation. (Student work sample two)

Joe's guided-level pedagogical approach to inquiry encouraged students to demonstrate their knowledge within relevant contexts, rather than as fragmented, memorised facts, in line with recommendations for the Junior Cycle science specification (Erduran and Dagher 2014). There was greater focus on developing a wide range of skills important for student inquiry and scientific literacy (OECD 2013), than on scientific knowledge, as demonstrated by the number of references during thematic analysis.

Conclusions and implications

This research presented two case studies exploring how experienced in-service teachers combined inquiry approaches and exploration of authentic SSI to develop students' skills and knowledge as part of the recently reformed Junior Cycle science specification (NCCA 2015). However, while the curricular documentation did not provide details on the recommended pedagogical approach to inquiry into SSI, the onus was on the teachers to choose suitable pedagogical approaches and SSI contexts (Balgopal 2020; NCCA 2018). The different inquiry approaches facilitated and SSI contexts chosen resulted in the development of different skills and knowledge.

In Clover Field School, students carried out an open level, experimental inquiry. Sam aimed to explore a relevant, contemporary and controversial SSI ['the ethics of animal experimentation'] but in practice this was given little focus. Instead, time was devoted to the development of students' experimental inquiry skills such as questioning; hypothesising; planning, carrying out and evaluating experiments; and drawing evidence-based conclusions. Sam's pedagogical approach resulted in little focus on the SSI and associated skills relating to argumentation and interrogation of the basis of arguments (Linn, Davis, and Eylon 2013; OECD 2013). Nonetheless, Sam's pedagogical approach resulted in the development of important inquiry skills that feature within the Junior Cycle science specification and more widely contribute towards scientific literacy (NCCA 2018; OECD 2013). Research suggests that open-level inquiry such as the approach used by Sam in this case study promotes positive attitudes, interest and engagement with science (Jiang and McComas 2015). However, open inquiry may not be effective for student acquisition of scientific knowledge, particularly for students who are less experienced in inquiry (Jerrim, Oliver, and Sims 2020; Jiang and McComas 2015; Kirschner, Sweller, and Clark 2006). This appears to be the case in Clover Field school where students were highly motivated and engaged but demonstrated little scientific knowledge.

In Daisy Park School, students carried out a guided discussion and research-based inquiry which placed authentic SSI at the centre. Research highlights the importance of teacher instruction, scaffolding and guidance during student inquiry to promote the development of scientific skills and knowledge (Jerrim, Oliver, and Sims 2020; Hmelo-Silver, Duncan, and Chinn 2007; Kirschner, Sweller, and Clark 2006). Students in Daisy Park School carried out secondary research and engaged in guided discussion (Linn, Davis, and Eylon 2013; Zeidler et al. 2009). This approach to inquiry developed skills related to peer collaboration, research and critical evaluation of evidence, which are more typically associated with those assessed in the Junior Cycle Science in Society Investigation (Linn, Davis, and Eylon 2013; Sadler 2009). Students were also encouraged to demonstrate their knowledge in a connected way, situating their scientific knowledge within societal contexts (Erduran and Dagher 2014; NCCA 2018).

In both Clover Field School and Daisy Park School, the teachers chose the SSI. The topics were chosen by the teachers for their perceived personal and local relevance to the students. By choosing appropriate SSI for the students, the teachers aimed to expose the students to authentic SSI, i.e. scientific topics with societal implications, that were contemporary and controversial (Oulton, Dillon, and Grace 2004). Because the teacher was responsible for choosing the SSI context to be explored by students, the level of inquiry was guided. Indeed, where an open level inquiry was used by Sam in Clover Field school there was little focus on the SSI. This may indicate difficulties combining open level inquiry approaches with SSI contexts. Recent research into inquiry into SSI recommends starting with inquiries that are heavily scaffolded and directed by the teacher (i. e. structured to guided), as an important stage in making the knowledge and skills required for inquiry into SSI explicit to students (Levinson 2018). In contrast, the NCCA (2018) suggests that students should choose their own SSI topic to explore in the Science in Society Investigation. Given the list of requirements for SSI, in terms of relevance, contemporary nature and controversy (Oulton, Dillon, and Grace 2004), it seems unlikely that students would have the necessary understanding to choose their own SSI. Students themselves would need to have the knowledge of current societal, economic and political issues or the ability to preconceive the possibility of diverse perspectives needed to undertake the complex task of choosing an appropriate SSI. In addition, students choosing their own SSI would put pressure on the teacher in terms of their comfort level teaching the SSI context (Bayram-Jacobs et al. 2009). Guided pedagogical approaches to inquiry, where the SSI is chosen by the teacher, may be more appropriate for the Science in Society Investigation (Levinson 2018).

Inquiry approaches are promoted as a way to develop the skills and knowledge of scientific literacy (Zeidler, Herman, and Sadler 2019; Rundgren 2018). This research contributes to the wider literature exploring the use of inquiry into SSI contexts at the lower secondary level. This study followed two teachers as they navigated their way through inquiry into SSI approaches to teaching the Irish lower secondary science curriculum. These experienced teachers were afforded agency in terms of their capacity to act on their beliefs, to adopt and sustain new pedagogical strategies, enacting the changes to the Irish Junior Cycle science specification (Balgopal 2020; Erduran and Dagher 2014). This resulted in the teachers using a range of pedagogical approaches to inquiry, including experimentation, discussion and research. These approaches were chosen by the teachers as suitable for their students based on their prior experience of inquiry into SSI and students' backgrounds. In these two case studies, students developed a range of skills and knowledge contributing towards scientific literacy (OECD 2013; Zeidler, Herman, and Sadler 2019). However, the lack of guidance within the Irish Junior Cycle science specification relating to suitable pedagogical approaches for inquiry into SSI is likely to prove challenging for teachers who are still developing their professional knowledge and skills of these approaches. This study highlights the need to provide targeted professional learning opportunities to support teachers' knowledge and use of inquiry and SSI in science education (Kelly and Erduran 2019; Rundgren and Chang Rundgren 2018).

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