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The Effect of Argumentation about Socio-Scientific Issues on Secondary Students' Reasoning Pattern and Quality

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Abstract
In recent years, there has been growing interest in exploring argumentation about socio-scientific issues (SSI) in the classroom to improve students' scientific literacy. Thus, this research aims to investigate how intervention based on argumentation about SSI affects secondary students' patterns of informal reasoning and reasoning quality. The action research was conducted with 16 secondary students in which all of them were given pre-test and post-tests. The collected data were analyzed qualitatively and quantitatively. The results suggest that participants frequently relied on rationalistic informal reasoning or integrated informal reasoning patterns to solve SSI. Students' reasoning quality also improved as there were higher frequencies of students with a higher level of reasoning quality and a significant increase in the construction of supportive argument, counterargument, rebuttal, and the total number of arguments in the two post-tests when compared to the pre-test. This study provided clear support for the potential of argumentation to improve secondary student'' scientific literacy by promoting the construction of evidence-based arguments to assist in making rational decisions when solving SSI.

Keywords Informal reasoning · Reasoning quality · Argumentation · Socio-scientific issues

Introduction

Argumentation about ill-structured SSI is considered an essential pedagogy to develop students' informal reasoning for deciding on SSI (Capkinoglu et al., 2020). However, the integration of argumentation about SSI in science classrooms has not been extensively researched and incorporated in biology lessons in Brunei secondary schools, despite studies have indicated its importance in enhancing students' scientific literacy.

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Context of the Study

In 2018, Brunei Darussalam joined the Programme for International Student Assessment (PISA) for the first time. According to the OECD report, Bruneian students overall scored lower than the OECD countries in reading, mathematics, and science (OECD, 2019). Specifically, only 54% of the students attained level 2 or higher in science, while the OECD countries' average was 78% (OECD, 2019). This indicates about half of the Bruneian students who participated in PISA 2018 who scored level 1 lacked competencies in explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically (OECD, 2019).

However, it will be an overstatement to assume that Bruneian secondary students generally lack competencies in scientific literacy based on the Brunei PISA 2018 result, as the assessment was only conducted on a single age group of Bruneian secondary students. Nevertheless, this result should not be ignored but is a reminder that some changes are needed in the Brunei science education curriculum. Thus, teachers as agents of change should aim to equip their students with scientific knowledge and competencies, to be able to adapt to the dynamic world and apply their knowledge and skills to solve real-life problems (She et al., 2019). Thus, bridging vision I which strongly concentrates on literacy in science content knowledge comprising of the processes and products of sciences and vision II which focuses on literacy about science-related situations that students are likely to encounter as citizens that enable them to look at science beyond just facts and knowledge and expose them to different perspectives of scientific views as proposed by Roberts (2007) to support the development of scientific literacy among students. As a result, the we believe that argumentation about SSI can provide opportunity to students to participate in a discourse on the real-world problem to promote their problem-solving and decision-making skills.

Research Questions

This research sought to answer the following questions:

1. How does argumentation affect students' pattern of informal reasoning about socio-scientific issues (SSI)?
2. How does argumentation affect students' reasoning quality about socio-scientific issues (SSI)?

Literature Review

Integration of socio-scientific issues (SSI) in the classroom is thought to be necessary because decision-making connected to SSI is an important aspect of vision II scientific literacy (Roberts, 2007), as well as providing valuable social contexts in science teaching classrooms (Capkinoglu et al., 2021). SSI represents real-world science problems often associated with social, political, ethical, and economic concerns, such as environmental, genetics-related problems, reproductive technology, and animal rights (Garrecht et al., 2021). Furthermore, SSIs are ill-structured and often do not have a clear-cut and definite solution. The discourse, opinion, and decisions made for such complex, debatable problems as SSI can be attained through informal reasoning (Kuhn, 1991; Sadler & Zeidler, 2005). Informal reasoning often involves inductive reasoning about causes, outcomes, advantages, and disadvantages concerning certain arguments or alternative viewpoints regarding ill-structured problems (Zohar & Nemet, 2002).

Current science education should emphasize students' understanding of scientific concepts and theories and their involvement in scientific discourse (Garcia-Mila et al., 2013; Jimenez-Aleixandre & Erduran, 2007). This would allow students to explore why scientific claims should be accepted and trusted rather than emphasizing what to believe (Garcia-Mila et al., 2013). Additionally, Kuhn's (2010) view of "science as an argument" is justified as science often advances through disagreement and argumentation rather than a general agreement among scientists.

Many studies support argumentation as an effective method to access and understand an individual's informal reasoning regarding SSI (Johnson et al., 2020; Ozden, 2020). Science education researchers establish that argumentation is a social constructivist learning strategy (Albe & Gombert, 2012; Sadler et al., 2007). Argumentation is the process of generating an argument, in other words, arguing (Venville & Dawson, 2010), whereas argument, as described by Kuhn (1991), is "an assertion with accompanying justification" (p.12). Furthermore, scientific argumentation is considered an essential element of scientific literacy as it allows students to engage in authentic science learning by creating, evaluating, and clarifying scientific claims through different ways of reasoning (Ke et al., 2021). Moreover, Venville and Dawson (2010) commented that SSIs are suitable to provide context for classroom argumentation to support the development of students' scientific literacy.

SSI and Argumentation

Several researchers accentuated the importance of incorporating both SSI and argumentation in the classroom (Dawson & Carson, 2020; Garrecht et al., 2021). Discussion and argumentation about SSI can engage students' thinking and reasoning processes and mimic real-life arguments among scientists for scientific advancement (Zeidler & Kahn, 2014). Yet, mixed results have emerged from past studies that employed argumentation about SSI on students' reasoning quality. Several studies reported significant improvement in the quality of students' level of argumentation, e.g., an increase in the number of supportive arguments, counterarguments, and rebuttals generated by students (Karpudewan & Roth, 2018), while others showed a non-significant difference in students' reasoning quality (Dawson & Carson, 2020; Wu & Tsai, 2007).

Despite its importance in science education, teachers and students face potential difficulties implementing argumentation. For instance, students need to remember appropriate information and create a reasonable association between this and their claim to form a quality argument, e.g., relating a claim with relevant supporting evidence (Kuhn & Lerman, 2021; Osborne et al., 2016). Additionally, Osborne et al. (2016) reported that it is difficult for students to criticize and identify flaws in arguments produced by themselves or others. Furthermore, constructing counterarguments requires students to evaluate their opinions and defend and justify their idea to compose the rebuttals (Kuhn, 2010; Osborne et al., 2016). Consequently, counterargument and rebuttal construction have been reported to be difficult as they involve a cognitively demanding process (Erduran et al., 2004). Therefore, Kuhn (2010) suggested using counterarguments and/or rebuttals in an argument can indicate higher scientific argumentation ability. In addition, students who can challenge their opponents' statements by recognizing the weakness in it are said to possess good argumentation skills (Walton, 1989). However, to weaken their opponent's claim, students need to critically evaluate the relationship between the claim and evidence to generate a counterargument, which is very challenging (Kuhn & Lerman, 2021).

To address these challenges, many studies have developed different strategies to teach argumentation in the classroom, such as utilizing explicit instruction and teaching argumentation from a socio-cultural perspective (Berland & Hammer, 2012). Explicit instruction, such as modeling thinking strategy (Özdem Yilmaz et al., 2017) and providing writing frames to scaffold students' thought processes for argument construction (Venville & Dawson, 2010), have proven beneficial when teaching argumentation. Equally, studies that teach this from a socio-cultural perspective through students' engagement in smaller or larger group discussions also shown positive results (Capkinoglu et al., 2019; Venville & Dawson, 2010). Although small group argumentation encourages collaborative learning and the exchange of different views (Albe & Gombert, 2012), some students may experience inconsistency; e.g., lower ability students could not contribute their ideas during group discussion (Dawson & Venville, 2010). Due to this, Lin and Mintzes (2010) suggested that whole-class argumentation may reduce this inconsistency through classroom talk between students and teachers to provide equal opportunity for every student to share their opinion. Consequently, modelling thinking strategy, writing frames, small group, and whole-class argumentation are included in the intervention of the present study.

According to Bravo-Torija and Jimenez-Aleixandre (2012), previous studies that explore argumentation about SSI with secondary school students seem to emphasize SSI related to reproductive technology and genetics contexts. One such recent study was conducted by Archilla et al. (2022), which used drama to promote argumentation on SSI issues such as genetics testing. In contrast, the current research focuses on environmental issues such as the SSI, given its global significance (Dawson & Carson, 2017). Moreover, discussion on environmental issues in the classroom enables students to link their scientific knowledge and pro-environmental actions. Some studies that used environmental issues claim that it could encourage pro-environmental efforts, promote scientific literacy, and prepare students to be responsible and informed citizens (Sadler, 2004; Sternäng & Lundholm, 2011).

Capkinoglu et al. (2019) argued that the majority of SSI argumentation studies have global significance, such as genetics (Sadler et al., 2016; Venville & Dawson, 2010; Zohar & Nemet, 2002), biotechnology (Nurtamara & Prasetyanti, 2020), and climate change (Dawson & Carson, 2017, 2020), while only a few studies involve SSIs with a local relevance (Capkinoglu et al., 2019; Wu & Tsai, 2011). However, upon examining the environmental-related SSI used across the research literature, no authentic and local context was relevant to Bruneian secondary students. We believe the current research should apply a familiar SSI context to research participants. As a result, plastic pollution was chosen as the SSI topic for the present study as it is close to students' life experiences. Selecting a familiar and real SSI for classroom argumentation can help increase students' interest and encourage active learning through enthusiastic participation in critical dialogues, hence improving their scientific competencies (Capkinoglu et al., 2019; Tsai, 2018).

Assessing Pattern of Informal Reasoning and Argumentation

Some studies attempted to determine the characteristics of informal reasoning in the context of SSI (Sadler & Zeidler, 2005; Zohar & Nemet, 2002). Sadler and Zeidler (2005) investigated explicit forms of informal reasoning patterns of students' thoughts, and they described three different patterns of informal reasoning: rationalistic reasoning is based on logic to support their opinion or decisions; emotive reasoning is constructed from empathy, sympathy, and concern for the well-being of others; and intuitive reasoning is immediate or "gut-level" reaction to the context of a particular scenario that often cannot be explained in a rational term. The three informal reasoning patterns do not always work separately. There is a possibility for three paired combinations: rational and emotive reasoning, emotive and intuitive reasoning, and rational and intuitive reasoning. The pattern of informal reasoning by Sadler and Zeidler (2005) is well accepted as numerous studies have used this method to assess students' informal reasoning in argumentation about SSI (Dawson & Venville, 2009; Venville & Dawson, 2010; Wu & Tsai, 2007).

Although much research advocated the importance and necessity of argumentation in science education (Berland & Hammer, 2012; Jimenez-Aleixandre & Erduran, 2007; Kuhn & Moore, 2015; Özdem Yilmaz et al., 2017), there is limited research on the assessment of student competency in argumentation (Osborne et al., 2016). Furthermore, some teachers show disinclination in teaching argumentation about SSI due to the difficulties in assessing the structure of students' argumentation (Nielsen, 2012). In addition to the difficulty of examining the argument structure, assessing the accuracy and relevance of the content of the argumentation components is also arduous (Dawson & Carson, 2017).

Toulmin's Argument Pattern (TAP) is a model to analyze argumentation structure in science classrooms (Toulmin, 1958). However, Erduran et al. (2004) commented that the TAP model's main difficulty is differentiating between claim, data, warrant, and backings. Venville and Dawson (2010) added that the problem with TAP is that it cannot evaluate the quality of the argument. Nussbaum (2020) commented that Toulmin's (1958) model is too simplistic, minimally dialogue, and does not provide explicit standards for assessing the strength and coherence of arguments.

As a result, an analytical framework to analyze students' patterns of informal reasoning and reasoning quality developed by Wu and Tsai (2007) based on earlier studies by Sadler and Zeidler (2005) is used in this research. This analytical framework has been used in recent studies. Studies (Karpudewan & Roth, 2018; Wu & Tsai, 2011) have shown that the analytical framework is practical to be implemented in a classroom setting.

Methodology and Methods

Research Design

The present action research employed a qualitative method to gather quantitative data across all participants. The written responses from the students were analysed according to the categories proposed by Wu and Tsai (2007) by two science teachers, which were later quantified using frequency.

Participants

Sixteen participants from a public secondary school aged between 14 and 16 were involved in this study. Participants have some prior knowledge of pollution and the effects of humans on the ecosystem but have not been explicitly taught argumentation. Furthermore, the participants have mixed learning abilities (25% high, 56% medium, and 19% low learning abilities) and good English Language command (obtained grade C or above) based on their previous Biology and English Language assessment scores, respectively.

Research Implementation

All research participants were given a pre-test and post-test 1 in the first cycle and only post-test 2 in the second cycle. The pre-test contained three open-ended questions, while the post-tests contained only one open-ended question on the environmental issue, specifically plastic pollution.

In the first cycle, students were given 30 min to complete the pre-test. The first author taught the effects of humans on the ecosystem, particularly on plastic pollution, for 70 min. The content of the lesson on plastic pollution was obtained from UNEP (2018). The intervention started by introducing argumentation to the class in a 60-min lesson in which the first author discussed the different components of argumentation, such as supportive argument, counterargument, and rebuttal, the purpose of argumentation, and the importance of supporting arguments with reliable evidence with students. During the lesson, students were allowed to perform small group and whole class argumentation using a different SSI scenario unrelated to plastic pollution as practice (i.e., Do you agree or disagree that all people should be vegetarian?). Students were provided with the issue's advantages and disadvantages to focus on generating different arguments during the practice session. The following week, students were divided into groups of four to six for small group argumentation (30 min) and whole class argumentation (30 min) regarding plastic pollution. In the consecutive week, a 30-min post-test was given.

In the second cycle, the intervention was modified based on the analysis of the pre-test and post-test 1 and verbal feedback from students in cycle 1. In the modified argumentation lesson, the first author provided verbal feedback on students' responses to the tests, such as highlighting the difference between reason and evidence in a sample argument, reiterating that students must include short, concise, and relevant evidence in their argument, and showed more examples on how to construct effective arguments using the advantages and disadvantages from the practice SSI scenario used in the first cycle. The first author also increased the duration of argumentation; small group argumentation was conducted for 90 min while whole class argumentation was for 75 min to allow more time for quality argumentation between students. A 30-min post-test followed the intervention. Table 1 summarizes the timeline of the intervention.

Table 1 The timeline of lessons

Cycle	Week	Duration (min)	Description
1	1	30	Pre-test
		50	Lesson on plastic pollution
	2	20	Lesson on plastic pollution
		60	Lesson on argumentation
	3	30	Small group argumentation on plastic pollution
		30	Whole class argumentation on plastic pollution
	4	30	Post-test 1
2	5	40	Modified lesson on argumentation
		40	Small group argumentation on plastic pollution
	6	50	Small group argumentation on plastic pollution
		75	Whole class argumentation on plastic pollution
	7	30	Post-test 2

The first author incorporated a decision-making framework that Lee and Grace (2010) developed to scaffold students' thinking when forming arguments during small group and whole class argumentation. The decision-making framework consists of three main stages: (1) collecting information from multiple viewpoints, (2) argumentation, and (3) decision-making based on criteria, as presented in Fig. 1.

The first stage was to encourage students to explore and consider different perspectives of stakeholders affected by the SSI in question through brainstorming ideas between group members and doing further individual research on the Internet at home. To ensure students do their online research effectively, the first author provided a list of suggested reliable websites and encouraged students to research based on their assigned roles (such as businessperson and environmentalist) by their respective groups. Consequently, this stage allowed students to relate their preconceived views, others' points of view, and new knowledge obtained.

The second stage enabled students to share their findings with their group members. Group members articulated the advantages and disadvantages of each solution, identified fundamental values to their choice, and formed supportive arguments, counterarguments, and rebuttals to justify their choice. Handouts containing guiding questions were given to all groups so group members could focus on discussing and analysing the more important findings to support their group claims and arguments.

In the third stage, each group decided on criteria to ease their decision-making. Then, each group made a final decision with justifications based on the generated criteria. The groups then took turns presenting their decisions and justifications to the whole class, followed by a whole class discussion on decisions made by groups. During the class discussion, the first author used a probing strategy to allow students to clarify and expand their ideas. Finally, each group discussed and reflected on their decision after the class discussion. At this point, it was acceptable for a group to agree on the same conclusion or for students to have their own decision that differed from their group members.

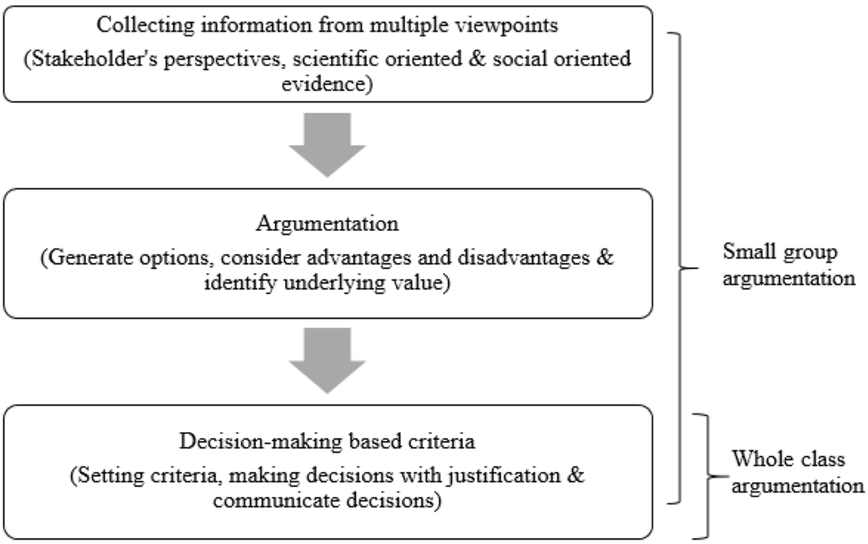

Fig. 1 The decision-making framework used in this study (Adapted from Lee and Grace (2010))

Instruments and Data Collection

Pre-test and Post-test

The pre-test consisted of three open-ended questions adapted from studies by Lin and Mintzes (2010) and Wu and Tsai (2007). Each question evaluated students' ability to construct supportive arguments, counterarguments, and rebuttals for the issue in question shown in Table 2.

Whereas post-tests 1 and 2 consisted of one question "Do you agree or disagree that our society can help reduce or stop the issue of plastic pollution? Justify your opinion with reasons and evidence." The pre-test and post-test were validated through content validity by two subject experts, and face validity was conducted with 25 Year 10 students who had similar learning abilities as the research participants.

Data Analysis

Students' responses to pre-test, post-test 1, and post-test 2 were qualitative and then quantitatively analyzed using the analytical framework adapted from Wu and Tsai (2007) to answer the two research questions.

Data Analysis for RQ1

The pattern of informal reasoning indicator used in the analytical framework by Wu and Tsai (2007) is based on a study by Sadler and Zeidler (2005) that examined students' decision-making process through informal reasoning. The pattern of informal reasoning can be categorized into a rational, emotive, intuitive, or integrated pattern of informal reasoning which consists of a combination of either rational and emotive, emotive and intuitive, or rational and intuitive (Table 3). Although empathy is often associated with humans, this study also considered the affective connection between humans and animals as a display of emotive consideration toward these animals, as stated by Young et al. (2018).

Table 2 Pre-test questions

Pre-test questions	Assessing
1. Do you agree or disagree that our society can help reduce or stop this issue of plastic pollution? Please write down your ideas and reasons	Assesses students' ability to produce supportive arguments
2. If someone disagreed with your opinions you expressed in the first question, (s)he might have some reasons. What might his/her reasons be? Please write down his/her reasons	Assesses students' ability to construct counterarguments
3. How would you convince somebody who disagreed with you if they had given such reasons in the second question?	Evaluating students' ability for rebuttal construction

Table 3 Definition of the pattern of informal reasoning (Sadler & Zeidler, 2005)

Pattern	Criteria
Rational	The reasoning is based on logic and uses scientific understanding and language. A student may weigh up risks and benefits and provide evidence to support opinions or decisions
Emotive	The reasoning is based on empathy, sympathy, and concern for the well-being of others
Intuitive	The reasoning is based on an immediate or "gut-level" reaction, often a personal and negative response to the context of a scenario that often cannot be explained in rational terms
Integrated	Combination of either rationalistic and emotive reasoning, rationalistic and intuitive reasoning, or emotive and intuitive reasoning

Data Analysis for RQ2

The reasoning quality indicator used in the analytical framework by Wu and Tsai (2007) is adapted from studies by, Sadler & Zeidler, (2005), as shown in Table 4. The descriptions of the claim, supportive argument, counterargument, rebuttal, and evidence are summarized in Table 5. In this research, a response is only considered an argument when the participant provides both reason and relevant evidence.

Establishing Trustworthiness

The data from students' pre-test and post-test responses were read and coded separately by the first author and an experienced science teacher. The initial percentage agreement between the raters was 88%. After several face-to-face and virtual discussions to elicit the

Table 4 Description of reasoning quality level

Level	Description
None	Only claim provided
Lower	Claim and supportive argument or counterargument provided
Medium	Claim, supportive argument, and counterargument provided
Higher	Claim, supportive argument, counterargument, and rebuttal provided

Table 5 Description of claim, supportive argument, counterargument, rebuttal, and evidence

Structure	Description
Claim	A conclusion, proposition, or assertion about an issue, such as stating "agree," "disagree," or "I don't know" (Toulmin, 1958; Venville & Dawson, 2010)
Supportive argument	The statement contains reason and evidence to support a claim (Lin & Mintzes, 2010)
Counterargument	Alternative assertion to a person's claim with accompanying evidence (Kuhn, 1991; Lin & Mintzes, 2010)
Rebuttal	Valid rejection of a reason that is in support of a counterargument with accompanying evidence (Lin & Mintzes, 2010)
Evidence	Evidence can be from students' knowledge or own experience (Kuhn & Moore, 2015), numerical or descriptive data, and concrete examples or facts (Lin & Mintzes, 2010)

raters' understanding of the categories in Table 5, a 100% agreement rate was eventually achieved between the two raters.

Findings

RQ1: Pattern of Informal Reasoning

The informal reasoning demonstrated by the participants in response to the plastic pollution issue included cognition and emotive consideration (Table 6). The patterns of informal reasoning were not always observed separately. Overall, participants frequently presented an integrated pattern of rational and emotive in response to the SSI scenario given. It was found that rationalistic informal reasoning increased from 43.8% (pre-test) to 62.5% (post-test 1) but decreased to 31.3% (post-test 2). While participants demonstrating the integrated pattern of informal reasoning (rational-emotive) decreased from 56.2% (pre-test) to 37.5% (post-test 1) however increased to 68.7% (post-test 2). Even though some students formed decisions using only rationalistic informal reasoning, no students displayed emotive or intuitive informal reasoning independently.

In all instances, participants relied on logic to support their claims. In these cases, participants considered conditions such as possible solutions for plastic pollution (e.g., use of alternative materials, plastic pollution awareness through education), cost (e.g., expensive alternative materials), and possible reasons for the persistence of plastic pollution (e.g., lack of public cooperation or concern about plastic pollution) and the problem with plastic pollution (e.g., bad effect of plastic/microplastic to human's health) to decide the issue. All these considerations were grouped as rationalistic informal reasoning.

Instances where participants applied emotions such as empathy and sympathy to the issue, like identifiable emotions toward the effect of plastic on wildlife, people's life, and the environment, are grouped as emotive informal reasoning. Table 7 is an example of participants' informal reasoning patterns.

RQ2: Reasoning Quality

The data overall show the frequency of supportive arguments. Counterargument, rebuttal, and the total number of arguments generated by students notably increased from pre-test to post-tests. However, there was not much difference in frequency between the two post-tests, as demonstrated in Table 8.

The frequencies of reasoning quality levels generated by participants in the pre-test, post-test 1, and post-test 2 are presented in Table 9. It is observed that the none level

Table 6 Research participants' pattern of informal reasoning during the pre-test, post-test 1, and post-test 2 ($n = 16$)

A pattern of informal reasoning	Freq. (%)		
	Pre-test	Post-test 1	Post-test 2
Rational	7 (43.8)	10 (62.5)	5 (31.3)
Emotive	-	-	-
Intuitive	-	-	-
Integrated (rational-emotive)	9 (56.2)	6 (37.5)	11 (68.7)

Table 7 The participants' patterns of informal reasoning

The pattern of informal reasoning	Student code	[a]Excerpt
Rational	S9 (post2)	[a]Educating people or by using other alternatives can also help to reduce plastic pollution. An organization called TerraCycle Loop has been able to convince 8 out of 10 plastic companies to renew their design and use a recyclable plastic instead of a single-use plastic
		[a]Moreover, companies and eateries can use other material for their packaging, such as paper or recycle bag, which play a role in reducing plastic pollution. Also, companies that are using other materials other than plastic for their packaging has received a good impact, and it help their companies to grow. Some of these companies are Marks & Spencer and McDonald's
Integrated (rational-emotive)	S2 (post2)	**Plastic can cause major problems to humans, wildlife, and environment. Studies show that there are 114 marine species that are contaminated with plastic**. *However, plastics are cheaper, and it also make lots of profit because the process of making plastic are less hard compared to other material such as making of iron, stainless (steel), it also requires more time than making plastic*
	S16 (post2)	*I agree that our society can help reduce plastic pollution because we can always use alternative materials instead of plastic. There are many materials, such as clay, glass, metal, bamboo, seaweed,* etc. *These materials are actually less dangerous than plastics. Plastics contain microplastics which may lead to cancer.* … **We can also remind the society how plastic pollution can harm wildlife since most of us feel humanity and empathy towards animals**
	S4 (post2)	**From a businessman view, they have manufactured plastic for decades. If the society banned of using plastic, the plastic company will slowly get bankrupt and forced to shut down their company. Worse, worker will lose their job plus at this time it is so hard to get a job.** *It is true that we can use metal or paper material as an alternative way to make straw or a cup,* etc. *Metal straws have long lasting life than plastic straw. In addition, metal straws are more durable than plastic straw, where we can use metal straw repeatedly, unlike plastic straw, that can be used once. In the US and other country, McDonald, Dunkin Donut have charged extra money if customer want to use plastic straw. These prevent from customer using plastic straw and convince them to use metal or cardboard straw*

[a]For integrated informal reasoning (rational-emotive): rationalistic evidence was displayed as an italic character; emotive evidence was displayed as a bold character

Table 8 The frequency of claim, supportive argument, counterargument, rebuttal, and the total number of arguments constructed during the pre-test, post-test 1, and post-test 2

Claim and type of argument	Frequency		
	Pre-test	Post-test 1	Post-test 2
Claim			
Disagree	13	11	11
Agree	2	5	5
I don't know	1	0	0
Supportive argument	13	27	26
Counterargument	1	8	8
Rebuttal	0	7	8
Total number of argument	14	42	42

Table 9 Research participants' reasoning quality level during the pre-test, post-test 1, and post-test 2 ($n = 16$)

Reasoning quality level	Freq. (%)		
	Pre-test	Post-test 1	Post-test 2
None	7 (43.8)	3 (18.8)	1 (6.2)
Lower	8 (50.0)	6 (37.5)	7 (43.8)
Medium	1 (6.2)	1 (6.2)	1 (6.2)
Higher	-	6 (37.5)	7 (43.8)

decreased from 43.8% (pre-test) to 18.8% (post-test 1) and further reduced to 6.2% (post-test 2). Moreover, the frequencies of lower-level decreased from 50% (pre-test) to 37.5% (post-test 1) and 43.8% (post-test 2), whereas the medium level had the same frequency in the pre-test and both post-tests. The most remarkable finding is the significant increase in the frequency of higher reasoning quality levels from 0% (pre-test) to 37.5% (post-test 1) and 43.8% (post-test 2).

The effect of the intervention on students' reasoning quality levels is more evident by analysing the individual progress of some students. Table 10 provides excerpts from the pre-test and post-tests written by students S2 and S8. In the pre-test, both students scored lower-level reasoning quality as they only offered supportive argument(s) to support their claim. However, S2 and S8's reasoning quality improved, and they obtained higher-level reasoning. They could not only back up their claim through a supportive argument but also criticised their idea by providing counterarguments and justified their claim further through rebuttal.

Discussion

Impact of Argumentation About SSI on Students' Pattern of Informal Reasoning

Past research has found that students still use intuitive and emotive informal reasoning when making decisions regarding SSI, even after intervention (Dawson & Venville, 2009). However, the present study shows students apply rationalistic or integrated (rational-emotive) informal reasoning when solving the selected SSI even before the

Table 10 Samples of students' excerpts from the pre-test and post-test to show the change in reasoning quality level

Student code	Reasoning quality level and pre-test response excerpt	Reasoning quality level and post-test response excerpt
S2	Lower-level reasoning quality I agree that our society can solve the plastic pollution issue. [claim] To reduce the use of plastic, we need something that can replace it for a long period of time (reason) … we drink water fro plastic bottle, so why don't we just use water bottle that made from aluminium or iron that can be used for a long time. (evidence) [supportive argument]	Higher level reasoning quality In my opinion, I agree that our society can help or stop the issue of plastic pollution. [claim] ..plastic can cause major problems to human.. We as a human also need to drink water but nowadays there's a lot of microplastic inside the tap water or even in the road. (reason) According to World Health Organisation (WHO) stated in 2018 there are 90% of microplastics inside the water bottle. (evidence) [supportive argument] However, plastic are cheaper and it also make lots of profit (reason) because the process of making plastic are less hard compared to other material such as making of iron, stainless, it also requires more time than making plastic. (evidence) [counterargument] Yes I know that plastic are cheaper, but making plastic requires 4% of non-renewable sources oil and gas for the industry. (reason) In the future, there's maybe an increase in the use of oil and gas up to 20%. (evidence) [rebuttal]

Table 10 (continued)

Student code	Reasoning quality level and pre-test response excerpt	Reasoning quality level and post-test response excerpt
S8	Lower-level reasoning quality I agree that our society can help reduce or stop the issue of plastic pollution. [claim] Right now the society try to reduce the issue of plastic pollution with not using plastic bags… There are a lot organization nowadays that held a cleaning campaign at public places such as the park and beach… restaurants such as McDonalds, they try to reduce it (plastic pollution) by not giving a plastic straw. (evidence) [supportive argument]	Higher level reasoning quality I disagree that our society can help reduce or stop the issue of plastic pollution. [claim] Many people actually use and need plastic objects such as straws, plastic bag, plastic bottles and styrofoam. (reason) In our daily life, we use plastic bottle as our drinking water, plastic take away when we want to take away food either from restaurants or from ceremony and plastic bag for throwing trash. (evidence) [supportive argument] Some people would say that we can reduce this plastic pollution by recycling them… (reason) There was a person who lives in a zero-waste lifestyle. She can do it. (evidence) [counterargument] However, in 2015, only less plastics are being recycled… (reason) Furthermore, as we have a poor waste management, recycle bin are rarely provided. Even if it was provided, when the recycle bin is full, people tend to litter it around instead. (evidence) [rebuttal]

intervention was conducted. After the intervention lesson, in cycle 1, the rational informal reasoning increased in frequency which was consistent with the findings of some previous research where the majority of the research participants in the studies showed an increase in rationalistic informal reasoning after the intervention (Dawson & Carson, 2017; Sadler & Zeidler, 2005; Wu & Tsai, 2007). However, the integrated (rational-emotive) informal reasoning decreased in frequency. Nonetheless, the observed pattern was the opposite in cycle 2, where the rational informal reasoning decreased in frequency and the integrated (rational-emotive) informal reasoning increased in cycle 2. These results may suggest that students' decision-making was influenced by morality, personal experience, and emotive factors, as described by previous work by Sadler and Zeidler (2005). As observed in the post-test responses, there is an increased number of students who displayed sympathy and empathy towards the wildlife and individuals who might be affected by the consequence of plastic pollution. Argumentation about SSI, particularly environmental issues, has seemingly cultivated pro-environmental behaviour and mentality in the participants. This finding is in line with a previous study by Sternäng and Lundholm (2011).

Furthermore, students were empathetic and morally sensitive based on the group and whole class argumentation session. For example, S4 took a businessman's perspective when solving the SSI. It displayed emotive consideration for the workers of a plastic-manufacturing company who might face unemployment if plastics were banned. This finding supported the claim made by Zeidler et al. (2019).

Argumentation About SSI and Improvement in Students' Reasoning Quality

There is an apparent decrease in none level and lower level of reasoning quality and a notable increase in higher level reasoning quality between the pre-test and the two post-tests. Despite the significant increase in the numbers of students with a higher level of reasoning quality from the pre-test to the post-test, students generally generated fewer counterarguments and rebuttals compared to the number of supportive arguments constructed. This confirms that it is relatively difficult for students to construct counterarguments and rebuttals. These findings are consistent with the claim that generating counterarguments and rebuttals are cognitively demanding (Erduran et al., 2004).

Such results from this research indicate that the students can apply their scientific knowledge to develop different types of evidence-based arguments, i.e., supportive argument, counterargument, and rebuttal, to make knowledgeable decisions about the given SSI. This ability is considered an important aspect of Vision II scientific literacy (Roberts, 2007).

Limitations of the Study and Recommendations

Certain limitations of this study could be addressed in future research. Firstly, with only 16 participants, the small sample size provides only an initial and possibly moderate contribution to the research literature, which limits the possibilities for generalizing the research results. Hence, the findings and implications of the study may be considered preliminary, tentative, and exploratory as it does not provide a firm conclusion.

Secondly, although the first author stressed the importance of providing reliable evidence in an argument during the intervention by encouraging students to obtain evidence only from trustable sources, the first author did not examine the reliability of evidence given by students in the pre-test and post-tests. This is because the current study focuses on students' reasoning quality, including the ability to construct a supportive argument, counterargument, and rebuttal. Future research should examine the accuracy of evidence presented by students in the arguments by requiring students to provide a reference for the given evidence. Moreover, it is also essential to include suitable task(s) containing questions to assist students in recognizing reliable and unreliable sources to create more scientifically literate individuals, as suggested by Allchin (2011).

Thirdly, the present research only collected and analyzed pre-test and post-test data to answer the research questions. However, this data did not fully reflect and measure how argumentation affects students' informal reasoning patterns and reasoning quality. It was observed that the development of students' patterns of informal reasoning and reasoning quality mostly occurred during the small group and whole class argumentation. Therefore, classroom observation should also be included in future research data collection and analysis to give richer and more meaningful data, as demonstrated from past studies (Dawson & Carson, 2020; Dawson & Venville, 2010).

Fourthly, in the current research, the first author did not participate in professional development training specifically for teaching argumentation as there was no known suitable training available at the research time; thus, this might affect the result. Furthermore, such professional development training is regarded important as several studies required teacher(s) involved in the research to participate in professional development training for teaching argumentation before their studies to ensure effective pedagogy and instructions are used when teaching argumentation (Dawson & Carson, 2020; Dawson & Venville, 2010). Nevertheless, the first author attempted some strategies to promote high-quality argumentation by providing writing frames as suggested by Venville and Dawson (2010), incorporating a decision-making framework developed by Lee and Grace (2010), and implementing both group and whole-class argumentation (Venville & Dawson, 2010).

Despite these limitations, this research can be seen as an initial step towards integrating two lines of research, SSI-based teaching, and argumentation, which have not been explicitly implemented in Bruneian secondary schools. Although the generality of the current results must be established by future research, the present study provided clear support for argumentation about SSI to encourage students to adopt rationalistic or integrated (rational-emotive) informal reasoning when solving SSI as making their reasoning quality better to improve scientific literacy.

Conclusion

The current study aims to address the literature gap and better understand how argumentation about SSI affects Year 10 Bruneian students' scientific literacy. This study supported the potential of argumentation about SSI to promote a rationalistic or integrated (rational-emotive) pattern of informal reasoning in students when solving SSI. Most students can make rational decisions and suggest a reasonable solution to the given SSI; this skill is essential to become scientifically literate. This study provides evidence that students can improve their reasoning and argumentation quality. However, the data does not necessarily provide evidence that the participants can transfer the skills developed in one issue (in this case, plastic pollution) to a dissimilar issue such as SSI related to genetics problem. Hence, it is recommended for future research to feature different issues in the intervention, as suggested by Kinslow (2018).

Even though the generality of the current results must be achieved by future research, the present study supported the potential of argumentation about SSI to promote rationalistic or integrated (rational-emotive) patterns of informal reasoning in students when solving SSI. Most students can make rational decisions and suggest a reasonable solution to the SSI. Such skill is considered important to become a scientifically literate individual. Furthermore, the results imply that argumentation about environmental-related SSI has encouraged pro-environmental behaviour and mentality in the students, as claimed by Sternäng and Lundholm (2011). The findings also highlight a significant improvement in students' reasoning quality level as demonstrated by higher frequencies of students with higher levels (able to provide a claim, supportive argument, counterargument, and rebuttal) after the intervention.

Even though SSI-based teaching and learning have not been explicitly implemented in Brunei Science Education Curriculum, we think incorporating such an approach is crucial and feasible to include in the curriculum as it has been proven to improve students' scientific literacy. This is demonstrated from the findings of current research that show the research participants may have enhanced their vision II scientific literacy because of intervention based on argumentation about SSI, as more participants apply their scientific knowledge to construct evidence-based supportive arguments, counterarguments, or/and rebuttal to make an informed decision about SSI after the intervention.

Although the present study provides evidence that students can improve their reasoning and argumentation quality, similar research should be conducted using a larger sample and putting more emphasis on examining the reliability of evidence provided by students in their responses to address the limitations of the current study and to achieve a general result on the effect of argumentation about SSI on Bruneian secondary students' scientific literacy. Furthermore, the data does not necessarily provide evidence that the participants can transfer the skills developed in one issue (in this case, plastic pollution) to a dissimilar issue, such as SSI related to genetics problem. Hence, it is recommended for future research to feature different issues in the intervention, as suggested by Kinslow (2018).

Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of Interest The authors declare no competing interests.

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