UNIVERSITY OF CAMBRIDGE
Faculty of Education

ISSN 2043-8338

Journal of Trainee Teacher Education Research

How using socio-scientific issues to teach about climate change enhances engagement and knowledge of the nature of science in a year 9 girls class

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Abstract

The engagement of girls with science in secondary education has been impacted by compartmentalisation of the curriculum, which reduces opportunities for students to link scientific knowledge to other subjects. Compartmentalisation also reduces student knowledge of the nature of science (NOS). This study aims to investigate whether using socio-scientific issues (SSIs) as an approach to studying scientific concepts, such as climate change, can enhance the engagement of year 9 girls with science, and their understanding of NOS. Evidence was collected from focus groups, questionnaires and practitioner reflections. Results showed that using SSIs enhanced some elements of student engagement, and understanding of NOS. Students reported high levels of engagement during SSI-associated tasks, but further research is necessary to distinguish whether factors such as interactions with others and movement around the classroom drives the increased engagement. Nevertheless, this study concludes that SSIs are a useful approach for teaching scientific concepts and about NOS.

https://doi.org/10.17863/CAM.84169

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Introduction

A high level of student engagement is linked to academic achievement and reduced drop-out rates at school. Engagement of students in science has reportedly been impacted by compartmentalisation of the curriculum, meaning that students have less opportunity to make links between science and other subjects (Billingsley & Ramos Arias, 2017). This also affects students' knowledge of 'the nature of science' (NOS) (ibid.). In particular, girls are affected because they tend to learn in a style where they place their understanding in a wider context (Billingsley, Nassaji, & Abedin, 2017). One way to tackle compartmentalisation is using socio-scientific issues (SSIs) to bridge learning in science with other subjects such as philosophy and ethics. Therefore, this study investigates whether teaching global warming and climate change through the use of SSIs could enhance student engagement and their understanding of NOS. Results suggest that using SSIs could have a positive effect on student engagement, although the impact was varied according to the type of student involved. Furthermore, enhanced engagement may have been due to the type of activity by which SSIs were delivered; namely working in groups and being active in the classroom. It also appeared that SSIs may have enhanced students' appreciation of NOS. However, only certain aspects of NOS could be delivered through using SSIs.

This report continues by outlining the evidence already available in the literature on student engagement, compartmentalisation and how this affects the engagement of girls in science and their knowledge of NOS, and how SSIs could be beneficial in tackling these issues. After detailing the intervention and methodology used to address and study these issues in a year 9 classroom, the results and implications are discussed. Finally, recommendations for teachers are suggested and future research proposed.

Review of the literature

This section of the report discusses what is already known in the literature about engagement and continues to explore engagement of students in science. One factor which may be affecting student engagement in science is compartmentalisation of the curriculum, and this is explored with a focus on how it impacts particularly on girls' science education. Finally, I will examine what is already known about the use of SSIs in science, and how this teaching approach can also enhance students understanding of NOS.

Engagement

The term 'engagement' can refer to the "observable and unobservable qualities of interactions with learning activities" of students (Ryan & Deci as cited in Wang, Fredricks, Ye, Hofkens, & Linn, 2016, p. 17). However, this simplified definition fails to capture the complex nature of student engagement, since engagement relies not only on intrinsic factors such as motivation, interest, feelings of autonomy, self-efficacy and relatedness, but also on extrinsic factors such as teacher support, peers, teacher and parent expectations and the nature of academic work (Skinner & Pitzer, 2009). Furthermore, student engagement also dynamically operates at multiple levels such as the school level, the subject area/specific classroom setting level, and the moment-to-moment activity level (Wang & Degol, 2014). Within the literature it has been well-established that behavioural, emotional and cognitive components (Table 1) drive a global concept of engagement (Fredricks, Blumenfeld, & Paris, 2004). Other components of engagement have been proposed. This includes social engagement, which describes the quality of social interactions with peers and adults, and the willingness of students to invest in forming new relationships and maintaining existing ones (Wang et al., 2016). Reeve and Tseng also propose a distinct fourth dimension of engagement; agnetic engagement (Reeve & Tseng, 2011). This is defined as "students' constructive contribution into the flow of the instruction they receive" (ibid., p. 258). For the purposes of this report, I will focus on behavioural, emotional and cognitive engagement, as these are the constructs of engagement which are best established in the literature.

Component of engagement	Description	Reference
Behavioural	Refers to a student's involvement in academic tasks, and the absence of positive conduct	Fredricks et al., 2004; Wang et al., 2016
Emotional	A student's emotional reaction to academic subjects, teachers, peers and classroom-activities	Wang et al., 2016
Cognitive	Involves self-regulated learning, where student becomes psychologically invested and expends cognitive effort in order to understand and use deep learning strategies	Wang et al., 2016

Table 1: Definitions of behavioural, emotional and cognitive engagement

Aside from the dispute on how many different sub-compartments of engagement exist, there is also an on-going discussion of whether engagement is distinct from motivation (Martin, Ginns, & Papworth, 2017). Theories of motivation are "concerned with the psychological processes that underlie energy, purpose and durability of human action" (Skinner & Pitzer, 2009, p. 22). However, whilst traditionally motivation has received the bulk of the focus in the literature, more recently efforts have been made to define the difference between motivation and engagement. One significant way of separating motivation from engagement is to define motivation as the underlying psychological process, and engagement as a descriptor for the level of involvement between student and activity (Ainley, 2012). As such, this study will focus on engagement as an "outward manifestation of motivation" (Skinner & Pitzer, 2009, p. 22), which concerns itself with the quality of interactions of students with learning activities. Overall, the definition of engagement is still a topical focus for educational research. However, as I will explore in the next section, understanding and maximising student engagement is critical for optimising school attendance and academic outcomes.

Engagement of students with science

Engagement has been found to be a major predictor of academic success in schools, and a strong predictor of likelihood of school dropout (Skinner & Pitzer, 2009; Finn & Zimmer, 2012; Janosz, 2012). Therefore, it is important to maximise student engagement in teaching of science. However, recent studies have painted a dismal picture with regards to attitudes towards science in secondary school students. Students' attitudes towards science decline from the first year in secondary schools, and engagement overall decreases with the onset of adolescence (Fredricks et al., 2004;

Mahatmya, Lohman, Matjasko, & Farb, 2009). Further studies into the underlying reasons for students' dissatisfaction with science at school cite reasons such as that school science lacks relevance, consists of too much repetition, gives few opportunities to discuss the implications of science, and overemphasises copying as the standard form of writing (Tytler & Osborne, 2012).

In particular, girls' attitudes towards science are significantly more negative than those of boys. Data from the Relevance of Science Education (ROSE) project showed that in England, girls are more likely to think that science is a difficult subject, which they dislike (Jenkins & Nelson, 2005). Boys are also more likely to agree that science is interesting compared to girls (ibid.). Overall, gender has been identified as one of the key determinants of student engagement with science (Tytler & Osborne, 2012). One of the reasons stipulated as to why girls are less engaged with science at school is that the curriculum is favoured towards a way of thinking that is more commonly associated with boys. This argument derives from the work of Gilligan, who showed that moral development is different in men and women, and that the latter place more importance on issues of relationships and connection (Gilligan as cited in Billingsley, Nassaji, & Abedin, 2017, p. 29). Further work extending from this origin went on to explore the idea that women have distinct 'ways of knowing', which involves making connections to the subject being studied (Brotman & Moore, 2008). Overall, it could be argued that girls are more interested in exploring the wider context around questions and knowledge in science, and reluctant to say that they have an understanding of a subject unless they can see how it fits into a broader context. On the other hand, boys tend to accept scientific concepts as inherently valuable, and are more comfortable thinking about these concepts in a concise, rules-based system (Billingsley et al., 2017)

However, although there is much research available to argue that the above statements are well founded, there should be caution when suggesting the idea that girls prefer a particular style of learning. Firstly, this may serve to reinforce the gender binaries that produce inequalities in the sexes that are seen in the uptake and completion of science courses in secondary education, higher education courses, and in the presence of women in wider STEM (science, technology, engineering and maths) careers worldwide (Brotman & Moore, 2008). Secondly, it has been recognised that not all girls may prefer this style of learning. In fact, previous studies have shown a range of responses, both positive and negative, to learning science through SSIs (Morris, 2014a). Nevertheless, a concerted effort is required to plug the flow of women out of science, as it is well documented that participation of women in science is considerably lower than that of men. This report continues by exploring reasons why student engagement in science in UK schools could be improved, with a particular focus on why girls in particular are marginalised from secondary school science.

The impact of compartmentalisation on the science curriculum and student engagement

Students' negative perceptions of their science education could be, at least in part, attributable to the science curriculum in English secondary schools. It has been argued that the focus on high-stakes testing has led to a narrowing of the curriculum, including a reduction in time being spent exploring SSIs (Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006). The narrowing of the school curriculum may also have led to the compartmentalisation of subjects, owing to the notion that little time is spent creating and fostering links between subject areas (Billingsley, Brock, Taber, & Riga, 2016). To be specific, compartmentalisation can be defined as "the creation of rigid boundaries between subject disciplines that make it difficult, if not impossible, for students to bridge those disciplines" (Billingsley & Ramos Arias, 2017, p. 44). Results from the Learning About Science and Religion (LASAR) project shows that compartmentalisation stifles student curiosity, and their capacity to ask and explore big questions, and also leaves students with a number of gaps, confusions and misconceptions about scholarship and epistemic insight (ibid.). Compartmentalising subjects is sustained by subject-specific curriculum documents, examinations, teacher education and- in secondary schools- specialist teacher recruitment and subject-specific classrooms (Billingsley et al., 2017).

Furthermore, girls might be more negatively affected by entrenched compartmentalisation than boys, with regards to learning, understanding and interest in science (Billingsley et al., 2017). This is because, as discussed above, girls tend to favour placing scientific concepts into a wider context in order to cement their understanding. Therefore, by limiting the opportunities where students can link what they are learning to other subjects and their relevance to students daily lives, girls are more likely to be less interested in science when it becomes compartmentalised.

Socio-scientific issues in science education

One approach for challenging compartmentalisation of the science curriculum, and therefore enhancing engagement of girls in science, is to utilise SSIs in the science classroom. SSIs can be defined as problems that represent social dilemmas with conceptual, procedural or technological associations with science, and involve ethical and moral dimensions (Morris, 2014b). A primary feature of SSIs is that they are multidisciplinary in nature, because of the need to have understanding across multiple subjects in order to address these problems (ibid.). For example, studying SSIs could include application of scientific concepts, addressing the historical, philosophical and sociological aspects of science, and considering contemporary economic, social and political concerns such as in health and the environment (Hughes, 2000a). In 2006, a new General Certificate of Secondary education (GCSE) was introduced, based on the model of '*Twenty First Century Science'*. This course contained a strong emphasis on teaching about SSIs, enhanced engagement in students (Millar, 2006) and increased the uptake of science courses by students in post-compulsory education in the UK (Millar, 2010). However, despite there being evidence to demonstrate the effectiveness of teaching SSIs in science classes, the teaching of basic skills such as scientific argumentation and scepticism, is not prevalent in mainstream science teaching (Fensham, 2016). Furthermore, Hughes argues that SSIs are marginalised and devalued in UK classrooms, since they are presented as a subordinate form of knowledge compared to the 'true' abstract scientific concepts. Hughes extends this idea to contend that this serves to reinforce the gender imbalance in science, as SSIs are regarded as female-orientated, whereas more 'rigorous' science is seen as masculine (Hughes, 2000a). Further evidence suggests that opportunities to study SSIs in A-level science are squandered due to heavy syllabus content demands and assessment deadlines (ibid.). Therefore, more importance must be placed on the value of SSI in the science curriculum, and this includes reinforcing an appreciation that SSIs can enhance all students understanding of science, and develop scientific literacy (Hughes, 2000b).

Nevertheless, there is evidence that utilising a SSI-approach for teaching science enhances engagement of girls (Hughes, 2000b; Morris, 2014a). As argued above, SSIs are inherently multidisciplinary, and they give girls the opportunity to make links between important scientific subjects and a wider context, such as how they are relevant in the wider social world. Therefore, SSIs can be argued to be a promising approach to enhancing engagement of girls in science.

The nature of science

Compartmentalisation of science and marginalisation of SSIs also arguably decreases student knowledge of 'the nature of science' (NOS). NOS as a phrase refers to "characteristics of scientific knowledge that are inherently derived from the manner in which it is produced, that is scientific enquiry" (Lederman, Antink, & Bartos, 2014, p. 286). It can be defined as being comprised of the concepts listed in Table 2. Ensuring that students have a solid appreciation for NOS has increasingly been seen as an important focus in the drive to develop scientific literacy in science curricula around the world (Lederman et al., 2014). This argument has developed in recent years, as citizens in the world have to make sense of the increasing impact that science and technology have on their daily lives. With a fundamental understanding of NOS and enhanced scientific literacy, citizens will be better able to recognise pseudoscientific claims, distinguish between 'good' and 'bad' science, and apply scientific knowledge to their everyday lives in order to make better informed decisions (Bell & Lederman, 2003; Lederman et al., 2014).

Components of NOS
The empirical nature of scientific knowledge
Scientific theories and laws
The creative and imaginative nature of scientific knowledge
The theory-laden nature of scientific knowledge
The myth of the scientific method
The tentative nature of scientific knowledge
The social and cultural embeddedness of scientific knowledge

Table 2: Components of NOS
(as defined by Lederman, Adb-El-Khalick, Bell, & Schwartz, 2002)

NOS and SSI are inherently intertwined. This is because, in order for an individual to make informed decisions about scientifically based social dilemmas, they must be able to analyse and measure the reliability, validity and inherent scientific value of the evidence available, and draw upon these reflections alongside moral and ethical standpoints that they, or wider society, may hold. Furthermore, by teaching science through SSIs, an inherently multi-disciplinary approach, it gives space for students to develop an epistemic insight, or 'knowledge about knowledge'. Therefore, not only is teaching science through SSIs a valid approach to enhancing the engagement of female students, but it also broadens their understanding of NOS and improves scientific literacy.

Research questions

In this report, I aim to study whether the use of SSIs in teaching year 9 girls about global warming and climate change can enhance their engagement. Furthermore, since SSIs and NOS are intrinsically linked, I aim to also determine whether this approach to teaching about global warming and climate change can enhance students understanding of NOS. These aims are reflected in the research questions (RQ):

RQ1: How does using socio-scientific issues enhance engagement in a year 9 class learning about global warming and climate change?

RQ2: How can using socio-scientific teaching methods enhance knowledge of NOS in year 9 girls?

Research Design

Action research

Within school-based and practitioner-led educational research, action research is an approach by which teachers engage in a process of self-reflective enquiry, in order to understand and improve their own practice (Wilson, 2009). As such, this report details action research on whether teaching global warming and climate change using an SSI-based approach can enhance engagement in year 9 girls. The following sections detail the rationale of undertaking this research and identification of research questions, and the design of the intervention to address these questions. The report continues to discuss the validity and reliability of the data, the implications of the research for practitioners, and the relevance of the findings in a wider context. Finally, suggestions for furthering the research are made.

Identification of research questions

Observations made in the science department of the school at the centre of this action research project identified that students were generally behaviourally and emotionally engaged in their science lessons. I saw very few examples of disruptive behaviour during lessons, and students interacted positively with teachers and their peers. Students appeared to be engaged with the work and successfully learning scientific concepts. However, very little time (often no time) was spent discussing SSIs in the classroom, as most of the lesson time, especially in KS4 and KS5 lessons, was geared towards delivering content that was necessary for preparing students for terminal examinations. Students asked very few of their own questions and were focussed on ensuring that they had captured information that would be relevant to the examinations. For these reasons, I questioned whether students were truly engaging cognitively with their work in science lessons in

KS4. Having read some of the literature discussed above, I postulated that SSIs may be a more engaging way of delivering the necessary content on climate change and global warming in a KS4 class. Some pilot data was collected prior to the intervention lessons (pre-intervention questionnaire), which suggested that students were only moderately engaged in science lessons (see Table 6 later).

Intervention design

Having identified the research questions, the planning phase of this action research study involved designing a number of lessons to utilise SSIs to teach students about global warming and climate change.

Context

The intervention described in this report was implemented in 4 lessons of 100 minutes each, delivered to a year 9 class of girls at a single-sex academy in England. Students were mostly from affluent homes who are looking for a traditional academic education for girls. Therefore, the majority of students are from middle-class homes with high aspirations and expectations. Two pupils had SEN status, and two were classified as receiving the pupil premium grant. No students had English as an additional language. The class comprised 29 students who were predicted a wide range of grades.

Data collection and analysis

Data was collected via mixed methods, utilising both qualitative and quantitative measures of student engagement. Table 3 gives an overview of the data collected, and indicates whether the measure was conducted pre, during or post the intervention. Details of each data collection method are then given below.

Pre-intervention	During intervention	Post-intervention
• Student engagement questionnaire (pre) (Quantitative)	• Reflections on student engagement (Qualitative) • Lesson observations (Qualitative)	• Student engagement questionnaire (post) (Quantitative) • Focus group interviews (Qualitative) • Teacher questionnaire (Qualitative)

Table 3: Overview and timeline of data collection

Student engagement questionnaire

Self-evaluation of engagement in students was determined using 'The Math and Science Engagement Scales' (Wang et al., 2016). These scales were developed to provide a self-report measure of engagement within the dimensions of behavioural, emotional and cognitive engagement. The authors also added a fourth dimension to the construct of engagement; social engagement. However, since the fourth dimension of social engagement has not been qualified in other areas of the literature and because it was deemed outside of the scope of this investigation, questions asking for the self-evaluation of social engagement were not included in the questionnaire. The original questionnaire contains 33 elements (including questions on social engagement). However, because of limited time available, the number of elements included on the questionnaire in this study was limited to 12. Questions included are found below in Table 4, alongside the sub-division of engagement which they are assessing. The questions were issued to students before the intervention lessons began, in order to assess students' underlying engagement in science classes. Students responded to each question on a Likert scale. The responses were numbered 1-5 from strongly disagree (1), to strongly agree (5), and the mean response of students to each question calculated along with the standard deviation in student responses. To gauge whether student engagement in the intervention lessons was different to lessons pre-intervention, the questionnaire was re-issued and the mean response calculated for each question. To get a better understanding of the impact of the intervention lessons on student engagement, descriptive statistics were used to examine the distribution of student responses. The percentage of students that replied 'agree'/'strongly agree' was compared to the percentage of students who 'disagreed'/'strongly disagreed', and the results presented in a bar graph. In the post-intervention questionnaire students were also asked some open-ended questions to assess their engagement via asking them what they enjoyed and did not enjoy during the intervention lessons.

Question	Component of engagement
I think about different ways to solve a problem	Cognitive
I stay focussed in science lessons	Behavioural
I talk about science outside of class	Behavioural
I think that science is boring	Emotional
I often feel frustrated in science lessons	Emotional
I enjoy learning new things in science lessons	Emotional

Table 4: Questions included on the pre- and post-intervention student engagement questionnaire and relation to sub-division of engagement

Reflections on student engagement

After each intervention lesson I completed some reflections on the engagement of students during the activities in the lesson. These comments were written under the headings of behavioural, emotional and cognitive engagement.

Lesson observations by teacher

During the intervention lessons, the usual teacher of the class was asked to make general observations of the lessons. Comments relevant to student engagement were captured and used as qualitative evidence for engagement of students during the intervention lessons. The comments were coded as evidence for behavioural, cognitive and emotional engagement.

Focus group interviews

At the end of the intervention, students were interviewed in focus groups to give them an opportunity to deliberate, and elaborate about questions on what they thought of the SSI-focussed activities, and their knowledge of NOS. Interviews with the focus groups were audio-recorded, transcribed and passages of the conversations were grouped accordingly into areas of focus of engagement and NOS. The focus groups were unstructured and the students were asked open questions to assess their engagement during the different intervention lessons, and their knowledge of NOS.

Teacher questionnaire

After the intervention lessons, the regular teacher of this class was issued with two open ended questions to assess student engagement throughout the intervention.

Assessing student knowledge of NOS

As part of the post-intervention student questionnaire, students were asked the open-ended question 'What is science?'. Student responses were coded into groups (Table 5), and the incidence of each response was counted. This question was also put to students during the post-intervention focus groups, alongside the question 'What is the difference between scientific facts and moral judgments?'. This qualitative evidence helped to elaborate on students' responses, and further their explanations of their knowledge of NOS. Previous studies have indicated that open-ended questions are best suited for assessing knowledge of NOS (Lederman et al., 2002).

Description	**Code**
Students gave an answer which directly referenced understanding how the world works, or an answer that suggested as such	Understand how the world works
Students referenced the use of theories or laws in producing scientific knowledge	Theories
Students referenced the use of experimentation in producing scientific knowledge	Experiments
Students referenced that scientific knowledge relied on having empirical evidence or data	Evidence
Students gave a specific example of a scientific concept that they had learned about	Descriptive learning of scientific concepts
Students suggested that science was the study of everything, or words to that effect	Study of everything

Table 5: Coding of student responses to the question 'What is science?'

Limitations

When designing and assessing educational action research, reliability and validity must be considered. Reliability refers to the 'rigour, consistency, and above all, trustworthiness of the research' (Evans, 2009). This can be further divided into internal reliability (regarding the reliability of the data collected), and external reliability (whether the same conclusions of this study would be reached in a different context) (ibid.). The methods for data collection and presentation of data are clear and transparent to support the internal reliability of this investigation. The questionnaire used to assess student engagement has been previously validated as a reliable tool (Wang et al., 2016). Establishing external reliability in this study is particularly difficult, as the ever-changing context of the classroom is dependent on multiple factors including the students present within the class, the teacher leading the lessons and school-wide factors. Therefore, the context of this report is explicit, and any conclusions reached can only be applied directly to the population under investigation.

The validity of a study can also be subdivided into external validity (whether the study can be generalised beyond the context under investigation and transferred to a wider population) and internal validity (whether the study measures what it purports to investigate) (Evans, 2009). The external validity of this study is limited, partly since it is undertaken in an single-sex environment and also because of the inherent variance in the ethnographic classroom context. Nevertheless, by placing the questions that this report strives to answer in a wider context of the available literature, the reader can assess the generalisability and transferability of the results of this study. As has been previously discussed, there are several problems with measuring engagement in the science classroom (Sinatra, Heddy, & Lombardi, 2015). This includes the notion that student engagement cannot be measured by a single measure. Self-report measures of engagement, such as that offered by Wang et al. (2016), suffer from issues such as the inherent problem of asking students to be retrospective. To overcome this issue, observations of students during lesson activities can be made in real-time. However, observations in themselves can be problematic, as they rely on inferring student engagement from indirect external indicators. Furthermore, observations can be biased due to the observer involved demonstrating positive bias towards examples of engagement and leaving out examples of negative engagement. Therefore, this study utilises a mixed method multidimensional approach to measure engagement of students in science lessons. The evidence is then triangulated, a practice whereby findings are confirmed through the use of different data collection instruments to overcome threats of validity within each type of evidence.

Ethics

This study was undertaken within the guidelines on educational research ethics issued by the British Educational Research Association (BERA) (2011). In line with these guidelines, a number of steps were taken to ensure students understood and agreed to the research, had the right to withdraw and were not disadvantaged whilst participating in this project. This included an explanation of the research project to students pre-intervention, with an opportunity for them to ask any questions about the research. Students were also provided with an information and consent letter which was to be signed by parents/guardians before the study began. All letters were returned signed by parents/guardians giving consent for their child to participate in the study. Students were advised prior to audio recording of the focus group interviews, and given the opportunity to opt-out of this data collection. All data has been anonymised in this report.

Results

Results were collected as described above and are presented and analysed below in two sections based on the research questions of this study.

How does teaching climate change through SSIs impact year 9 girls engagement?

Student perception of their engagement during intervention lessons

When students were asked to reflect on their engagement during the intervention lessons, the results were varied. Mean scores calculated from the pre- and post-intervention engagement questionnaire responses of students are presented in Table 6. In order to get a clearer idea of whether student's engagement had shifted over the course of the intervention, the percentage of students that 'agreed'/'strongly agreed' versus those that 'disagreed'/'strongly disagreed' were compared. Students who reported a neutral position were not included in either of the two categories. Consequently, percentages in the final bar charts may not total 100%. For example, in Figure 1, 24.1% of students agreed with the statement 'I think that science lessons are boring' before the intervention lessons. This rose to 31% of students agreeing with the statement after the intervention lessons. Furthermore, the percentage of students that disagreed with the statement 'I think that science lessons are boring' rose from 41.4 pre-intervention, to 51.7 post-intervention. Accordingly, although not presented, students that were neutral before the intervention totalled 34.5%, which decreased to 13.8% after the intervention lessons. Results are presented below (Figure 1 to Figure 6 – the order of figures does not follow the ordering of questions in Table 6). The overall percentage of students that agreed or disagreed are compared in Table 7 and Table 8, respectively.

	Pre-intervention		**Post-intervention**	
Question	**Mean**	**SD**	**Mean**	**SD**
I enjoy learning new things in science lessons	3.52	1.09	3.61	0.83
I think about different ways to solve a problem	3.41	0.82	3.11	0.88
I stay focussed in science classes	3.45	0.74	3.39	0.88
I talk about science outside of class	2.62	1.21	2.32	1.06
I think that science is boring	2.83	1.04	2.75	1.17
I often feel frustrated in science lessons	2.97	1.18	2.43	0.96

Table 6: Mean scores from a post-intervention questionnaire to measure engagement of students in lessons with a SSI-focus

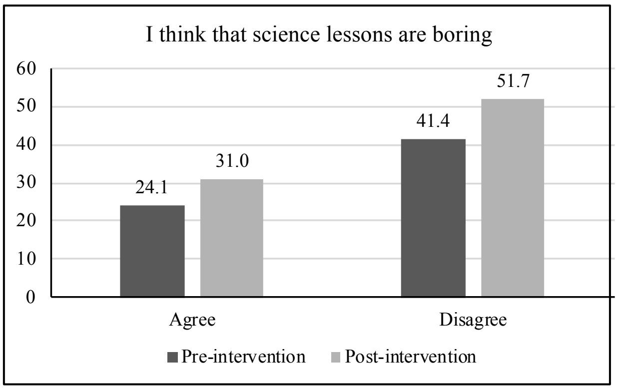

Figure 1: I think that science lessons are boring

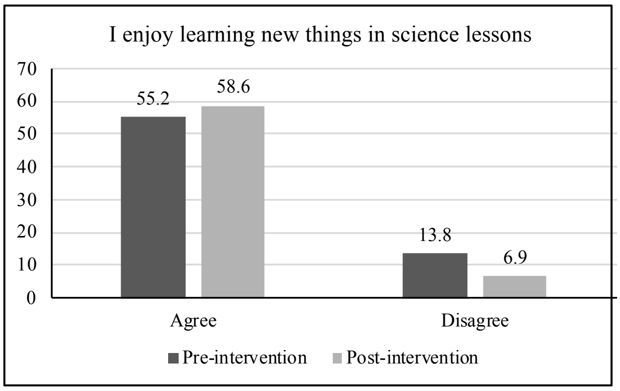

Figure 2: I enjoy learning new things in science lessons

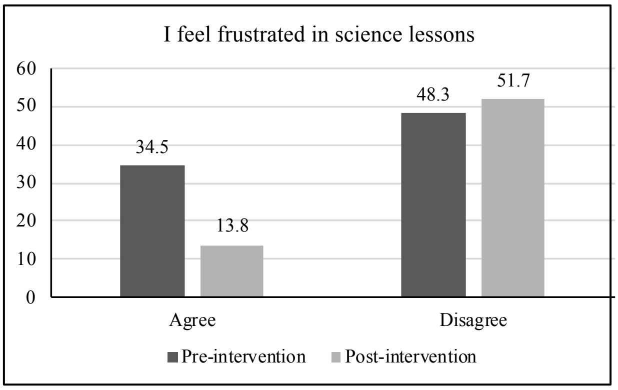

Figure 3:
I feel frustrated in science lessons

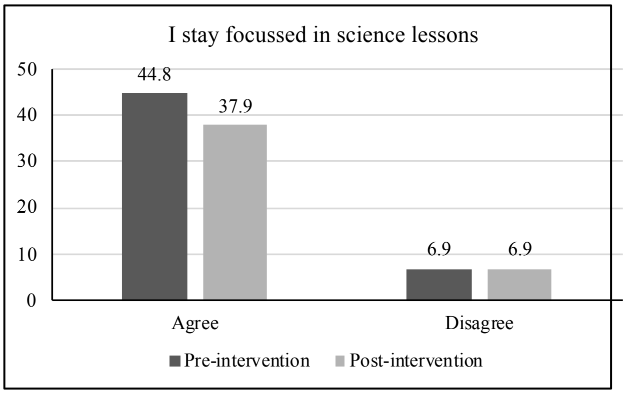

Figure 4:
I stay focussed in science lessons

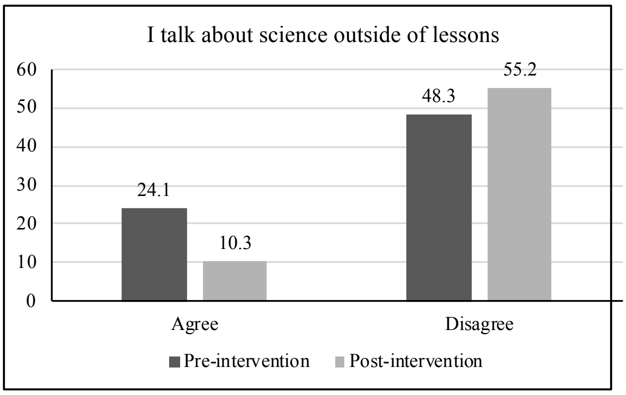

Figure 5:
I talk about science outside of lessons

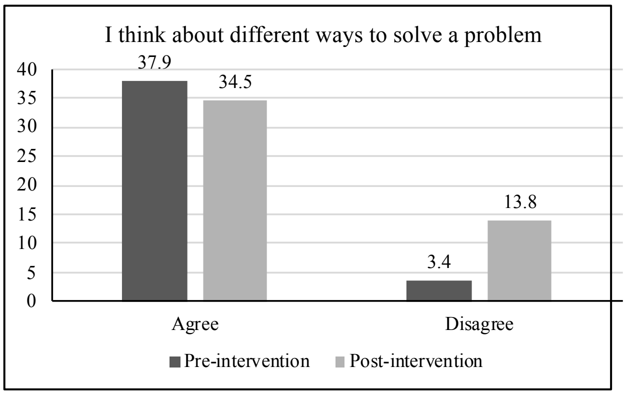

Figure 6
I think about different ways to solve a problem

Responses from the engagement questionnaire are mixed, as shown in Figures 1-6. In terms of behavioural engagement, students responses suggested that they were slightly less focussed during the intervention lessons (Figure 4), and students reportedly spoke less about science outside of lessons during the intervention (Figure 5). In fact, the percentage of students who agreed with the statement ‘I talk about science outside of class’ fell by 13.8 percentage points after the intervention lessons (Table 7). Furthermore, results from the measurement of students emotional engagement were also mixed. Students were polarised in response to the statement ‘I think that science is boring’ (Figure 1), with the numbers of students who both agreed and disagreed with the statement rising after the intervention lessons. However, analysis of the changes of student responses pre- and post-intervention showed that there was a bigger change in the percentage of students disagreeing with this statement (an increase of over 20 percentage points, Table 8), than there was in those that agreed (an increase of 6.9 percentage points after the intervention lessons, Table 7). On the other hand, another measure of emotional engagement, 'I enjoy learning new things in science lessons' showed little change after the intervention (Figure 2). Nevertheless, over half of students agreed that they enjoyed learning new things in science both pre- and post-intervention, and the number of students that disagreed with the statement was generally low. These results suggest that students found the intervention lessons slightly more enjoyable than their normal science lessons. In addition, the largest difference between the pre- and post-intervention questionnaire was in response to the statement 'I feel frustrated in science lessons' (Figure 3), where there was a decrease of approximately 20% in the number of students who agreed with this statement. Finally, in relation to cognitive engagement, students' agreement with the statement 'I think about different ways to solve a problem' becomes more negative when thinking about the intervention lessons (Figure 6).

Question	**Pre-intervention**	**Post-intervention**	**Pre-post difference**
I enjoy learning new things in science lessons	55.2	58.6	+3.4
I think about different ways to solve a problem	37.9	34.5	-3.4
I stay focussed in science classes	44.8	37.9	-6.9
I talk about science outside of class	24.1	10.3	-13.8
I think that science is boring	24.1	31.0	+6.9
I often feel frustrated in science lessons	34.5	13.8	-20.7

Table 7: Percentage of students that agreed with the engagement questionnaire questions pre- and post-intervention

Question	Pre-intervention	Post-intervention	Pre-post difference
I enjoy learning new things in science lessons	13.8	6.9	-6.9
I think about different ways to solve a problem	3.4	13.8	+10.4
I stay focussed in science classes	6.9	6.9	0
I talk about science outside of class	48.3	55.2	+6.9
I think that science is boring	31.0	51.7	+20.7
I often feel frustrated in science lessons	48.3	51.7	+3.4

Table 8: Percentage of students that disagreed with the engagement questionnaire questions pre- and post-intervention

However, evidence from other sources suggested that there was more impact on student engagement than was reflected by the engagement-element of the student questionnaire. Open ended questions included at the end of the post-intervention questionnaire provided some evidence that students did enjoy elements of the intervention lessons. The responses were grouped into categories and scored for the number of responses that were present in the answers to these open-ended questions (Table 9, Table 10). The largest number of responses to the question 'what did you enjoy about these lessons?' (Table 9), were recorded in reference to students enjoying moving around the classroom. Other elements of the intervention lessons that students enjoyed were partaking in different activities to normal, and working in groups or with others. One student responded that they enjoyed learning in a different style to usual, suggesting that at least some students were aware that lessons were conducted in a different fashion to usual.

Student response	Number of responses
Moving around the classroom	8
Different activities to normal	6
Working in groups/with others	5
Researching information	2
Learning in a different style	1
Taking notes	1
Nothing	1

Table 9: Student responses on the post-intervention questionnaire to the question: 'What did you enjoy about the lessons?

Table 10 shows responses of students from the same questionnaire, to the question 'what did you dislike about the lessons?'. Students mostly disliked the amount of writing involved in these lessons, and that the homework set was more lengthy, or harder to complete. Evidence to suggest that students found the work harder in these lessons was also evident in a comment from a lesson observation made by the regular teacher; *'students did note (through informal conversations) that it was harder work'*. Aside from this, other negative responses to the intervention lessons were mainly focussed on tasks that were outside of SSI-activities. For example, watching videos and completing associated tasks (classified as 'tasks that were not SSI-focussed in Table 10).

Student response	**Number of responses**
Amount of writing/taking notes	4
Too much homework	3
Tasks that were not SSI-focussed	2
Nothing	1
Everything	1
No experiments	1
Having to write in your own words	1
Freedom to choose who to work with	1

Table 10: Student responses from the post-intervention questionnaire, to the question: 'What didn't you enjoy about the lessons?'

One student replied that they enjoyed nothing about the intervention lessons, and didnot enjoy everything about the lessons. The pupil in question is a low attaining student who requires support for special educational needs including working memory, processing speed, reading speed and visual tracking. The responses of this student in the questionnaire correlate with some reflections I made during the intervention lessons on the fact that lower attaining students struggled to access the SSI-based activities. For example: '*I noticed that lower attaining students were struggling more with answering the questions at each station. However, when I went over to encourage them I could coax the answers out of them by phrasing. This might reflect that they had some difficulty understanding what the questions were asking of* them'. Furthermore, in the post-intervention teacher questionnaire, the teacher of the regular class reflected that *'Lower ability students needed much more guidance to be able to access work and activities. They often lack the skill to begin such open-ended inquiries or to research/question on their own [and it seemed like these students] often felt confused about what to do/purpose of activity/learning and instead just copied down work from peers. This widens the achievement gap for lower and higher ability students'*. Therefore, results from this investigation suggest that whilst teaching climate change through SSIs is engaging for some students, lower attaining students may experience some barriers to learning in that the materials are perhaps more cognitively demanding, and these students struggle to access them.

During the focus groups, students were asked open-ended questions on their thoughts of each of the intervention lessons. The results showed a variety of reactions to activities within these lessons, which provided a more detailed insight into the results from the post-intervention questionnaire, as to the specific parts of the lessons that engaged or disengaged students. A summary of student responses can be found in Appendix 1. Students made several positive comments with regards to activities that involved moving around the classroom, such as the data analysis activity in lesson one, and the is-ought activity in lesson four. These included that they enjoyed moving around the classroom as it involved being active, and that they enjoyed the fact that this sort of activity involved them finding out information for themselves, rather than it being delivered to them by the teacher.

On the other hand, students also reported some negative feelings towards this kind of task. In some cases, this related to being active, which highlights that students each have differing opinions on the sorts of classroom activities that they enjoy. Further reasons for disliking this active sort of task included that some students disliked the logistics of these types of activity. For example, students disliked that they had to move their belongings around the room, and also because there was an element of time pressure which meant not all the students completed the activities (Appendix 1). Several students referenced that they enjoyed these active tasks and other tasks that were SSI-focussed just because they were inherently different to what they usually do in science lessons. A prime example was using the computers to research and write a letter to challenge climate change denial. The task of writing this letter was also enjoyable for students, who gave reasons such as that they enjoyed researching the information on the internet before applying it into a piece of work. The idea that students enjoyed these kind of autonomous research task was reinforced when one student suggested that the pollution debate could have been enhanced by adding a research-element to the activity, where students could find out the information for themselves (Appendix 1). Therefore, students reported several features of the SSI-focussed activities within intervention lessons that they enjoyed and were engaged with. These include working with others, being active in the classroom, and doing activities which were different to normal.

Observations and reflections from teachers on student engagement during intervention lessons

Evidence of student engagement was also monitored by observations from the regular teacher of the class, and via my personal reflections on engagement during the lessons. The regular teacher of the class also filled in a questionnaire at the end of the intervention, commenting on student engagement during the intervention lessons. These results showed that students showed many external signs of engagement throughout the intervention lessons. Results were coded as evidence for behavioural, emotional and cognitive engagement, although due to the inter-linked nature of engagement subdivisions, some evidence spanned several of these categories. High levels of behavioural engagement were recorded in my own reflections on the lessons throughout the intervention. For example, with regards to the last intervention lesson, I noted; *'Positive conduct through the lesson, as always with this class. They responded to instructions well and were easy to manage behaviour-wise'*. This demonstrates that when focussing on a lesson-wide perspective of engagement, students were generally behaviourally engaged across the delivery of the intervention lessons. Evidence from the regular teacher of the class focussed more on behavioural engagement during specific tasks. For example, when commenting on the SSI of how we know that humans are causing increased global warming, the teacher commented that; *'High level of student engagement- students on task and worked hard to complete work.'* This provides some evidence that students were behaviourally engaged in SSI tasks.

The evidence for behavioural engagement overlaps somewhat with emotional engagement. For example, during my own reflections, I recorded that in the second intervention lesson; *'There was a good positive attitude in the room generally, I feel as if I have built a good relationship with these students, despite a limited amount of teaching time with them. I feel the novelty of being a new teacher might have impacted this. Also, students were very intrigued with the idea of being part of a research study and I think they might be very curious to see what happens in the next few lessons*.' This evidence suggests that the emotional engagement of students is, at least in the context of the level of the classroom, is partly dependent on the relationship with the teacher. Evidence that supports this idea is evident from the post-intervention questionnaire completed by the regular teacher of the class states; '*Students really enjoyed group work and opportunity to discuss ideas with both peers and teachers'*. All in all, evidence from my reflections, and comments from the regular teacher of the class suggest that students were behaviourally and emotionally engaged throughout the intervention lessons.

During the intervention lessons, students were found to be cognitively engaged with the SSI-focussed activities. Evidence to support this notion are found in comments from the regular teacher of the class in their lesson observations and the post-intervention interview. These include '*Students* *thinking critically*', '*Students were motivated to discover answers on their own and many refused to use hints even when provided',* and*; 'Activity encourages students to make links across lessons on their own – for example, "Can I use information from my homework in the letter"'*. Cognitive engagement was also evidenced by students engaging in questioning throughout the lessons, as I noted: *'One station that provoked a lot of questioning was the information about pigs being sentient and being able to have empathy for the suffering of other animals. This activity led onto a good discussion about whether humans should eat meat or not, and how people should treat the Earth's resources in general.'* This was also supported by the statement ' '*Evidence of student engagement based on number of hands up (many wanted to contribute!)'*, which came from a lesson observation by the regular teacher in lesson one of the intervention. Therefore, results from this study suggest that using SSIs to teach climate change could enhance the cognitive engagement of girls in science.

How can using SSIs enhance knowledge of NOS in year 9 girls?

As discussed, SSIs and NOS are inherently intertwined, because studying SSIs requires an understanding of multiple disciplines. Therefore, a secondary aim of this investigation was to see whether teaching through SSIs also enhanced students understanding of NOS. Students were asked to answer the open-ended question 'what is science?' in both post-intervention questionnaires (Figure 7) and during focus groups (Table 11). Results from both sets of data showed that students generally classify science as a subject that aims to understand how the world works. For example, one students response after the question was posed in a focus group was '*The study of the Earth and how it works'*. Some students alluded to a more wholesome view of NOS, including ideas about theories, experiments and collecting evidence. Whilst these ideas mainly came from higher attaining students, one lower attaining student's response was; *'It is full of theories, and guesses, and then it is proven'*. This therefore suggests that both higher and lower attaining students are able to formulate ideas about NOS.

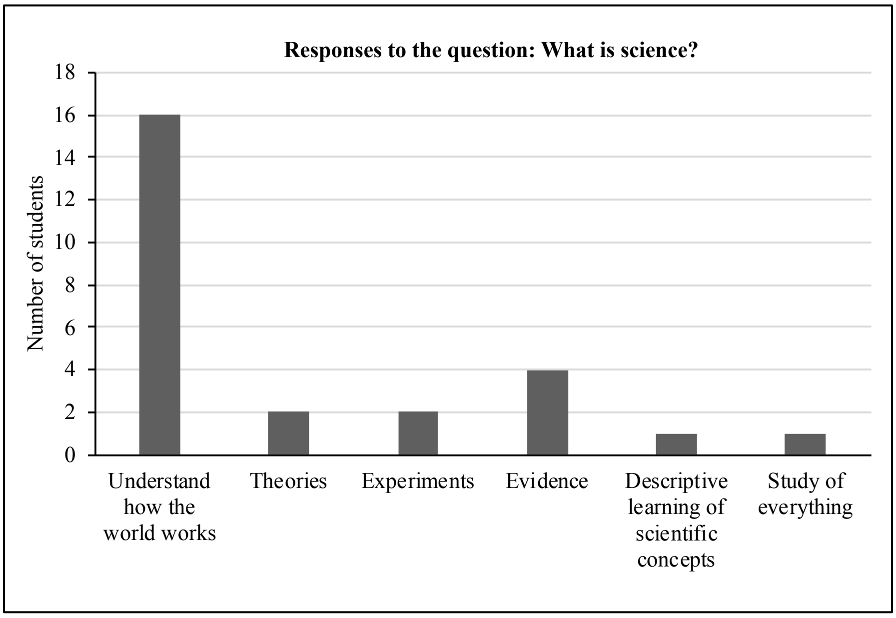

Figure 7: Results from a student questionnaire showing number of students whom included different responses to the open-ended question; what is science?

Overall, results showed that students had a limited perception of NOS. From the evidence described, it could be argued that teaching through SSIs had little impact on students' knowledge of NOS. However, in the final intervention lesson, students used 'scientific' statements to help them make moral judgments, therefore directly addressing the differences between these two epistemologically distinct sources of knowledge. When students were asked, as part of focus groups, 'what is the difference between scientific facts and moral values?' (Table 12), many could distinguish between the idea that moral values are ultimately subjective, alluding to the idea that they are based on an instinct or opinion. On the other hand, they made comments to imply that they understood that scientific knowledge is more objective, or required evidence. For example; *'Moral values are like a judgment about how you should do something, whereas science is like, evidence'.* This evidence insinuates that teaching through SSIs can help students to evaluate and advance their epistemic insight, and develop an understanding of NOS.

What is science?
S: It's like an insight into the world *I: Do you agree?* S1: It explains how everything works S2: It's understanding everything, and understanding how it works S3: What is the actual definition of science? I'm curious now!
S: The study of the earth and how it works S1: It's not just the Earth S: It's like how we got here S2: It's the study of the unknown S: That's.... that's good! *I: But, you could say that Philosophy is the study of the unknown, could you not?* S2: Yeah, but philosophy uses science to do stuff as well *I: Well that's true, but are they different subjects?* S2: Yes. *I: Why?* S2: Well they both use science, philosophy is more emotional and more about philosophical big questions, whereas science is the study of *everything* that is unknown. Because I mean, philosophy can come under science, because you need to do experiments, and gather evidence, and all these scientific things, in philosophy, it's just that in philosophy, you're taking it more with your own opinion than you do with natural science
S: Oh science, science is erm, a subject that you learn at school S1: Learning about the world, it's very informational, about the world S2: It explains things, stuff about the world S3: Yeah it's just explaining things that happen in the world *I: But say, we could explain things that happen in the world, for example in religious studies as well, like they're kind of explaining what the world is like. Why is science different to that?* S: It's not facts S3: It just describes it S2: It's not factual S: When you look at religion, and you think about faith, then you can't really see a lot of the time, whereas science provides actual proof...
S: It is full of theories, and guesses, and then it is proven S: I have no idea what science is like S: It explains like about the earth, and what things are, and why things happen S: I think science is science S: It is a broad topic explaining why things, and how things happen

Table 11: Student responses during focus groups to the question: what is science?

What is the difference between scientific facts and moral values?
I: And do you think it's the same kind of knowledge? Like the scientific facts and the moral judgments. Is that the same kind of knowledge? Or are the different? S: I think they're different. *I: Why do you think they're different?* S: Because with moral judgments, they're more like instinct, so. But with scientific facts, it's more like a range of evidence
I: So we were thinking about using scientific knowledge, and using moral values. Do you think they're two different things? Scientific facts and moral values? S: Yes S1: Yeah S2: Yes *I: Why do you think that?* S: Because if science isn't right, it could prove nature wrong. S2: But then science is very to the fact, but then morals are more of a grey area S: One's more opinion S1: Yeah because you could be biased S2: But then without science, you don't have any facts to back it up, you just have opinions
S: I think they're different types of knowledge, but they like help each other S1: One's like opinion and the other ones fact S2: I think that a moral judgment is more based on like the emotions that you feel, and your opinion S?: But that's also based off of scientific facts S2: Yeah but the scientific facts provide evidence and facts to influence your judgment. The moral decision is what you make on the facts *and* from your opinion
I: So tell me, do you think there is a difference between scientific facts and moral values? S: Yeah S1: Yeah S2: Yeah *I: What's the difference?* S: I have a good answer. *I: Go on then.* S: Scientific facts are proven, and moral values are a erm, rough suggestion or opinion. S1: Moral values are like a judgment about how you should do something, whereas science is like, evidence.

Table 12: Results from student responses in focus groups to the question 'is there a difference between scientific facts and moral values?'

Summary of results

Overall, the results from this action research project suggest that the engagement of students can be enhanced by teaching global warming and climate change through the use of SSIs. The findings are summarised below:

- Overall, from a self-reporting measure, results do not imply that students perceived an increase in their engagement during the intervention lessons
- Evidence from teacher reflections and lesson observations suggest a high level of engagement with SSI-focussed activities during the intervention lessons
- Students reported high levels of engagement during activities in which they were active and worked with others
- Using SSIs to teach about global warming and climate change can enhance student understanding of NOS, by exploring differences between different types of knowledge

Discussion

How does using socio-scientific issues enhance engagement in a year 9 class learning about global warming and climate change?

The results of this investigation tentatively suggest that using SSIs to teach global warming and climate change could increase the engagement of students. Although students self-reported a positive effect of this teaching strategy on their engagement in only some measures, other evidence from teachers, open-ended questionnaire questions and focus groups suggest that there was an increased level of engagement during SSI-focussed activities.

There are several reasons why the results from the student questionnaire did not reflect the evidence from other sources. Firstly, the timing of the intervention may not have been long enough to raise students perception of their own engagement. Another reason may be that the self-report measures were broadly phrased (e.g. I enjoy learning new things in science), rather than focussing on the specific SSI-focussed tasked used in the intervention lessons. Therefore, one reason why the self-report measure results did not correlate with results from other sources of evidence may be because the focus was on reporting different levels of the engagement of students. The self-report questionnaire gathered evidence on student engagement in the intervention lessons as a whole, whilst teacher observations, self-reflections, and evidence from focus groups focussed more on the SSI-focussed tasks themselves. Furthermore, some have argued that because of the subjective nature of self-report measures, they should only be used to assess emotional and cognitive engagement, because collecting data on these subtypes from other methods is highly inferential (Fredricks & McColskey, 2012). This may be another reason why evidence from the self-report measure and other sources of evidence did not provide the same results, as external and internal indicators, and how they are reported and recorded, could provide differences in the data collected.

One further well recognised issue with self-report measures of engagement is whether students answers accurately reflect their actual feelings (Fredricks & McColskey, 2012). In other words, the answers students give may be influenced by multiple external factors. For example, the questionnaires were issued in an open-environment where students could see one other students answers. Furthermore, although students were reassured that their answers were anonymous, they still may not have felt comfortable enough to answer the questionnaire honestly. In addition, in the post-intervention questionnaire, students may have answered in order to try and 'please' both myself or the regular teacher of the class. Ultimately, the context in which these questionnaires are issued and answered will impact upon the answers given. This includes relationship with teachers and peers, the attitudes of students at the particular time of issuing the questionnaire, the classroom environment and other school-wide factors. In fact, recent reviews of self-report measures found that few of these approaches for data collection were psychometrically sound measures of student engagement, which were able to capture a multidimensional construct (Fredricks & McColskey, 2012; Fredricks et al., 2016).

This investigation tentatively supports the idea that using SSIs to teach about global warming and climate change increases the engagement of students in science lessons. However, it is very difficult to specifically pinpoint the source of student engagement (Sinatra et al., 2015). For example, the use of SSIs in the intervention lesson was implemented via activities that involved students actively moving around the classroom and working with others. Separating whether it was the utilisation of SSIs themselves, or the nature of the activities was the source of student engagement is incredibly difficult. During focus interviews, students often referenced the fact that they enjoyed moving around the classroom and working with others. However, activities where they were not moving around the classroom (for example, writing the letter to challenge climate change on the computers) were also engaging for students. Nevertheless, the data from this study is limited with regards to identifying the source of engagement of students in science lessons, and further research is necessary in order to draw conclusions as to whether SSIs intrinsically enhance engagement, or whether the nature of these activities enhance engagement.

The problem with trying to define what exactly is underpinning the increase in student engagement observed in this study is further highlighted when one considers the difficulties with defining engagement within the literature. For example, although the aim of this study was to influence students cognitive engagement, there is still a vast amount of deliberation as to the exact definition of cognitive, behavioural, emotional engagement, and even if engagement is a multi-dimensional construct (Fredricks & McColskey, 2012; Fredricks et al., 2016). In this study the term engagement has been accepted as multidimensional, but even then, the boundaries that divide these compartments are fluid, with each affecting the others. With this in mind, findings from this study can only be said to enhance engagement as a global construct which refers to our original definition as the "observable and unobservable qualities of interactions with learning activities" of students (Ryan & Deci as cited in Wang et al., 2016, p.17). Whilst the effect of the SSI-focussed activities was assessed in terms of the impact on cognitive, emotional and behavioural engagement, the evidence supplied is not strong enough to prove that one of these compartments had been more affected than the others. On the other hand, picking apart such a complex, global construct such as an engagement on a scale small enough to be able to differentiate between the contributions of these different factors would be almost impossible. Therefore, it is more valid to conclude that the use of SSIs raises engagement in a more wholesome sense.

A further problem with identifying the source of student engagement is that engagement is influenced by multiple factors. For example, it has been argued that teacher warmth, adequate structure for learning and support for autonomy are the three factors which are most likely to facilitate student engagement (Skinner & Pitzer, 2009). Since none of these factors were measured throughout the intervention lessons described in this study, it cannot be certain that they influence student engagement. In addition, student engagement may have been enhanced purely by the fact that they were aware they were taking part in a research study, a problem widely cited in the literature and known as the Hawthorne effect (Evans, 2009). Ultimately, engagement is such a complex construct that trying to unpick the exact factor which is impacting students' engagement is an almost impossible task. Therefore, from this study it can be said that overall the intervention lessons, which had an element of SSIs, raised the engagement of students.

Whilst it could be said that the intervention of this action research raised the engagement of students, this finding cannot be generalised to all science classrooms. For a start, SSIs may not be applicable to all topics in science. Secondly the findings of this report only reflect the nature of girls engagement because of the fact that the school involved was of single-sex intake. As discussed above, the literature suggests that girls may be more likely to be engaged in lessons that involve SSIs because their multidisciplinary nature appeals to a female way of knowing which seeks to connect their understanding to wider contexts, but this isnot to say that boys will not be engaged by a similar style of lesson. Some of the results from this study showed that one of the reasons students gave for having enjoyed the lessons was because it was in some way ‘different’ to their typical science lessons. If all science was taught through SSI-focussed aspects, this may become routine and therefore less engaging if it is what students come to expect in their lessons. Therefore, the idea that using SSIs can raise engagement in science lessons will always be context dependent.

How can using socio-scientific teaching methods enhance knowledge of NOS in year 9 girls?

When students were asked to define science, the majority incorporated the idea that the subject described how the world works. This response doesnot reflect many of the ideas that others (Lederman et al., 2002) have described within the concept of NOS. These include ideas about the empirical, tentative, creative and theory-laden nature of scientific knowledge (ibid.). Therefore, it could be argued that these intervention lessons did little to enhance student understanding of NOS. On the other hand, a minority of students did allude to the idea of scientific facts and theories. These tended to be higher attaining students, who may have already addressed these metacognitive concepts at stages other than the intervention lesson. However, the majority of students could highlight the idea that science as a subject refers to facts or evidence to make an argument, and that moral judgments are more subjective and dependent on one’s own opinion. Furthermore, one previous study has also suggested that using SSIs in the teaching of global warming enhances student understanding of NOS (Sadler, Chambers, & Zeidler, 2004). Therefore, there is some evidence to suggest that by teaching through the use of SSIs, students compare different epistemological approaches, and can start to appreciate science as a particular kind of knowledge.

On the other hand, in the present study, students did not have the opportunity to investigate all aspects of NOS. Furthermore, not all aspects of NOS are relevant to teaching through SSIs. For example, the ‘myth of the scientific method’ (Lederman et al., 2002). That is, students generally believe that there is a fixed set and sequence of steps by which scientists work to answer a scientific question; when in reality different investigations follow very different paths (for example, descriptive, correlational and experimental scientific inquiry). This aspect of NOS may be better investigated during practical sessions or explored within a historical approach to explaining the experiments that underpin some of our knowledge of scientific concepts. Therefore, whilst this study suggests that SSIs can enhance student understanding of NOS, in order for students to develop a wholesome view of NOS, more time needs to be devoted to studying this subject with multiple approaches.

Conclusions

Recommendations for practice

Overall, this study recommends the use of SSIs when teaching global warming and climate change to year 9 girls. This approach can enhance some aspects of engagement and student knowledge of NOS. However, whilst this approach was moderately successful in this particular context, it may not have such a positive effect in other situations. For example, there is a need to ensure that lower attaining students are not impacted by teaching in a way which might be more demanding of higher order thinking. In addition, engagement is a complex construct which is affected by many different factors. What is apparent from this research is that activities that engage one type of student will not engage all types of student. Therefore, one recommendation that can be made is that a variety of different methods are used throughout the teaching of science to ensure that all students are engaged throughout the curriculum. However, there are certain activities that the majority of students reportedly enjoyed. These include activities where they were working with others, and those in which they get to move around the room. The fact that teaching SSIs often means interacting with others, and lends itself easily to active lesson activities perhaps underpins why this approach enhanced engagement. Therefore, these types of activities can also be utilised in classrooms in non-SSI contexts, and student engagement can still be enhanced.

Implications for future research

There is a tension between the use of SSIs, development of knowledge of NOS, and preparing students for terminal high-stakes examinations (Hughes, 2000a). Teaching through SSIs, and about NOS often takes up valuable time in which teachers also have to work through the curriculum content that students must know in order to be able to achieve good exam results. Therefore I would argue that the next cycle of action research should focus on whether SSIs can enhance students learning of climate change by studying their academic outcomes. Furthermore, the research should focus on how using SSIs can enhance the engagement and learning of all types and abilities of students.

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Appendix 1

A summary of student responses to the question 'what did you think about that lesson?' during post-intervention focus groups.

'L' - Lesson. Describes which of the specific intervention lessons of the sequence that the student was responding to.

'S'- Student. Describes a response by a student. Students are numbered in the order in which they joined in the discussion. The numbering across discussions is unrelated, (i.e. S1 does not relate to the same student throughout sections).

'I'- Interviewer. Describes further prompting made by the interviewer in order to follow up or extend students responses.

SSI activity	Evidence of student engagement from focus groups, in response to an open question of what students thought about SSI activities in intervention lessons
L1_The greenhouse effect - How do we know humans are increasing global warming?	S1: I like moving about. I'm not very good at sitting still. So when you're moving about… and we worked with people that we like working with as well. That helps because it's easy to get on with the work.
	S1: I just don't really like getting up and moving S2: I prefer that to just sitting down though S3: Yeah S4: Yeah S1: Yeah because then you have to pick up all your stuff, and then all the sheets fall out your book S2: And everyone puts their stuff over your stuff…and then it all just gets everywhere S5: I just get annoyed because there's so much writing, and by the time you'd finished two stations your hand hurts S6: I always run out of time, I never get to write what I need to write in time
	S1: It was more helpful to like analyse data, and actually…because usually you don't really think about where it comes from, you just think I've been given that, it must be right. So it helped thinking about that, but I don't know whether it was better because we moved around, or whether it would be the same if we didn't
	S1: I didn't really like it, it was interesting *I: So you thought it was interesting, but you didn't like it? What didn't you like about it?* S1: It was still about graphs
	S1: It was boring.
L2_Global warming and climate change - Challenging climate change scepticism	S1: Oh, I really liked that one [lesson]. *I: You liked that one? Why did you like it?* S1: I just like being on the computers S2: Yeah, being on the computers S3: I didn't like writing the letter, because that was just like really long *I: You didn't like writing the letter?* S4: No I didn't like it, it was just very long S5: I don't think it was very interesting

	I: You did like writing the letter? Why? S1: Because I like finding the stuff that I need to find and then putting it into something, and not just kind of writing it down in my book S2: It's fine if it's just a short thing, but if it's really long, then…it's just annoying S3: I don't know if writing a letter like that, whether really affected whether we'd remember stuff or not, cos if we're on the computer it's easy just to copy and paste things S2: We could have like just done a debate about it….
	I: The second lesson was when we went to the computer room and wrote the letter. What did you think of that? S1: That was good. S2: I liked working with the computers, it makes a change S3: I wish we got to choose our partners *I: Why?* S1: Because it's a nice change from just like, someone you work with every lesson S1: It mixes it up a little bit S1: It makes it more comfortable, like, giving your opinions. You know because sometimes, like, if they write something wrong, you don't want to say, like they might take it badly
L3_Pollution - Who is responsible for decreasing pollution	S1: I feel like it might have been better if we had done laptop research as well, rather than just looking at a sheet. Then you could use the laptop to look at different sources and different websites as well, and that could have just added to your answers a bit more…
	S1: More people speaking, because it like came down to one person, but it would have been better If everyone got to make a decision S2: Yeah I think that if you like had a group speaking, then you could all bring up different points and you could create more cross points of views
	S1: That was quite fun. S2: Yeah *I: What did you enjoy about it?* S1: I think it was good, because even though if we didn't believe that the fossil fuel company was like responsible … If you didn't believe, but you weren't that … You had to think about the argument for that. So you'd see like all the different sides
	S1: It was different S2: And we had our own jobs to do S3: It's not just writing S4: [Student A] was good at arguing as well, it was funny
L4_The Earth's resources - Should humans eat meat?	S1: Just working with different people, and going round different posters and having to write down all the information S2: Like, you're actually doing the work for yourself, and having to try and find it out from the information S3: I quite liked that too, it wasn't just about the facts and figures, it was more like morals and rights
	S1: I don't know, it just takes quite a long time to move around and find all the information, sometimes I'd rather just have the teacher tell us and we write it down, and then we write our own opinions S2: I would not like that at all!
	S1: I enjoyed it, I quite liked looking at the reasons why we should eat meat, and the reasons why we shouldn't eat meat and like the two sides to it