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Introducing Argumentation About Climate Change Socioscientific Issues in a Disadvantaged School

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Abstract Improving the ability of young people to construct arguments about controversial science topics is a desired outcome of science education. The purpose of this research was to evaluate the impact of an argumentation intervention on the socioscientific issue of climate change with Year 10 students in a disadvantaged Australian school. After participation in a professional development workshop on climate change science, socioscientific issues and argumentation, an early career teacher explicitly taught argumentation over four non-consecutive lessons as part of a 4 week (16 lesson) topic on Earth science. Thirty students completed a pre- and post-test questionnaire to determine their understanding of climate change science and their ability to construct an argument about a climate change socioscientific issue. Students' understanding of climate change improved significantly ($p < .001$) with a large effect size. There was also a significant increase ($p < .05$) in the number of categories provided in written arguments about a climate change issue. Qualitative data, comprising classroom observation field notes, lesson transcripts, work samples, and teacher and student interviews, were analysed for the extent to which the students' argumentation skills improved. At the end of the intervention, students became aware of the need to justify their decisions with scientific evidence. It is concluded that introducing argumentation about climate change socioscientific issues to students in a disadvantaged school can improve their argumentation skills.

Keywords Argumentation · Climate change education · Socioscientific issues · Disadvantaged schools

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Introduction

Internationally, people face an uncertain future, with global issues such as climate change presenting a multitude of challenges. These issues, and others, require international collaboration to ensure that solutions are found. Advances in science and technology will play a role in ameliorating the impact of these problems. It is important that school science education equips young people with the skills, knowledge and dispositions to understand and make evidence-based decisions about these issues. These issues may be personal (e.g. reproductive choices, diet, drug use) or global (e.g. climate change, use of energy resources, population control, food and water security). Individuals not only require an understanding of the underlying scientific concepts, but they require a repertoire of skills and strategies to be able to evaluate the nature of evidence (e.g. source, quality), construct and evaluate sound arguments, and justify their decisions to their peers and others both in written and oral formats. According to the Australian Curriculum, Assessment and Reporting Authority (ACARA), these skills need to be developed alongside an understanding of science (2017).

While the underlying science of these issues may have been routinely taught in school science (e.g. greenhouse effect, reproduction, energy sources, water cycle), links to the global and controversial nature of these topics were rarely made. This has changed in recent years where, internationally, national curriculum documents have been updated to include explicit reference to these complex, contemporary scientific issues (e.g. ACARA 2017). These curriculum changes have been difficult for some teachers as they challenge the traditional view of science teaching as the transmission of canonical knowledge from teacher to student (Bryce and Day 2014; Hodson 2013). Today's students need opportunities to use their science knowledge to discuss, debate and practice making decisions about issues. Indeed, opportunities to debate science in meaningful ways may enhance learning as students use their science understanding in authentic contexts rather than viewing school science as a set of disconnected facts (Newton et al. 1999).

The aim of this case study research was to examine whether an early career science teacher in a disadvantaged school, after participating in a professional development program, could teach his Year 10 (15–16 year old) students about the socioscientific issue of climate change and improve their argumentation skills. Changes in students' understanding of the science underpinning climate change and their ability to construct quality written arguments in the context of a climate change socioscientific issue were examined.

Theoretical Framework

The theoretical framework underpinning this study is based on socioscientific issues, argumentation and disadvantaged schools.

Socioscientific Issues

One of the outcomes of school science education is that students are able to use their science knowledge to participate fully in society. Science education researchers have argued that socioscientific issues (SSI) can and ought to be used as contexts for learning science (Sadler and Dawson 2012). SSI are controversial topics that have a scientific basis and are important, or of concern, to human society. They are often debated in the media with scientific perspectives and evidence sometimes in equal competition with non-scientific perspectives (e.g. vaccinations). The underpinning science of SSI is often multidisciplinary, complex, emerging and contested. In making decisions about SSI, individuals may need to consider more than scientific evidence. For example, they may need to examine social, economic, religious, ethical, or political aspects (Sadler et al. 2007). Further, Sadler et al. (2007) assert that recognising the complexity of SSI and examining them from multiple perspectives are important aspects of decision-making.

Internationally, research studies have examined the impact of introducing SSI across a range of science topics including genetics (Venville and Dawson 2010; Zohar and Nemet 2002), climate change (Bravo-Torija and Jiménez-Aleixandre 2012; Klosterman and Sadler 2010), stem cell cloning (Molinatti et al. 2010), air pollution (Simon and Amos 2011), electromagnetic radiation (Kolstø 2001), environmental conservation (Grace 2009) and biosecurity (Tomas and Ritchie 2012). Outcomes of introducing SSI into school science include improved argumentation and decision-making skills, improved understanding of science content and nature of science, increased interest and motivation for learning science, and improved student self-efficacy (Sadler and Dawson 2012).

Different approaches for the inclusion of SSI in the science classroom in research studies include the following: the use of scenarios in role plays and debates (Albe 2008; Simonneaux 2001), communities of practice (Hogan 2002; Roth and Lee 2004), virtual environments (Zembal-Saul et al. 2002) and mass media (Klosterman et al. 2012). In many studies, there is a teacher-led intervention of context-based learning, in which case studies or dilemmas are included within a science topic (Dori et al. 2003; Klosterman and Sadler 2010; Venville and Dawson 2010; Zohar and Nemet 2002). These interventions may include explicit teaching of higher order thinking skills such as argumentation, and outcomes such as conceptual understanding and argument quality are often measured. The approach to inclusion of SSI in the science classroom is varied; however, research supports the imperative role of the teacher in the success of the intended outcomes (Marin and Halpern 2011; Sadler 2004).

Argumentation

The ability to construct and evaluate arguments is important, as argumentation is a central component of critical thinking (Ennis 1985), a fundamental aspect of the human scientific endeavour (Newton et al. 1999), and has the potential to improve students' understanding of science concepts from both a theoretical perspective (Duschl and Osborne 2002; Lemke 1990) and a practical perspective (Zohar and Nemet 2002). Deanna Kuhn (1992) stated, "It is in argument that we are likely to find the most significant way in which higher order thinking and reasoning figure in the lives of most people" (p.156). Argumentation skills enable young people to make decisions and solve problems, particularly those complex problems encountered in SSI (Jonassen and Kim 2010; Newton et al. 1999; Sadler 2004). The notion of argumentation is at the heart of scientific understanding where competing claims and hypotheses are supported or disproved based on empirical evidence (Duschl and Osborne 2002). As a result, the explicit teaching of argumentation skills in science classrooms has been advocated by multiple researchers (e.g. Newton et al. 1999; Sadler 2004).

Argumentation is the development of an assertion or claim with supporting reasons and justifications. It is a "discursive and social activity that aims at convincing" (Leitao 2000, p. 333). The use of argumentation in the context of SSI is appropriate as argumentation is the "activity subjects engage in when discussing controversial themes" (p. 333). Argumentation may be done individually or in groups. An argument (written, oral, or thought) is the product and comprises a claim with data or evidence. Toulmin (2003) developed a structural framework that could be used both to assist in developing skills in generating arguments and to analyse argument quality. The parts of Toulmin's model include the following: a claim (assertion), data (relevant evidence), warrant (linking of claim and data), backing (underlying theory or assumptions to support data/warrants), qualifier (conditions under which claim or data is supported) and rebuttals (conditions where the claim or data is not supported).

The benefits of teaching argumentation within the science classroom have been widely documented and include an increase in conceptual understanding of a science topic (e.g. Klosterman and Sadler 2010; Venville and Dawson 2010; Zohar and Nemet 2002), an improvement in understanding of the nature of science (Khishfe 2014; McDonald 2010), development of citizenship values such as morality (Fowler et al. 2009) and an improvement in higher order thinking skills such as argumentation (e.g. Dori et al. 2003; Osborne et al. 2004; Wu and Tsai 2007). The potential benefits have resulted in classroom-based research about approaches to teaching argumentation at all levels of schooling from primary (e.g. Martin and Hand 2009; Howe et al. 1992) to secondary (Osborne et al. 2004; Sadler 2004; Zohar 2004).

However, concerns have been expressed by teachers about the ability of low-achieving students to effectively engage in higher order thinking skills such as argumentation (McDonald and Heck 2012; Osborne et al. 2013; Zohar et al. 2001). Yet, research has shown low-achieving students to also benefit from the teaching of these skills. For example, Dori et al. (2003) showed that in the context of biotechnology, the teaching of higher order thinking skills to Year 10–12 students significantly improved the content knowledge and demonstration of higher order thinking skills of students at all academic levels.

Focusing on the pedagogical processes used by teachers in the promotion of argumentation skills, Simon et al. (2006) developed a framework to analyse classroom dialogue. They conducted an analysis of the classroom discourse of science teachers who taught argumentation skills to their Year 8 students using an SSI about building a zoo. They compared lesson transcripts of teachers whose students' argumentation skills improved with those who had no change in order to identify the types of classroom strategies that led to improvement. Using grounded theory, they developed a framework of eight argumentation strategies used by successful teachers. The strategies were as follows: *talking and listening*, *knowing meaning of argument*, *positioning*, *justifying with evidence*, *constructing arguments*, *evaluating arguments*, *counter-arguing* and *reflecting on argument process*.

This framework then provided a diagnostic tool that could be used to assess the extent to which teachers used these processes when teaching argumentation skills in the classroom. Dawson and Venville (2010) also used this framework to evaluate classroom discussion in argumentation lessons with Year 10 students studying genetics. It was observed that the teacher used all eight argumentation strategies on multiple occasions. It was shown that after a brief intervention of two lessons, the students' argumentation skills and conceptual understanding improved more than in a comparison group of students (Venville and Dawson 2010).

McNeill and Pimentel (2010) focused on question types in their discourse analysis, dividing teacher questions into open, closed, rhetorical and managerial. Their results suggested that the use of open-ended questions played a key role in supporting quality argumentation in students. Other authors (e.g. Ben-David and Zohar 2009; Osborne et al. 2013) focus on pedagogical strategies known to improve dialogue and reasoning such as authentic contexts, small group work, student-led dialogue, effective teacher questioning and scaffolding. Scaffolding of argument development can be provided through materials such as the Science Writing

Heuristic (SWH) (Hand et al. 1999) that scaffolds students' thinking by providing prompts to generate questions, claims and evidence to support their reasoning in a scientific context.

Once classroom-based research began to be published, there emerged a critique around the use of Toulmin's argumentation model as a measure of argumentation skills (Erduran 2008; Leitao 2000). Toulmin's argumentation model outlines the structural components on an argument. It is possible that an argument could include all components yet contain false, illogical, misinterpreted, or irrelevant data and/or backings. Also, from a practical perspective, problems have arisen in identifying the components of an argument in students' oral or written work where warrants may be absent or implicit. One way to overcome this difficulty is to use coding schemes where it is not necessary to distinguish data from warrants.

Most methods of analysing argument quality focus on using coding scores or levels, which provide a measurement of complexity of both written and oral arguments in terms of one or more of the following three foci: structure, justification and content (Sampson and Clark 2008). Combinations of these foci and methods of application have been used in evaluating both written and discourse argumentation. For example, assessments focusing on structure using Toulmin have been used by Chin and Osborne (2010), Osborne et al. 2004) and Jiménez-Aleixandre et al. (2000); those focusing on content have been used by Christenson et al. (2014) and Zohar and Nemet (2002); and analysis of justification complexity has been used by Grace (2009) and Sadler and Fowler (2006).

In their review of different methods of analysis of students' socioscientific arguments, Sampson and Clark (2008) emphasise the importance of using a method which includes aspects of both structure and content. In their study of arguments in the context of genetic engineering, Sadler and Donnelly (2006) analysed position and rationale, multiple-perspective taking and rebuttal, arguing that the inclusion of multiple perspectives and rebuttals showed that a student could think beyond their own position to consider that of others. Similarly, Wu and Tsai (2007) analysed Year 10 Taiwanese students' arguments in the context of nuclear energy using not only the number of structural features of counterarguments and rebuttals but also the number and types of categories of their supporting evidence. Like Sadler and Donnelly (2006), they concluded that the inclusion of more categories indicates a greater consideration of multiple perspectives.

Nature of Disadvantaged Australian Schools

The Australian education system is committed to the principle of equity and social justice and to the goal of encouraging and enabling all children to fulfil their educational potential. Yet, national and international data on the educational outcomes of socially disadvantaged students in Australia suggest otherwise. While Australian students generally perform well on international tests, the poor achievement of Australian students from socially disadvantaged backgrounds, particularly from low socioeconomic areas and schools outside metropolitan areas, is well documented (Thomson et al. 2013; Tytler and Symington 2015).

A close examination of the Australian data in international tests such as the OECD Programme for International Assessment reveals a disturbing pattern of inequity. There are three groups of students who, at the end of their schooling (15 years of age), are up to two and a half years behind their peers. These students are from low socioeconomic backgrounds, rural and regional locations and are of Indigenous or overseas-born backgrounds (i.e. refugee or immigrant children). This educational disadvantage near the end of the compulsory years of schooling is likely to have long-term ramifications on the lives of these young people. The inequitable outcomes in PISA are mirrored in the National Assessment Program–Literacy and

Numeracy (NAPLAN) testing conducted in Years 3, 5, 7 and 9 (Lamb et al. 2015). Lamb et al. (2015) analysed Australian academic achievement data and found that one in four young people was failing to reach minimum benchmarks throughout their schooling. These children are predominantly from disadvantaged backgrounds. Schools located in disadvantaged areas are more likely to be staffed by early career teachers or staff teaching out of field (Weldon 2016).

In Australia, socio-educational advantage is measured through a scale called ICSEA (Index of Community Socio-Educational Advantage). ICSEA is a measure of educational advantage that allows comparisons of socioeconomic status to be made between schools across Australia. A school's ICSEA is calculated based on parents' occupation and education, geographical location and proportion of Indigenous students. ICSEA is set at an average score of 1000 with a standard deviation of 100. The distribution of students in each socio-educational quartile is also reported. Scores and further information about ICSEA are available on the *MySchool* website (https://www.myschool.edu.au).

The development of thinking skills (including argumentation) is especially important with low-achieving students because it can improve academic achievement in science (Zohar and Ben-David 2008). Zohar and Ben-David (2008) concluded that explicit teaching of critical thinking skills may be of more benefit to low-achieving students than high-achieving students because high-achieving students are already able to demonstrate the skills unaided. These findings are supported by Marin and Halpern (2011) who conducted a study in 'low-performing' US schools and found a significant improvement in critical thinking skills (e.g. argumentation) following short-term explicit teaching using web-based learning activities.

Significance of the Study

This study is significant because of the context, SSI topic and method of evaluating argument quality. The context of the research is an early career science teacher in an Australian disadvantaged school environment who aimed to teach and develop his students' argumentation skills in the context of a complex socioscientific issue, climate change. There are few studies focussing on argumentation in Australian schools despite the explicit requirement to teach argumentation in the Science Inquiry Skills strand of the Australian Science Curriculum (McDonald and Heck 2012). Similarly, there are only a few studies that focus on early career teachers teaching argumentation in challenging schools (e.g. Simon and Amos 2011). They examined how one UK teacher with 3 years experience used provided resources, group discussion and debate to teach argumentation to average to low-achieving 14–15-year-old students. Over two lessons, students used computer simulations to engage in a role play about policy options to reduce air pollution. The teacher found small group discussion difficult to manage. As stated previously, some teachers seem to perceive that classroom management issues, combined with a belief that students are uninterested and/or unable to develop higher order skills, prevent them from teaching argumentation (Osborne et al. 2013). Because of the extra challenges, there is a need for research on argumentation with early career teachers in disadvantaged schools.

There are many examples of SSI that could be used to promote argumentation skills. Suitable SSI are those that are controversial for young people who will generate informed discussion with a diversity of views. In this study, climate change was selected, as it is a global issue impinging on young people in all countries. The underlying science is contested and is replete with alternative conceptions (e.g. Shepardson et al. 2009). The topic of climate change appears frequently in the media and raises significant ethical and social issues. Further, climate change is now a mandated component of many international science curricula documents, including the

Australian Curriculum in Year 10 Earth and Space Sciences (ACARA 2017). Sadler (2004) recommends the use of local contexts to engage students. Although climate change is a global issue, in this study, local authentic contexts were used to develop argumentation skills.

There is much debate about how to measure argument quality (e.g. Erduran 2008; Sampson and Clarke 2008). The use of Toulmin's argumentation structure has been criticised when used alone because an argument could have all the required elements but be incorrect. Further, there is a difficulty in separating data from warrants. In this study, the presence of data, backings, qualifiers and rebuttals to measure argument structure is supplemented with identification of relevant categories. The significance of these simple measures is that they are potentially able to be used by classroom teachers to assess their students' argumentation skills.

The research questions addressed in this research study were the following:

1. What pedagogical strategies are used by an early career science teacher in a disadvantaged school to teach argumentation and climate change SSI?
2. What is the impact of explicit teaching of argumentation and climate change SSI on students' argumentation skills?

Research Design

Using a case study design, both quantitative and qualitative data were collected to address the research questions (Creswell 2012). Quantitative data comprised a pre- and post-instruction questionnaire, and qualitative data included lesson transcripts, classroom observation field notes, teacher and student interview transcripts, and student work samples. The multiple data sources enabled triangulation of the findings. Initially, a quasi-experimental design was planned where a comparison group of Year 10 students would be included in the study. However, the teacher left teaching at the end of the school year, and we were unable to include a comparison group. University and school sector ethics approval were obtained prior to commencing the study. The school is not identified and pseudonyms are used throughout.

Context and Sample

The study was conducted in a low ICSEA school with an early career science teacher (Mr M) and his 31 Year 10 students. The science classes were not streamed and comprised students of variable academic ability. The school in this study has an ICSEA of 926 with 58% of students in the bottom socio-educational advantage quartile and only 3% of students in the top quartile. In the 2015 NAPLAN (the year the study was conducted), students in Grade 7 and 9 performed below the Australian average in numeracy and all literacy components (*My School,* 2017). The school population comprises a high proportion of refugee children from sub-Saharan Africa with more than half (59%) of the students speaking a language other than English at home. Mr M was in his third year of teaching and had previously worked in the mining industry. He had an undergraduate degree in physical science, and a 1-year Graduate Diploma in Education.

Professional Development and Curriculum Resource

Before the argumentation lessons, Mr M participated in a formal half-day professional development workshop with other science teachers interested in improving the teaching of climate change. Here, he was provided with a climate change curriculum resource. The format of the professional development workshop and the development of the climate change curriculum resource has been reported elsewhere (Carson and Dawson 2016). Briefly, the professional development workshop provided information about recent developments in climate change science, the nature of SSI and strategies for teaching argumentation skills. The curriculum resource aligns with the Australian curriculum in science and focuses on overcoming common alternative conceptions about climate change. The resource also includes up-to-date information about climate change science, classroom activities and writing frames related to argumentation about climate change SSI. The writing frames contain questions to scaffold the development of a quality argument and can be used individually, in small groups or as a whole class. In addition to the formal professional development, Mr M was provided with pre-readings regarding SSI and argumentation. At each of three subsequent classroom visits, Mr M met with one of the researchers to discuss and reflect on his approach to teaching argumentation. This collaborative approach ensured that Mr M was an active participant in the research.

Classroom Argumentation Lessons

Prior to teaching the lessons, Mr M was provided with suggested activities from the workshop to use when teaching argumentation. The suggested structure of the classroom intervention, which occurred over four lessons, was to introduce the nature of SSI and controversy using familiar contexts, to introduce the idea of how to convince or persuade others, to explicitly introduce Toulmin's argument model using familiar examples and to practice and reinforce argument construction using writing frames. The writing frames comprised two scenarios (wind farms and waste-to-energy) which had been trialled previously with Year 10 students from five schools (Dawson and Carson 2017). The context of a wind farm was based on a local issue where a company had planned to build a wind farm on farming land that was being used for grazing sheep and cattle. In this scenario, students' role played a local farmer and they needed to decide and justify whether they would or would not allow a wind farm to be built on their farm. The second scenario related to the burning of rubbish to generate electricity and generate landfill. At the time of the study, a northern suburbs city council was considering building a waste to energy plant.

The purpose of the questions in the writing frames was to scaffold individual and whole-class argument construction. After reading the scenario and making a claim or decision, the first question asked students to provide as many reasons as possible to justify their decision (encouraging explicit data and backings). Students were then asked to consider the disadvantages of their decision which encouraged qualifiers and students who were asked what they would say to convince someone who disagreed with their claim (to encourage rebuttals). Finally, students were asked if they had changed their claim (to encourage reflection).

The argumentation lessons including the scenarios and pre- and post-instruction questionnaire had previously been trialled in a pilot school with a science teacher and her 29 Year 10 students. The teacher had previously participated in a genetics professional development workshop on argumentation and taught argumentation in a genetics context. The students were not studying Earth science at the time and the teacher briefly introduced climate change and the greenhouse effect before teaching argumentation over two 60-min lessons. The students experienced no difficulty completing the wind farm writing frame.

Data Sources and Analysis

Data sources comprised classroom observations, lesson audio transcripts, a questionnaire conducted before and after the climate change topic, and teacher and student interviews.

Classroom Observations

Comprehensive field notes were recorded and three out of four 55-min lessons were audiotaped and fully transcribed. The sequence of learning activities was summarised into a case record. The lesson transcripts were analysed using Simon et al.'s (2006) framework that listed specific strategies used by teachers to successfully introduce argumentation. Teacher-student and student-student dialogue was coded and tallied to determine the extent to which each strategy was used.

Teacher and Student Interviews

The teacher was interviewed on three occasions about the intended outcomes of the lessons and his perceptions of what students learned. At the end of the argumentation lessons, six students of variable academic ability (selected on that basis by Mr M) were interviewed in pairs about their perceptions of the argumentation lessons and what they had learnt. Although unintended, all of the students spoke English as a second language. The teacher and student interviews were fully transcribed and analysed to identify emergent themes (Creswell 2012).

Questionnaire

Thirty students completed a written questionnaire before and after learning about climate change SSI and argumentation. The questionnaire comprised two parts. Part 1 measured students' understanding of climate change science and the greenhouse effect. The maximum score was 30. There were 12 multiple choice questions on climate change and the greenhouse effect. Nine questions were selected from the Climate Science Knowledge Inventory (Lambert et al. 2012) with the remainder from online climate change quizzes. The questions selected aligned with the science content of Year 10 Earth and Space Sciences (ACARA 2017). In addition, there were six true/false questions and three open-ended questions about the definitions and consequences of climate change and the greenhouse effect. These questions had been trialled and coded previously with Year 10 students (Dawson 2015; Hansen 2010; Klosterman and Sadler 2010). Students' responses for each question were coded and entered into SPSS. Students' scores pre- and post-test were compared using a one-way repeated measures ANOVA. The reason that students' understanding of climate change and the greenhouse effect was examined was to see if students' understanding still improved when studying SSI and argumentation. It is not intended to link any changes in understanding to changes in argumentation.

Part 2 comprised a SSI scenario about hydrogen fuel buses where students were asked to read the scenario, make a decision and construct an argument to defend their decision (see Appendix). The scenario described a trial to compare hydrogen fuel and diesel fuel buses in the city where this study was conducted. After the trial, despite the lower greenhouse gas emissions, the government ceased the use of hydrogen fuel buses citing cost as the reason. Students were asked whether this was the correct decision (with choices of "yes", "no" and "I don't know") and to justify their decision.

Face validity and construct validity of the scenario used to measure argumentation quality was ensured through a two-phase development and piloting process (Dawson and Carson 2017). In Phase 1, scenarios were written using authentic contexts that had generated community debate in recent local media reports and were related to climate change issues (in this case reducing greenhouse gas emissions), and contained an obvious controversy. The authors had previous experience writing scenarios (Dawson and Venville 2010). Five current teachers of Year 10 science checked the language difficulty and relevance of the underlying science in the hydrogen fuel bus scenario. Minor word changes were made and a definition of carbon dioxide equivalent was added. In Phase 2, the scenario was trialled with 159 Year 10 students from five diverse schools. The written responses were examined and coded using Toulmin's argumentation structure. Through this process, it was determined that Year 10 students could develop arguments comprising data, qualifiers, backings and rebuttals and be coded into levels according to argument complexity. Using an inductive approach, the content of the arguments was examined and four discrete categories which were clearly distinct (environmental, economic, human factors, ethical) were identified. A small proportion (6%) was coded as *other*. All 159 arguments were subsequently coded blind by two researchers with an agreement rate of 90% (Dawson and Carson 2017).

In this study, the students' arguments were analysed using two methods. First, to determine the structural quality of the argument, a classification scheme based on Toulmin's argumentation framework was used (Toulmin 2003). Arguments were assigned a level or score from 0 to 4 depending on the presence of claims, data, warrants, backings, qualifiers and rebuttal. Level 1 arguments consisted of a claim only; level 2 arguments comprised a claim and data/warrant; level 3 arguments included a claim, data/warrant, backing OR qualifier OR rebuttal; and level 4 arguments included a claim, data/warrant, backing AND qualifier OR rebuttal. No response was scored as 0. Second, types of categories were identified in each statement, coded (i.e. environmental, economic, ethical, human factors) and scored as a *1* for each category. The total number and type of categories/argument were tallied. An exemplar of each of the four levels and each category is presented in Table 1. All students' written arguments were anonymised and coded blind by two researchers with an agreement rate of 90.3%. Where there was disagreement, these were discussed until a consensus was reached. Because the data were non-parametric, pre- and post-instruction scores were compared using a Wilcoxon signed rank test.

Results

Implementing Argumentation and SSI in the Classroom

In addressing research question 1, qualitative data comprising classroom observation field notes, work samples, interview transcripts and lesson transcripts were examined to determine the types of strategies used by Mr M. He was a keen participant in the climate change professional development and afterwards asked if he could participate in the research and teach argumentation and SSI as part of a 4-week (16 lesson) Earth Science unit. During the first interview, he stated that his students were 'mostly English-as-a-second language students' and that he thought that argumentation scenarios could potentially improve their literacy skills.

The Earth Science unit covered carbon and water cycles, weather and climate, ocean currents, consequences of climate change and the enhanced greenhouse effect. Initially, Mr M planned to spend two lessons on argumentation. However, he taught four non-consecutive 55-min lessons. Figure 1 summarises the key activities that occurred over the four lessons.

Table 1 Exemplars of student arguments and categories

Argument level	Exemplar
Level 2 (claim and data/warrant)	Claim: No. This is because even though you are paying an expensive price, it will benefit us greatly in the future by reducing the amount of carbon released in air *(data)*. Therefore, paying that expensive price will seem like we are paying for a better environment. (pre 766)
Level 3 (claim, data/warrant, backing OR qualifier OR rebuttal)	Claim: Yes. I think the WA government made the right decision *(claim)* as the buses would cost a lot of money and would put our state to bankrupt *(data)* meaning we will have to cut down on other expenses and Centrelink payments for those who are struggling *(backing)* just so we can have ecofriendly public transport. Also not many people uses buses as many own cars *(data)* which means it is not really helping the environment. The different it will make is not very big. (pre 740)
Level 4 (claim, data/warrant, backing AND qualifier or rebuttal)	Claim: No. The reason for this is because as the statistics showed, 300tCO_2e were saved by using these types of buses *(data)*, which indicate that a great number of tCO_2e had been prevented from entering the atmosphere and causing further damage *(backing)*. Furthermore, it is also stated that the only waste emissions produced are water and heat *(data)*; therefore, less harmful greenhouse gases are produced *(backing)*. If less greenhouse gases are produced *(qualifier)*, this means that the damage to the natural balance of producing greenhouse gases is slowed down *(data)*, which means that by using this Ecobuses, it will be worth it for the long run as this will be beneficial for the environment *(backing)*. Therefore, the cost would not matter to the WA government because paying for the Ecobuses is like paying for a better future as less damage will be done to the environment. (post 766)
Category	
Economic	Although the price is too high, I believe that it is more worth the money because the more people that get on the bus, the more amount of money you will receive back. (post 759)
Environmental	With Ecobuses, you can slow down carbon dioxide process to the atmosphere. (pre 748)
Human factors	Making our environment nice and clean is the best way for human to live healthy. (pre 751)
Ethical	We are going to be living here for a long time, so we should respect it and keep it clean. (pre 757)
Other	If the temperature becomes warmer, our buses may not be able to operate. (pre 767)

The first argumentation lesson introduced students to what an SSI is and to argumentation structure (i.e. claim, data, backings, qualifiers and rebuttals) and quality (e.g. consideration of multiple perspectives and alternative options, use of scientific evidence). Mr M used a provided argument exemplar about mining in a marine park. In this example, a marine biologist and a miner are debating whether or not mining should be allowed in marine parks. The context is authentic and controversial as requests to mine marine parks arise frequently in coastal areas and generate debate in the media over the need to preserve species' habitats versus the need for jobs and economic prosperity. The exemplar does not conclude with one correct answer. Rather, students' attention is drawn to different views and the need to justify their decisions with evidence.

An SSI about using a wind farm as a renewable energy source was then introduced. Using a writing frame, students were asked to work by themselves to respond to questions about

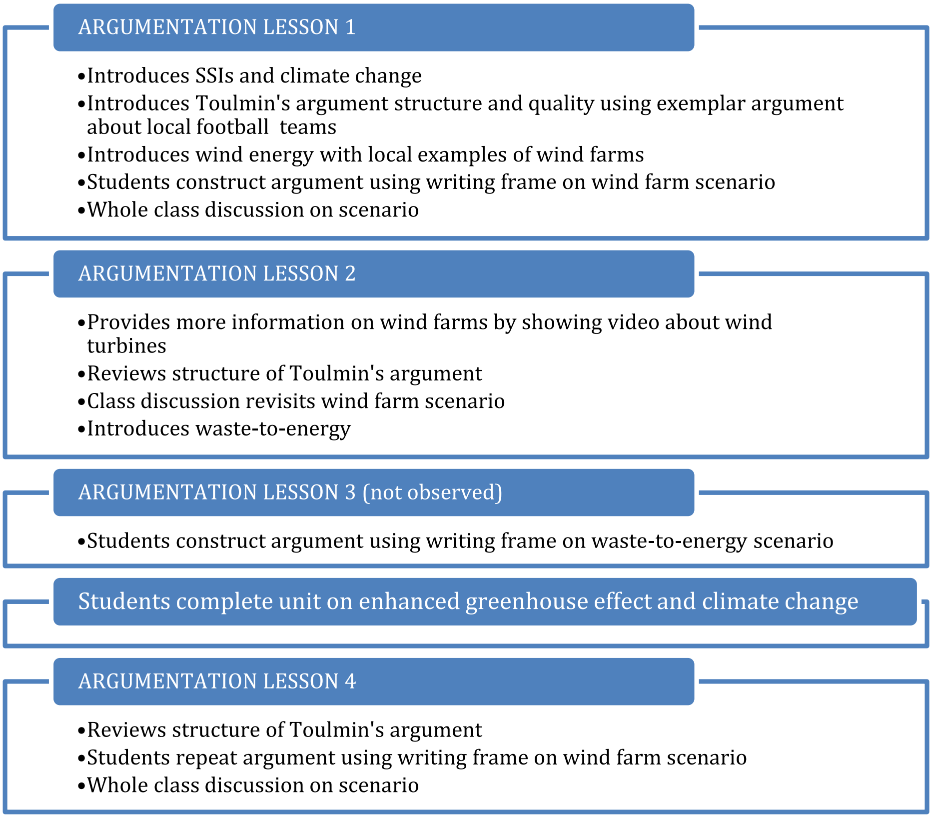

Fig. 1 Key activities used in argumentation lessons

whether or not wind turbines should be built on farm land. As outlined in the method, the wind farm SSI had been trialled previously with Year 10 students (Dawson and Carson 2017). However, some of these students did not know what a wind turbine was. The teacher had assumed that because students had studied renewable and non-renewable energy sources in Grade 9 and wind turbines appear frequently in the media, they would know about them. In this first lesson, it was observed that Mr M spent considerable time monitoring and addressing behaviour issues. There was considerable off-task student behaviour from individual students (e.g. walking around the classroom, swearing loudly, calling out, hitting each other with rulers). This behaviour was distracting to other students.

Once Mr M became aware that students did not know what wind turbines were, in the second lesson, he showed a video explaining the structure and purpose of wind turbines. He then redistributed the wind farm writing frame and reviewed parts of an argument using a recent persuasive essay students had written on the big bang theory as an example: “It’s a bit like you’ve got a claim as your introduction, what statement you’re making about the big bang theory; what statement you’re making about climate change. Your data, your backings and your qualifier, will be those 3 or 4 paragraphs that follow it up… So you guys know how to do this.” He focussed especially on data and rebuttals using whole class discussion, as evidenced in the following: “Your friend might say, ‘Yeah they don’t make any [greenhouse gas emissions] but it doesn't matter because humans don't do it anyway [cause climate change] and you can give them the greenhouse gas emissions argument… there as a rebuttal'."

He then introduced a second SSI on waste-to-energy recycling. He began a class discussion by asking students what they knew about waste-to-energy. "Do you know what happens to your garbage from home?" After determining that most students were not familiar with the concept of burning rubbish to create electricity, he described the process. "Trucks load into a bin basically and they burn it. They boil the water and the steam turbine makes our electricity and out into the grid. Remaining ash takes up about a tenth of the space." This initiated a class discussion about the possible toxins from burning rubbish, as well as the benefits of recycling.

In the third lesson (not observed due to an unexpected change in lesson sequence), students completed the writing frame on the waste-to-energy SSI. Analysis of students' writing frames demonstrated that all students answered at least one question and most students had completed all questions. The fourth lesson was towards the end of the unit after students had been taught about the enhanced greenhouse effect and consequences of climate change. Mr M re-introduced the importance of argumentation in science: "Argumentation is to help us make decisions. It's to use as a vehicle in your science for not just learning about things like the greenhouse effect, but for thinking scientifically in such a way that if you have an opinion on something, you provide evidence." He reviewed argument structure using the exemplar argument on marine parks and mining and the wind farm SSI from the first lesson. Students worked in small groups of 2–3 on the wind farm SSI writing frame, and Mr M moved from group to group providing individual help where needed. Although off-task behaviour persisted, students appeared to be more focused than in previous lessons. Mr M spent time discussing the importance of evidence and the reasons for students' claims, actively guiding students to support their claims with data and backings. For example:

> Mr M: What are the pros of having one? What are the pros of saying 'yes'?
> Student: Guaranteed income.
> Mr M: Guaranteed income for sure. So droughts, floods etc, if you're going to lose your crops or your sheep, at least from that chunk of land you have a guaranteed income from the company.

The three lesson transcripts were coded and analysed for the extent to which argumentation strategies as described by Simon et al. (2006) were evident. Table 2 provides a description of each strategy and an example from the lesson transcripts. Analysis of the lesson transcripts revealed that the argumentation processes of *knowing meaning of argument, positioning, justifying with evidence, constructing arguments, evaluating arguments* and *reflection* were explicitly encouraged by Mr M. *Talking and listening* and *counter-arguing* were not reinforced. Counter arguing and debate are important skills if students are to convince others of their claims.

Teacher and Student Interviews

After the argumentation lessons, Mr M stated that the writing frames and teacher-led discussion did assist students in developing their argumentations skills and literacy. He explained, "It's a bit more like English, more literacy focused by accident really, but it also gives the structure of scientific arguments." He considered that argumentation was a "vehicle for learning" as students "connected information", improved 'oral skills of English as a second language learners' and helped students to "apply knowledge to the real world."

Table 2 Examples of argumentation strategies demonstrated in argumentation lessons

	Argumentation strategy	Evidence from transcripts
1.	Talking and listening (Variable due to frequent off-task student behaviour)	In lesson 1, six students dominated whole class discussion In lesson 4, small group discussion occurred in pairs or threes and students did listen to each other
2.	Knowing meaning of argument (Demonstrated through provided exemplar and reinforced)	Mr M: We need to be thinking about arguments and using argumentation as a vehicle for you understanding climate change and also having the scientific literacy skills to present an argument with quality backing that makes sense, reasoned arguments with evidence so that you can make good decisions in the future. (lesson 2)
3	Positioning (Actively encouraged ideas by using the scaffolded questions on the writing frames, writing student responses on whiteboard)	Mr M: Amir, I'm telling you, you're a farmer and you said 'Yes I want one on my property', what's good about that for you? (lesson 2)
4	Justifying with evidence (Limited in whole class discussion. Evident in writing frames)	Bahar: So due to droughts, so farmers will experience droughts and number of crops will fall. Mr M: And that is because of what? So this drought is because of what? Bahar: Umm… increase in temperatures. (lesson 3)
5	Constructing arguments (An exemplar was provided to students. Writing frames supported argument structure. Not regularly reinforced in discussion)	Mr M: Once you have found out all the information and decided to make a decision based on what you got, what are the advantages of your decision? What is good about what you have decided? What are the possible advantages of your decision? (lesson 1)
6	Evaluating arguments (Encouraged in teacher led discussion)	Mr M: Hey Jon, who had the better argument? The environmental scientist or the oil company? Jon: Environmental scientist, because the other one was too short. Mr M: Because it was short? Zara: No because it wasn't persuasive. Jon: It had no facts. (lesson 1)
7	Counter-arguing (Infrequent)	Mr M: There is also the rebuttal that is a statement made that considers and responds to a counter-claim…. For example, I believe global warming is caused by humans, others may say that it is not, however scientific data shows a rising global temperature occurring at the same time as the rising atmospheric CO_2. So that is a rebuttal. (lesson 1)
8	Reflecting on argument process (Asks about mind change. Only one student changed their mind but all were asked)	Mr M: That's alright though. At the end of the day it is OK to change your mind. So why did you change your mind? If you changed your mind, answer question 5 and tell me why you changed your mind. (lesson 2)

The students who were interviewed supported the lesson transcript evidence that Mr M used explicit strategies to encourage the development of their argumentation skills. Quotes provided by students that show they were aware of argumentation strategies included the following:

> The PowerPoint showed an argument, a scientific argument and how we should structure it. (741) *(2 - knowing meaning of argument*).
> I reckon you can really provide two different opinions. Even though you might be helping our environment, it has a negative side to it as well sometimes, like the side effects, or some people don't like it, and it kind of opens up the subject a bit more when learning about it. (760) (*3 - positioning*).

You need stuff to back it up. A lot of facts and examples. (742) (*4 - justifying with evidence*).
He helped me to understand how to make better arguments. (742) (5 - *constructing arguments*).
You have to have facts and if you give simple answers, your argument is not good enough. (759) (*6 - evaluating arguments*).
We discussed it as a class and I think we had a very open conversation with everyone putting their hands up and asking questions. That also made me change my mind to a *yes* because he was able to give me proof and evidence about the turbines. (760) (*8 - reflection*).

Argumentation Quality

In addressing research question 2, the quality of students' written arguments about the hydrogen fuel bus was analysed using two coding schemes. A total of 30 students completed the pre- and the post-instruction test. There was no change in the proportion of students' claims about the hydrogen fuel bus trial with 23 students writing "no", six students, "yes" and one student, "I do not know," both before and after instruction. The students' written arguments about the hydrogen fuel bus were scored from 0 to 4 using Toulmin's argument structure of Levels 0 to 4 as outlined in the method and previously trialled (Dawson and Carson 2017). Because the data was non-parametric, differences in argumentation levels before and after the argumentation lessons were compared using a Wilcoxon signed rank test. Figure 2 summarises the argumentation levels before and after the lessons. There was a non-significant overall increase in the structural quality of students' levels of argumentation from 1.90 ± 0.48 to 2.10 ± 0.61.

The categories provided by students in their arguments were also coded according to the coding scheme previously developed (Dawson and Carson 2017). It was shown that students' arguments could be coded as environmental, economic, human factors, ethical or other. The number of categories before and after instruction is summarised in Table 3. Because the data was non-parametric, a Wilcoxon signed rank test was used to compare the number of categories stated by students before and after instruction. After the argumentation lessons, there was a significant increase in the mean number of categories from 1.37 ± 0.93 to 1.73 ± 0.74 $z = 2.40$ (corrected for ties), $p < 0.05$, with a small effect size of $d = 0.31$. After instruction, there was an increase in the number of students providing environmental reasons (60 to 87%) and economic reasons (40 to 60%), no change in human factors (17%) and a decrease in ethical reasons (17 to 7%) (Table 4).

Understanding of Climate Change

In order to determine whether students' understanding of climate change science improved, students' content knowledge was measured before and after studying climate change. Thirty students completed both a pre- and post-instruction questionnaire. The Shapiro-Wilk statistic indicated that the assumption of normality was not violated, and F_{max} was 1.13, indicating homogeneity of variances. Thus, a one-way repeated measures ANOVA was used to compare pre- and post-instruction total scores. The ANOVA indicated that there was a significant increase from the pre- to the post-questionnaire total scores, $F(1,29) = 69.91$, $p < 0.001$. The effect size was large at $d = 1.35$.

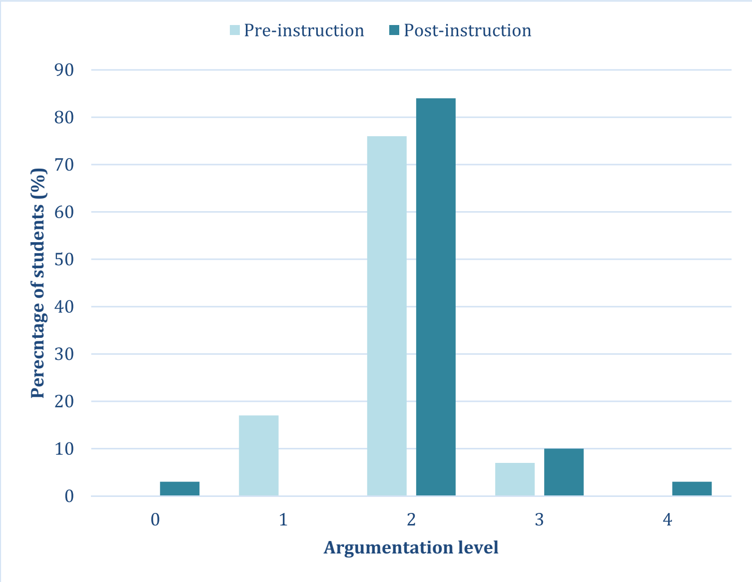

Fig. 2 Argumentation levels before and after instruction ($n = 30$)

The improvement in climate change understanding was significant across the multiple choice, true/false and open-ended questions about the definitions of climate change and the greenhouse effect and consequences of climate change. The greatest areas of improvement were in students' understandings of the differences between weather and climate, types of greenhouse gases, the time scale for climate change, the role of the enhanced greenhouse effect in increasing the Earth's temperature and the role of irradiated infrared (IR) radiation. For example, in defining climate change, student 741 initially wrote, "The increase or decrease of the average global temperature" (pre 741, score = 0). After the argumentation lessons, the student wrote, "Climate change is the change in the weather patterns of a particular region or place for a period longer than thirty years. This is mainly about temperature." (post 741, score = 2).

In response to the question, *What is the greenhouse effect*? Before instruction, student 747 wrote:

When the sun hits the windows of a greenhouse giving energy to the plants. (pre 747 score = 0)

And after:

Greenhouse effect is a natural process that makes life on Earth possible. When solar radiation passes through the greenhouse atmosphere and hits its surface, 30% of energy

Table 3 Number of categories in students' arguments before and after instruction ($n = 30$)

Number of categories	Pre-instruction, n (%)	Post-instruction, n (%)
0	5 (17)	1 (3)
1	13 (43)	9 (30)
2	8 (27)	18 (60)
3	4 (13)	1 (3)
4		1 (3)

Table 4 Number of types of student categories before and after instruction ($n = 30$)

Categories	Pre-instruction, n (%)	Post-instruction, n (%)
Environmental	18 (60)	26 (87)
Economic	12 (40)	18 (60)
Human factors	5 (17)	5 (17)
Ethical	5 (17)	2 (7)
Other	1 (3)	1 (3)

> is reflected back, while 70% is absorbed. Some escape but the ones that are trapped heat the Earth up. Enough for life to survive on earth.
> (post 747, score = 3)

One of the interviewed students indicated that the wind farm SSI and argumentation lessons contributed to their understanding. For example:

> The lesson about climate change is quite diverse, so putting it in scenarios makes it easier to understand, easier to process…. Having an in-class argument about it, because when you argue a point it means that you actually know what you are talking about. (767).

Discussion

The results of this research demonstrate that an early career science teacher in a disadvantaged school was able to use a range of teaching strategies to teach argumentation skills in the context of climate change SSI to his Year 10 students who were studying an Earth Sciences topic. As recommended by Sadler (2004) and Osborne et al. (2013), the teacher used an authentic context (climate change), an explicit introduction to argumentation structure, classroom dialogue (whole class and small group) and scaffolding (writing frames) to support students' thinking. Furthermore, he exemplified six of the eight argumentation strategies identified as effective by Simon et al. (2006). He did not, however, encourage the higher order strategies of counter arguments and debating with rebuttals.

It can be difficult to demonstrate improvement in argumentation skills even after extensive interventions (Osborne et al. 2013). However, like Grace (2009) this brief intervention explicitly teaching argumentation skills in the context of an authentic SSI can lead to a modest improvement in argumentation skills. There was a non-significant improvement in the average structural quality of students' written arguments after instruction. There was a significant improvement in the number of types of categories in students' arguments indicating an awareness of multiple perspectives. The students who were interviewed claimed that they learnt how to construct an argument and they provided specific statements on the importance and criteria for quality arguments.

The students significantly improved their understanding of climate change and the greenhouse effect. In particular, they understood the difference between weather and climate, the role of the greenhouse effect in maintaining life and types of greenhouse gases. It is not claimed that students' understanding of climate change and the greenhouse effect improved because of the argumentation and SSI lessons. Rather, it appears that these lessons can be included in regular instruction (four out of 16 lessons) without jeopardising science understanding. Other researchers have found that an SSI-based curriculum on climate change can result in a significant improvement in students' understanding of climate change science as well as helping them to understand the issues (Klosterman and Sadler 2010; McNeill and Vaughn 2012).

There were several limitations in the study design. As explained in the method, because Mr M left teaching at the end of the school year, there was no comparison group to be able to determine the impact of the argumentation lessons. However, adolescents' argument quality is unlikely to improve in the absence of instruction (Kuhn 1992). It has previously been shown that increased understanding of content alone does not improve argumentation skills (Venville and Dawson 2010; Zohar and Nemet 2002). In this study, it is not known whether climate change content knowledge impacted on argumentation skills. The intervention was brief and it is not known whether the changes are sustained over time. A further limitation is that given the literacy and language issues experienced by some of the students, it is possible that requiring written arguments may have underestimated students' argumentation skills.

Although the findings cannot be generalised beyond this case study, they are important as they indicate that a brief classroom intervention in a challenging school environment can improve students' argumentation skills. It is hoped that these findings will counter the perception held by some teachers that critical thinking skills such as argumentation should only be taught to high-achieving students as they are too difficult for low-achieving students (McDonald and Heck 2012; Warburton and Torff 2005; Zohar et al. 2001). It is recommended that future professional development on argumentation aims to overtly address this perception by using evidence, such as the findings of this study.

Simon et al. (2006) suggest that science teachers need skills and confidence to successfully use role plays and scenarios such as those used in this study. The teacher in this study, although inexperienced, believed in his ability and that of his students, and this led him to persist beyond the first lesson. As early career teachers are more likely to teach in disadvantaged schools (Weldon 2016), preservice teacher educators need to provide opportunities to develop the generic classroom strategies of effective small group and whole group discussion, scaffolding and questioning. Finally, in this study, a simple method of evaluating argument quality based on structure and content was used. This method of coding can be readily used by teachers to assess their students' argumentation skills.

Conclusion

The results of this research demonstrate that an intervention on argumentation and climate change SSI with Year 10 students and an early career teacher in a disadvantaged school resulted in a modest improvement in students' argumentation skills and an awareness of the need to be able to provide evidence for their claims. The findings of this research are of importance to all science educators who aim to improve the learning outcomes of all students worldwide.

Appendix Hydrogen fuel bus

Between 2004 and 2007, Transperth trialled three EcoBuses in Perth which ran on hydrogen fuel cells as their fuel source. The benefit of using a hydrogen fuel cell is that the only waste emissions produced are water and heat. At the conclusion of the trial, the three buses had travelled 258,000 km and carried over 320,000 passengers. Three hundred tCO_2eq were saved by not using regular diesel buses. Although the trial was deemed a success by Transperth, the WA government has decided not to proceed any further with the EcoBuses, claiming the cost to maintain that each bus was too high a price to pay compared to a regular bus.

Do you think the WA government made the right decision?

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