Promoting lower secondary students' critical thinking by Socio-Scientific Inquiry-Based Learning in chemistry education

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Master: Science Education and Communication.

SEC Research Project-45 ECTS

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Abstract

As a crucial dimension of citizenship competence and an essential ability in daily life, critical thinking should be integrated as an important aim in science education (Facione, 1990). Socio-Scientific Inquiry-Based Learning (SSIBL) is a new pedagogy that is expected to improve students' citizenship competence. The aim of this research was to investigate how lower secondary students' critical thinking can be fostered by SSIBL. To achieve this, a design-based research method was used to develop a lesson module based on SSIBL pedagogy. The lesson module was implemented in three classes (60 students, aged 13-14) at an international school in the Netherlands. Pre- and post-tests, in-class audio recordings, lesson materials and semi-structured interviews were used for data collection. Our findings suggest that SSIBL can foster students' critical thinking to a certain extent. Specifically, it guides students to make inquiries into Socio-Scientific Issues (SSIs), discuss SSIs from multiple perspectives and use credible sources to support their arguments. Future work should investigate how SSIBL improves other skills in citizenship competence.

Keywords: Socio-Scientific Inquiry-Based Learning, Critical thinking, Citizenship Education, Sustainability, Design-based Research.

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Introduction

Critical thinking, being a 21st Century skill, is widely considered as an important dimension of science education (Bailin, 2002). The National Science Board (1983) makes explicit reference to the development of critical thinking skills as a goal for science education. Since this is an era where scientific information reaches the world through new discoveries every day, students should be prepared to face the fast pace of developments in scientific and technological knowledge (Vieira, 2000).

In today's science class, students are not only required to learn scientific knowledge or the necessary processing skills, but also to know how to make autonomous decisions and to question beliefs that are not based on substantial evidence in this fast changing world (Driver, Leach, & Millar, 1996; McComas, Clough, & Almazroa, 1998; Osborne, 2007; Rutherford & Ahlgren, 1991). In this context, critical thinking is the key to successful learning (Barak, Ben-Chaim, & Zoller, 2007). Critical thinking, which is understood to be the ability to think

rationally, can help students to deal with various questions and make sensible decisions quickly and effectively in their future work or daily life (Ennis, 1989).

Although many school curricula, in different countries, have introduced critical thinking as an important learning objective, and even though its importance has been emphasised repeatedly (Vieira, Tenreiro-Vieira, & Martins, 2011); many secondary schools were not able to adapt their curricula to help students develop their higher order thinking skills (Elder & Paul, 2008). The score that assessed the representations of Nature of Science (NOS) in Science textbooks series that command the significant market shares in the United States remains unchanged over a few decades (Abd-El-Khalick, F. et al., 2017). Therefore, most of the scientific knowledge in the textbooks is outdated. Except the obsolescent knowledge from the textbooks, the conventional science classroom that regards teachers and the textbooks as the primary sources of knowledge also demotivates students from actively engaging in the class (Ekborg, Nyström, & Ottander, 2010). This type of learning module also discourages students from improving the vital skills in the citizenship competences, because they have very slim chances of thinking and acting in ways taking account of personal, local, national and global concerns (Cogan & Derricott, 2014). The science curriculum should contain up-to-

date content to raise young people's interest, as a result of which, they are more likely to use skills learned from science in the outside world (Sjøberg & Schreiner, 2006).

Socio-Scientific Inquiry-Based Learning, a new pedagogy coordinated by a European project called PARRISE (Promoting Attainment of Responsible Research and Innovation through Science Education)[1], aimed to solve the problem by improving the conventional teaching ways. This teaching pedagogy intends to effectively teach students up-to-date knowledge and the essential skills for the 21st century by introducing Socio-Scientific Issues (SSIs) combined with Inquiry-Based Learning (IBL) in the classroom. Studies show that applying the latest and true-to-life socio-scientific issues involving the moral or ethical problems in the classroom can motivate students to express their scientific, social and moral viewpoints dynamically (Sadler, 2004).

Bryce and Gray (2004) suggested that the advantage of SSIs is disappeared in the traditional classroom setting because students are limited to form their opinion, think critically and express their view with thorny issues, while teachers find it hard to decide to what extent they can participate in the classroom discussions. Thus, SSI should teach with Inquiry-Based Learning, in which students and teachers can explore the solutions for the

[1] See http://www.parrise.eu/

issues together (Akhter & Fatima, 2016; Furtak, Seidel, Iverson, & Briggs, 2012). As the combination of SSI and IBL, SSIBL is therefore expected to alleviate the problems mentioned above; hopefully, students' interest in studying science and teachers' willingness to teach SSIs in science class will be stimulated.

Sustainability, as one of the Socio-Scientific Issues, can arise students interest and engage students into the disclosure around these science-inflected issues (Gough, 2002). Its relevance to daily life and its open-ended nature that leaves the room for multiple solutions, also help students think autonomously and discuss critically and improve their critical thinking as a learning result (Ennis, 1991).

Although the characteristics of SSIBL seem to be promising to teach students latest scientific knowledge and to develop students' citizenship competences, such as critical thinking, insufficient research on whether the SSIBL pedagogy can improve students' critical thinking has been conducted. Therefore, this study aims to design an SSIBL based chemistry module for lower secondary education to foster their critical thinking. The overall objective of the study is to investigate how SSIBL pedagogy can teach lower secondary students to critically reflect on socio-scientific issues.

Theoretical background

Socio-Scientific Inquiry-Based Learning (SSIBL)

Socio-Scientific Inquiry-Based Learning (SSIBL), is a pedagogy that was developed by a 4-year European project, PARRISE.

Levinson and PARRISE consortium (2017) define SSIBL as the following:

"At the heart of SSIBL is researching a question aimed at improving local and/or global conditions, producing realisable outcomes through democratic processes, and drawing on scientific knowledge that may be recontextualised as part of this process."

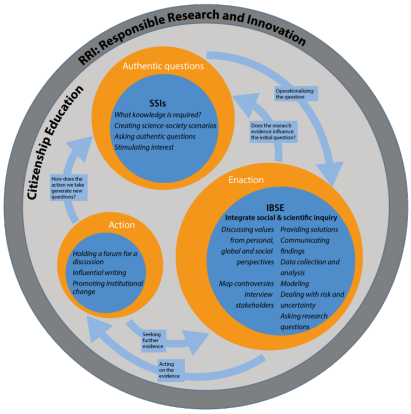

Figure 1 SSIBL framework, Levinson et al. (2017)

SSIBL consists of three interconnected pillars: socio-scientific issues (SSIs) with inquiry-based learning (IBL), and citizenship education (CE; Figure 1). The characteristic of SSIs, IBL and CE will be explained.

Socio-Scientific Issues (SSIs)

Socio-Scientific Issues contain conflicting opinions of science and its controversial societal impact (Dearden, 1981). They are open-ended social issues with conceptual or procedural links to science without clear-cut solutions (Sadler, 2004). Dealing with SSIs, participants require to think critically, and to be open and honest (Hodson, 2014). In order to teach SSIs in the classroom, the school has to offer an atmosphere of mutual respect, making students aware of the importance of others (Levinson et al., 2017).

The range of SSIs is from local issues such as neighbourhood environmental crises to global problems like the use of nuclear power in different countries. Since SSIs are transdisciplinary and context-dependent, the selection of SSIs should be based on students' knowledge, experience, social situation, intentions, needs and wants (Levinson et al., 2017). Moreover, when the issues are closely related to situations they might encounter in the daily life, students are motivated to use scientific knowledge and skills to discuss and make an informed decision (Sadler, 2004).

Through studying SSIs, students are more likely to identify the complexity of SSI issues, to examine them from multiple perspectives, and to show the scepticism when facing potentially biased information (Sadler, Barab, & Scott, 2007).

Inquiry-based learning (IBL)

Inquiry-based learning (IBL), as the core of the SSIBL framework, is a teaching method where students are stimulated to ask questions by themselves. The method guides students to explore knowledge with open-ended questions instead of offering the direct answers from teachers, which gives students more freedom, autonomy, and responsibility for their own work (Hmelo-Silver, Duncan, & Chinn, 2007). By implementing the IBL approach in science education, students become more willing to engage in learning activities and learn how research is conducted by scientists (Maxwell, Lambeth, & Cox, 2015).

Although the primary feature of IBL is consistent with SSIBL framework which is learning through collaboration and research, the main difference in SSIBL is that students or teachers would formulate an open-ended question or hypothesis and then take action (Figure 1).

Citizenship Education (CE)

Citizenship education is aimed to educate students from their early childhood to become clear-thinking and enlightened citizens who are able to participate in making decisions concerning society. It should extend students' knowledge, skills, attitudes and values and stimulate participation (Veldhuis, 1997).

The term critical CE is specially mentioned in this pedagogy. Johnson and Morris (2010) formulated a useful framework to represent the dimensions of critical CE, in which they stated that CE should help students learn and appreciate different types of opinion, to be motivated to change society responsibly and to raise critical questions.

The combination of these three education concepts is SSIBL. The SSIBL educational framework includes three stages: raising questions, finding out and taking action. (Figure 2).

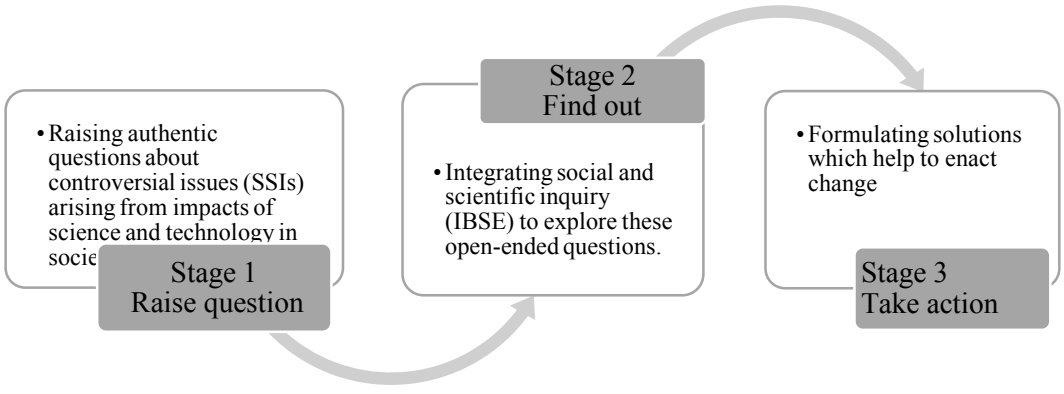

Figure 2 Three stages in SSIBL theory. Adapted from *Booklet of PARRISE: Science and society in education* (p.29), by Levinson et al., 2017. Copyright 2017 by PARRISE.

Although SSIBL already has been implemented in the pre- and in-service teacher professional development sessions during the PARRISE project in universities across Europe, it is still a relatively new pedagogy. It does not have many studies to evaluate the learning outcomes such as critical thinking in a secondary school context.

Sustainability

Sustainability, as a socio-scientific issue, means an interplay between social and environmental domains (Blauert & Zadek, 1998). It covers a board range of topics, among which population and resource consumption are the major issues. The increasing population and limited resources are considered to adversely affect the sustainable future, while education has a connection with both fertility rate and resource consumption (McKeown, Hopkins, Rizi, & Chrystalbridge, 2002). The UN Decade of Education for Sustainable Development calls for integrating the principles, values, and practices of sustainable development into all aspects of teaching and learning. Fortunately, sustainability can naturally fit into the science curriculum (Dani, 2011). It provides an engaging and dynamic context for science education to bring up students' interests and prepare them for public engagement around science-inflected issues (Gough, 2002).

Brundtland (2010) defined sustainable development as “the development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Renewable energy

For the sustainable development of resources, renewable energy such as solar, thermal, photovoltaics, and bioenergy, is promoted to improve the living conditions of the population. Renewable energy technologies have developed in a large number of countries across the globe to meet their energy demand (Kandpal & Broman, 2014). However, there are technological, economic and socio-cultural barriers for the public to understand because there is not enough promotion of renewable energy knowledge (Quadir, Mathur, & Kandpal, 1995). Therefore, the introduction of renewable energy resources and technologies in the science curricula is of primary importance. International Baccalaureate (IB) chemistry textbooks already have some pages that introduce the use of renewable energy.

Critical thinking (CT)

Critical thinking is an essential ability in daily life, which benefits students in the regulation of their study skills, and helps them work creatively in their chosen profession

(Aizikovitsh-Udi & Cheng, 2015). It should be integrated as a learning objective for every grade level at school (Facione, 1990).

Critical thinking is a concept that can be traced from Greek philosophy, Socrates (Paul, Elder, & Bartell, 1997). It has several definitions. One of the earliest definition was raised by Robert Ennis which was "reasonable, reflective thinking that is focused on deciding what to believe or do" (Ennis, 1987, p10).

In this research project, the most common definition of critical thinking is used, which divides critical thinking into skills and dispositions (Facione, 1990). The six skills include: 1) Interpretation: to understand information; 2) Analysis: to identify the main arguments that presented; 3) Evaluation: to judge the credibility; 4) Inference: to decide what to believe based on solid statements, and to be aware of the results of their decisions; 5) Explanation: to communicate the process of reasoning to others; 6) Self-regulation: to monitor their own thinking and correct their logic.

Seven dispositions of critical thinking were identified as: 1) Inquisitiveness: the concern to become well-informed); 2) Truth-seeking: facing one's own bias and rethink views; 3) Critical thinking self-confidence: trusting themselves to reason; 4) Open-mindedness: considering different opinions; 5) Systematic: thinking in a linear process; 6) Analyticity:

picking apart their own and other's logic; 7) maturity of judgment: use credible data to judge (Facione, 1998).

Research question

To foster students' critical thinking, a vital learning objective in the current science curriculum, SSIBL will serve as an educational framework for the researcher to design a lesson module in this research project. Thus, the goal of the research is to improve students' critical thinking by integrating SSIBL.

The main research question is: How can the SSIBL pedagogy help secondary school students to foster their critical thinking in chemistry education?

The sub-questions are:

1. To what extent does the lesson module make students inquiry into socio-scientific issues(SSIs)?
2. To what extent does the lesson module support students to analyse the controversy in SSIs?
3. To what extent does the lesson module help students look at SSI from different perspectives?

4. To what extent does the lesson module help students learn critical thinking strategies to analyse SSIs?

Methodology

In this study, designed based research is used to develop a lesson module based on SSIBL, and the learning effect of this lesson module is studied. Students' learning outcomes were measured by analysing the pre- and post-tests in the form of questionnaires, semi-structured interviews of students and their teacher, in-class worksheets, class observation and audio recordings of the classroom discussions.

Design-based research is meant to bridge the gap between educational practice and theory (Bakker & Van Eerde, 2015). Useful products (e.g., educational materials) are designed during the process, offering scientific insights into how particular ways of teaching and learning can be improved (McKenney & Reeves, 2012). This research project implemented DBR to investigate how SSIBL can be used to improve lower secondary students' critical thinking. Students were expected to enhance their critical thinking when dealing with sustainability in chemistry class through the SSIBL approach. The design of this research project is based on the three phases of DBR (Figure 3): 1) Preparation and Design, 2) Teaching experiment, 3) Retrospective analysis.

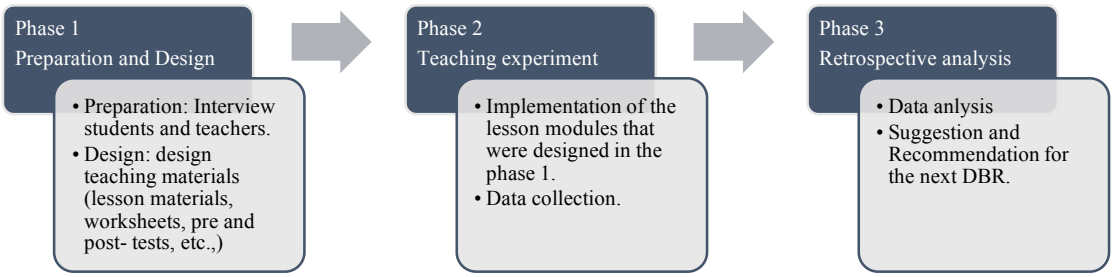

Figure 3 The implementation of three phases of DBR

Phase 1, Preparation and Design

Participants:

In this phase, six chemistry teachers (four female teachers and two male teachers) and six students (three girls and three boys around age fourteen) in different international schools in the Netherlands were interviewed (protocols can be found in Appendix A). All chemistry teachers are teaching MYP 4-5, the equivalent of ninth and tenth grade in the Dutch educational system, at International Baccalaureate (IB) schools in the Netherlands. All of the students are from lower secondary levels at IB schools, so they have a similar knowledge background.

The interviews with teachers were to investigate teachers' attitudes, experience and self-efficacy of teaching sustainability and critical thinking in their class. The interviews with

teachers lasted about 15-20minutes. The interviews with students were to explore students' attitudes, current knowledge, and interests towards sustainability. Students' interviews lasted about 8 minutes. All interviews were transcribed verbatim and analysed (Appendix A). These interviews and phases of SSIBL (Ask-Find out-Act) served as the starting point for the design of the lesson module, which also provided the researcher insights to design the learning materials.

According to the analyses of interviews (Appendix A), every teacher showed great interest in using the SSIBL approach to teach sustainability in their science class, but some were sceptical about the learning outcome of improving students' critical thinking. All students being interviewed were passionate about learning sustainability in the science classroom. They were most interested in the topic of recycling, followed by energy use. Combined with the teaching schedule of the IB school and interviewed students' preference, renewable energy was chosen as the main topic of the lesson module.

In the design phase, the lesson module was developed in the format of the IB school unit plan, and it was modified with teachers at International School Eindhoven. The final version is available in Appendix B and is implemented in the second phase: teaching experiment and

for the lesson module. A hypothetical learning trajectory(HLT) was made (Appendix C, Table 1 is the shortened version).

Table 1 Shortened version of the hypothetical learning trajectory for the three lessons.

Lesson element	Teacher/students activity	Hypothesis learning results
Lesson 1		
Opening	-Students brainstorm a list of items that need the energy to operate in their school	Students get engaged in the subject.
Class discussion about energy source	-Students list the energy sources that can be used for electricity	Students' prior knowledge is activated.
Working on the electricity bill	-Teacher distributes the energy bills of the school. -Students have a discussion about it.	Students articulate their first question about the topic
Introduction to the unit	-Teacher explains the topic and the learning objectives.	Students are aware of the topic and learning goals.
Knowing the task.	-Teacher distributes worksheet 1 and explains the task and homework.	Students know their task and feel a sense of ownership to their task.
Lesson 2		
Reviewing the last lesson	-Teacher review the knowledge in the last lesson.	Students get engaged in the subject and get prepared for the topic.
Finding out the information	-Students find out the relevant information by fulfilling worksheet 1.	Students learn new knowledge by themselves.
Lesson 3		
Presentation	-Teacher distributes worksheet 2 before the presentation. -Students present their work and fulfil the worksheet 2 while listening to others' presentation.	-Students learn new knowledge from each other; -Students improve critical thinking by commenting and receiving comments from each other.

Class discussion	-Students share their comments with each other.	Students get insights from others and are aware of the differences in peoples' opinions.
Class reflection and Unit closing.	-Teacher summarizes the knowledge and critical thinking strategies with students. -Students reflect their learning outcomes about how to conduct a reliable research study.	Students learn new knowledge and new strategies and know how to apply them in daily issues.

For the analysis part in the retrospective phase, the pre- and post-test design is used to evaluate the participants' learning outcomes. As one of the most commonly used experimental models in educational research (Campbell & Stanley, 2015), it aims to measure the changes in educational outcomes resulting from modifications to the learning process, which are often the focus of research. The student participants need to fill in one pre-test and one post-test before and after the unit for the evaluation of their learning outcomes (Appendix C).

Both the questionnaires for the pre- and the post-tests consist of two parts, which are (i) reading a short article and (ii) answering nine questions (one multiple choice and eight open-ended questions). The articles used in the first part are both related to sustainability but are based on the different dilemmas, one is how plastic influences nature and the other one is how the vegan diet impacts the environment. The nine questions in the second part are the same for the pre- and post-test. The setting up of the questions (Table 2) are based on six

dispositions of critical thinking: inquisitive, truth-seeking, open-minded, analytic, systematic and maturity of judgment (Facione & Facione, 1992).

Table 2 The setting up of questions in the second part of the pre- and post-tests.

Question	Topic	The research goal of the question
1		Participants' first impression on the text and their critical thinking skills
2	Critical thinking: Inquisitive	Participants' attitude of inquiry
3	Critical thinking: Analytical	How participants analyse the arguments in the text
4	Critical thinking: Systematic	How participants organise their opinion on this topic.
5	Critical thinking: Truth-seeking	How participants are going to find the truth about this topic.
6	Critical thinking: Maturity of judgment	Which kind of source for participants is credible and convincing
7	Sustainability: Active participation.	Participants' solution and how they take action on it.
8	Critical thinking: Open-minded	If participants would change their mind when acquiring new information.
9	Critical thinking: Self-confident/ open-minded	If participants are confident about their first answer and if they would change the answers after their reasoning process.

After the unit, two students from each class (three male students and three female students in total) were randomly chosen to take part in a one-on-one semi-structured interview, which was meant to analyse their learning outcomes in a more elaborated way (the protocol can be found in Appendix E).

Phase 2, Teaching experiment

Participants:

In the second phase, the teaching experiment, the participants consist of three classes (total n=60 students) and one chemistry teacher from International School Eindhoven. Students are from grade MYP4, aged 13-14 years. According to the teacher' interview, all classes knew some basic factual knowledge of renewable energy and unrenewable energy, but they did not study the topic sustainability in the science class before.

Implementation:

All classes spent three weeks to implement the lesson module. The teaching schedule was one 60min lesson in the first week, one 60min lesson in the second week, and one 120min lesson in the third week. Because the school held a morning assembly after a vacation, one class postponed its schedule to the next week and finished the whole lesson modules one week later than the others; However, its teaching plan remained the same.

The lesson modules were based on the SSIBL pedagogy, including three stages, 1) raising questions, 2) finding out, and 3) taking action (Figure 1). Critical thinking was

explicitly taught in the lesson modules by introducing it to students as the learning objectives in the first lesson and teaching the critical thinking strategies in the third lesson.

The first lesson, for the first stage, raising questions, aimed to stimulate students interests in the topic of renewable energy. After getting the demonstrated electricity bill of their school, students would discuss the bill and generate their own questions of it. At the end of the first class, students are expected to question how they could help to change the electricity bills of the school.

In the second lesson, applying the second stage, finding out, students need to find solutions for the question they generated in the first lesson. Students would search for the information and data with worksheet 1 (Appendix B), which is useful for them to organise their findings. However, the information should not be limited by worksheet 1 and can be any other relevant information. If students did not finish it in class, they had to complete it at home.

For the second lesson, worksheet 1 consists of:

-Factual knowledge about the use of different energy sources.

-Comparison of unrenewable energy and renewable energy.

-Description of students' research process and research results.

-A table which helps to analyse the central question from different perspectives.

-Two questions that gradually scaffold students to reach a final conclusion.

In the third lesson, focusing on the third stage of SSIBL, taking action, students need to present their solution to the central question using a poster. The solution is required to be realistic and credible. When listening to others' presentation, students fill in worksheet 2 (See Appendix B).

For the third lesson, worksheet 2 consists of:

-A table that students could compare others' work and their own work.

-One question: what do you learn from others?

-Two open-ended questions about the reliability of replacing new energy source to the school, in which students should explain their reasoning process.

Data collection

To evaluate the effectiveness of the designed unit and to answer the research questions, several types of data was collected:

- During the teaching phase of the lesson module in practice, classroom observation was conducted by the researcher, to record how teachers and students performed in different stages of the lesson module and to analyse if the lesson is implemented as intended.

- During the lesson, worksheet 2 was collected and analysed to support the analysis of students' learning outcomes about critical thinking and sustainability (Appendix B).
- Before and after the lessons, a questionnaire (Appendix D) was distributed to students, and they finished it as homework. The differences in these two questionnaires (pre-post-test) assessed students' learning outcomes.
- After the lessons, semi-structured interviews (for protocols see Appendix E) with both teacher and students were audio-recorded to assess how the unit was implemented, to see if the learning goals were achieved and their general opinion and suggestions on it. The data served as supporting sources for the pre- and post-tests.
- The summative assessment of the unit: posters of every group were recorded by taking pictures.
- All lessons were video recorded, and in-class group discussions were audio recorded during the lessons, for recording their learning process.

Phase 3, Retrospective analysis:

Data analysis

Since the pre- and post-tests (questionnaires) are not a the compulsory assignments and were counted as homework by students, only 35 pre- and 39 post-questionnaires were collected respectively. The data of the pre- and the post-test was analysed based on open coding. The coding results were compared, to see if there is a change in the answers of the eight questions which relates to different dispositions of critical thinking. The instrument was validated by adopting the inter-rater reliability approach. The second coder coded 20 samples out of 84, and the inter-rater reliability between the first coder and the second coder is 0.85. The interviews were conducted after the ending of the unit. Six students were randomly chosen, and each interview lasted for around 8 minutes. All the semi-structured interviews with students and teacher were transcribed (verbatim transcriptions are in Appendix F) and analysed based on selective coding, to give more in-depth insight in students' critical thinking and improve its reliability.

Results

The coding book to code the pre- and post-tests and the full version of coding results are available in Appendix G.

Sub- research question 1

1. To what extent does the lesson module make students inquiry into socio-scientific issues(SSIs)?

1.1 Comparison of pre- and post-tests

The inquisitive disposition of critical thinking was examined in the pre- and post-tests by the second question in the questionnaires: *Does this text raise any questions for you? Which ones?* the answers of which are coded based on the types of questions that students wrote (Table 3)

Table 3 The different types of questions raised by students in the second question in the pre- and the post-tests.

Question no.	Code *(Example)*	Pre-test (n=35)	Post-test (n=39)	Change (%)
2 **Inquisitive:** To know participants' attitude of inquiry (Referring to Table 2).	Information source: *(Who writes the text?)*	4/35	1/39	11% → 3%
	Social factor: *(How can people try to save the planet by banning the plastic?)*	9/35	10/39	26% → 26%
	text-related: *(Why people use many plastics?)*	6/35	9/39	17% → 23%
	Science-related:	7/35	12/39	20% →31%

(Is there any way to protect the environment without banning the plastics?)			
Multiple perspectives: *(How can we reduce the amount of plastic we use? Is there an alternative for plastics?)*	2/35	3/39	6% → 8%
NA *Non-Applicable Answers*	11/35	10/39	31% → 26%

How students made inquiries into SSI can be found by analysing the second question in the pre- and post-tests. Fewer students gave NA in the post-test (5%), which means that more students were able to raise questions for SSIs. An increase can be seen in the number of science-related questions given by students (+11%) in the post-tests, and even, more students (+2%) asked more than one questions in the post-tests. In contrast, fewer students (-8%) in the post-test questioned about the information sources. Overall, the number of questions formulated by students after the intervention raised, and those questions were more context-related, instead of text-related.

1.2 Recordings from the lesson module

During the first lesson, as the asking authentic question stage of SSIBL pedagogy, students discussed their opinion after reading the electricity bill of their school. According to the audio recording, they formulated the different types of the questions; for example, they formulated the economy related questions, "*Is the bill really realistic? I am suspicious a bit."*, "*How*

much is the average bill of a house?"; the social factor related questions, "*Is it a typical energy bill, for people living around the plan?*" and the science-related questions, "*Why space heating used more energy than lighting?*". These audio-recordings could support the finding that the lesson module encouraged students to make inquiries into SSIs.

Sub-research question 2

2. To what extent does the lesson module support students to analyse the controversy in SSIs?

2.1 Comparison of pre- and post-tests

The third question asked students which arguments were presented in the texts, to find out if students could identify two conflicting arguments in SSIs that given in the article. The answers were coded based on the number of controversial statements analysed by students (Table 4).

Table 4 The number of conflicting statements that students analysed from the articles in the pre- and post-tests.

Question no.	Code *(Example)*	Pre-test (n=35)	Post-test (n=39)	Change (%)
3 **Analytical:** To know how participants analyse the arguments in	0: *(It is very toxic for us to drink water from plastic bottles.)*	4/35	1/39	11% → 3%
	1: *(Animals are dying in the plastic soup.)*	19/35	23/39	54% → 59%
	2:	12/35	12/39	34% → 31%

the text (Referring to Table 2).	*(Plastic is a very important material for humans and industries, though it causes multiple environmental problems.)*

Unexpectedly, there is not a great difference between the pre- and the post-tests. Only a minor decrease (3%) was found in the students who could find out both arguments in the text. However, more students (5%) could identify at least one argument in the post-test and the percentage of students who could not find any relevant arguments decreased (-8%).

2.2 Semi-structured interviews with students

During students' semi-structured interviews, When the interviewer asked about what they thought about the topic of sustainability and how they related sustainability with energy, students answered:

Student B: "*Solar is kind of not sustainable (energy), it depends on various factors, it is not that sustainable (as we thought). If you use it to replace some non-sustainable energy like petroleum, coal, it is more sustainable but not evident.*"

This student gave an explicit example, solar energy, and analysed both advantages and disadvantages for the use of solar energy. This student is able to find the controversy in the topic of renewable energy and explain his/her thought in detail. Based on the responses of other students, they could identify the relevance between sustainability and energy. The Full version is available in Appendix F.

2.3 Worksheet 2

When listening to other's presentation, students filled in worksheet 2 and answered three open-ended questions. For the third question, students were asked if there is one energy source that can cater to the need of all aspects. 36 out of 49 students gave a positive answer, some of which mentioned both the pros and cons of using renewable energy.

"yes, for example, windmills are cheaper and better for the environment. On the other hand, windmills make a lot of noise, which could cause disturbance to residents, so public opinion would not be very positive."

Although the rest students gave negative answers, they could also state the controversial points in the energy issue:

"no, I think all sources have a downside, solar is very expensive but good for the environment and coal or gas are cheaper but really bad for the environment."

Taken together, 19 /49 students could analyse the controversy in the topic of renewable energy.

Sub-research question 3:

3. To what extent does the lesson module help students look at SSI from different perspectives?

3.1 comparison of pre- and post-tests

The fourth question was set to measure the systematic disposition of critical thinking: *What is your argument/opinion about this issue,* the answers of which were coded by the different perspectives that students have considered (Table 5).

Table 5 The perspectives used by students to look at SSIs in the pre- and post-tests

Question no.	Code *(Example)*	Pre-test (n=35)	Post-test (n=39)	Change (%)
4 **Systematic**: To know how participants organize their opinion towards this topic (Referring to Table 2).	Nature/environment: *(People should understand how harmful plastic is to animals underwater)*	10/35	14/39	29% → 36%
	Social: *(We should recycle more and try to cut the use of plastic.)*	13/35	15/39	37% → 38%
	Policy: *(I think single-use plastics like straws should be banned, but plastics on phones, smartwatches should be allowed.)*	4/35	0/39	11% → 0%
	Self-interest: *(I don't think it is necessary to cut meat completely, but decreasing our consumption is also important.)*	0/35	10/39	0% → 26%
	Multiple perspectives: *(I believe everyone should switch, so that our planet is on good condition for my generation and the next generation. Craving for meat should be disregarded, and we need to develop a liking for vegan food.)*	3/35	10/39	9% → 26%

The social angle was at the top of the answers in both tests and did not show a change in terms of occurrence, followed by the science angle that has a moderate growth (+7%). Notably, in the post-test, more students (+17%) formulated their arguments from multiple angles.

Fewer students (-11%) considered the issue from the policy perspective, and many more students (+26%) considered it from the self-interest perspectives.

3.2 Students' Posters

In the third lesson, as the last stage, taking action, of SSIBL pedagogy, students presented their solution in the form of posters. According to their posters, students could consider the problems from multiple perspectives. The most common one is the economic consideration; for example, solar energy group mentioned both the short-term cost, like installation cost and the long-term cost, like transportation fees. Students also looked at the social factors involved, for example, the wind energy group discussed how windmills might cause noise pollution, and the natural gas group compared the contribution of gas and coal to national GDP. The poster of the geothermic energy group mentioned both negative and positive impacts of promoting geothermic energy on the future: building the power plants would decrease a country's stability but mitigate the effects of climate change in the long run.

Sub- research question 4

4. To what extent does the lesson module help students learn critical thinking strategies to analyse SSIs?

4.1 Comparison of pre- and post-tests

The answers of the fifth and sixth questions in the pre- and the post-tests were set to measure truth-seeking and maturity of judgment dispositions of critical thinking. The answers of the fifth question were coded by the number of different strategies students would use to find information about SSIs and the answers of the sixth question were coded by which types of source are credible for them to rely on (Table 6).

Table 6 The number of strategies that students would use to find information and which kind of sources that students considered are credible in pre- and post-tests.

Question no.	Code *(Example)*	Pre-test (n=35)	Post-test (n=39)	Change (%)
5 **Truth-seeking**: To know how participants are going to find the truth about this topic (Referring to Table 2).	0: *(I wouldn't. I know it is wrong but I still want to eat meat, eggs and cheese.)*	4/35	6/39	11% → 15%
	1: *(I would look at graphs and charts to see if going vegan is really helping.)*	23/35	16/39	66% → 41%
	2: *(Survey how much meat family eat and buy; look at the issues about climate change.)*	8/35	15/39	23% → 38%
	3: *(Find graphs, look at trends in the past and their effects. Books, internet, studies.)*	0/35	1/39	0% → 3%

6 **Maturity of judgment:** To investigate which kind of source for participants is credible and convincing (Referring to Table 2).	Scientific data: *(Statistics on health for vegan vs non-vegan.)*	22/35	26/39	63% → 67%
	Social study: *(Conduct an interview.)*	3/35	4/39	9% → 10%
	Opinion from others: *(Information from health institutes and doctors.)*	1/35	8/39	3% → 21%
	Multiple strategies: *(Different articles, or if there are pros that eating meat and animals' products affect the environment.)*	2/35	7/39	6% → 18%

In the answers of the fifth question, we can see a significant change in code 2 (+15%) and a slight growth in code 3 (+3%), that means an increasing number of students would use two or three ways to find the information.

In the answers to the sixth question, scientific data ranked the highest in both tests, which increased slightly (+4%) in the post-test. The number of students who looked for social study in the post-test is nearly even with that in the pre- and post-test. An increase (+18%) was found in the category, opinion from others. In the post-test, many more students (+12%) used multiple strategies to back up their arguments.

4.2 Semi-structured interviews with students

During the interviews, students shared their strategies to evaluate the credibility of the information source:

Student F: *I wasn't sure about all the information. So, I researched one more time, if I get the same information again then I made sure the source was fine and I could use it.*

When asked about the strategies they would use next time to explore the SSIs, all of the participants provided one or more credible strategies:

Student A: *Think (about) the questions from others' perspectives.*

Students' responses showed that they would use more sources or more perspectives to check the credibility of the information. 5 out of 6 students addressed the practical strategies they would use next time to find credible information, such as looking for the textbooks, visiting the websites that end with .org or .gov, and checking the information from different sources. Besides, after finding out the sources and data, they would use graphs and charts to organise or present these data.

Open-mindedness

Open-mindedness is also an essential disposition in critical thinking, representing the degree of flexibility to consider alternative viewpoints (Facione, 1998).

5.1 Comparison of pre- and post-tests

In the design of the questionnaire, the eighth question is set to measure the degree of students' open-mindedness by asking if they will change the opinion when acquiring the new information (Table 7).

Table 7 The responses were given by students when they hear other/different voices.

Question no.	Code *(Example)*	Pre-test (n=35)	Post-test (n=39)	Change (%)
8 Open-mindedness: To know If participants would change their mind when acquiring new information (Referring to Table 2).	Yes: *(I would stick with my argument.)*	11/35	23/39	31% → 59%
	No: *(I will change, this is a good argument.)*	3/35	4/39	9% → 10%
	Yes, with explanation: *(A significant amount of results opposing my argument could cause me to think differently.)*	14/35	9/39	40% → 23%
	No with explanation: *(I would stick with it because there are so many other ways people could do to help.)*	6/35	3/39	17% → 8%

In the post-test, students showed a stronger faith in their original answer, because more students would stick to their answers in the post-test than in the pre-test (59% vs 31%). The percentage of students in the post-test explaining why they stick to or change their original answer also showed a decrease.

5.2 Semi-structured interviews with students

Participants were asked about how they felt to hear others' feedback, most of whom gave positive feedbacks, for example, other groups' presentation helped him/her view the issue from a new angle:

Student A: *"For example, nuclear energy, I thought there was a nuclear accident in Japan which would cost lots to time to recover. But after listening to my classmate's job, I think nuclear energy is not as dangerous as I thought."*

From the responses, students could formulate a well-informed argument, and reconsider this issue from a new angle, which means the improvement in the open-minded disposition of critical thinking. Therefore, it can be concluded that the group work like presentation can help students have a broader perspective and improve their open-mindedness.

Active participation (in the community)

Although active participation is not included in the dispositions of critical thinking, it is one of four main aspects of citizenship education. When students actively take part in their community, they are able to use the knowledge, skills, values and attitudes they have learnt at school (Eurydice, 2005).

6.1 Comparison of pre- and post-tests

In the questionnaires, the seventh question was asking about how students would take action for the issue and what the impact would be (Table 8).

Table 8 The solutions are given by students to solve the issue.

Question no.	Code *(Example)*	Pre-test (n=35)	Post-test (n=39)	Change (%)
7, Active participation: To know the participants' solution and their action on it (Referring to Table 2).	0, irrelevant answer: *(A circular economy will not make non-recyclable waste.)*	4/35	1/39	11% → 3%
	1, giving a proper solution: *(I feel like people should eat less meat or maybe even become vegan.)*	16/35	21/39	46% → 54%
	2, giving a proper solution and explaining its impact. *(We could switch to veganism entirely this way, greenhouse gas emissions go down, global warming goes down and in general we help save our planet.)*	12/35	15/39	31% → 38%

It is clear to see that after the lesson module, students could list more actions to solve the issue (code 1, +8%). More students are able to describe how their action would impact the world/society/themselves (code 2, +7%).

6.2 Worksheet 2

In worksheet 2, a question asked if students think it is feasible and desirable to change the school's current plan about energy sources, almost every student gave the affirmative answer (45 out of 49) and explained the impact of their answers:

Student 2: "Yes, because we need to think about future generations and our planet. So, we should use cleaner and cheaper sources such as solar, biomass, nuclear, etc."

The majority of the students considered the environmental impact of using coals over the future, and some of them also wrote the economic, political, and practical impacts to support their arguments.

Discussion

The main goal of this research is to design a lesson module based on the SSIBL pedagogy to foster students' critical thinking. In this process, the pre- and post-tests measured six dispositions of critical thinking in order to track progress. Besides, additional data sources from interviews, in-class audio recordings and lesson materials also provided more profound insight into the learning process.

Inquisitive disposition

The evident variation is seen in the second question in the pre- and post-tests suggests that this lesson module is effective in cultivating students' inquisitive disposition, one of six dispositions of critical thinking. Overall, more students raised valuable questions, like the category, non-applicable answer, dropped 5%. To be more specific, the number of science-related questions increased drastically by 11%. This finding agrees with previous research, which proves that SSIBL can teach students how to carry out socio-scientific inquiries (Levinson & PARRISE consortium, 2017). This vast improvement can be linked with the discussion sessions set up in the lesson module, for example, in the first lesson, students had a discussion about the school electricity bill, during which they raised many different questions.

Analytical disposition

According to the data collected from the pre- and post-tests, analytical disposition of students suggests less improvement. It is worth pointing out; however, one part of the learning material worksheet 1 was designed to facilitate students analyse the controversy by listing the pros and cons of different energy sources. The fact that only several groups filled in Worksheet 1 might contribute to this outcome. Meanwhile, the results of semi-structured interviews and Worksheet 2 reveal that students can analyse the controversy in SSIs, such as "*some of the substances are not very environmental, but helpful in our life"*.

Systematic disposition

Another disposition of critical thinking, systematic disposition, was improved by the lesson module. Drawn from the analysis of the fourth question in the pre- and post-tests, an increasing number of students find themselves better organise arguments through multi-angle (+17%). Additionally, the content of students' posters also sustains this funding. Students presented the ability to consider the given issue from various angles such as economics, public opinions as well as technic limitations. In this sense, the implementation of SSIBL would enable students to organise their thoughts systematically, in the time of coming up feasible solutions.

Truth-seeking and maturity of judgement dispositions

Similarly, the designed lesson module reinforces truth-seeking disposition. It can be found from answers to the fifth question in the pre- and post-tests that more students gained the ability to integrate two or three different strategies (+15% and +3% respectively) to search for information. Furthermore, students are more likely to cite credible sources to support their arguments, as the maturity of judgement disposition indicates. There is an increase in both the willingness of students refer to others' opinions and search for from multiple-perspectives (+18% and +12% respectively).

Likewise, in the semi-structured interviews, students mentioned they preferred to run fact-check on the information by reviewing distinct perspectives during the second lesson, as the finding-out stage of SSIBL. Correspondingly, the finding-out stage of SSIBL proved to be efficient in advancing the truth-seeking disposition of critical thinking.

Open-minded disposition and active participation

Despite the fact that open-minded disposition was not incorporated in the sub-research questions, an independent eighth question was constructed to measure students' open-mindedness. Surprisingly, the result showed a tremendous drop (-28%) for this disposition. One possible explanation is the difference in the topics of articles in the pre- and post-tests.

For instance, students held their opinion firmly in the vegan topic because eating meat or not is highly close to their life, and their different views regarding vegan might be due to the different types of families. Therefore, choosing the vegan topic as SSIs to measure students' open-mindedness is not comprehensive.

Although active participation in the community is not included in critical thinking, it is a crucial component of citizenship competence. In the post-test, there is an 8 % increase in code 1, which implies students stated only solutions to the problem, and a 7% rise in code 2, which means students give both the proper solutions and implications of their solutions. This discovery was backed by Worksheet 2 and posters. Therefore, the lesson materials like Worksheet 2 and poster that engage students to solve the local or global issues can effectively encourage students' participation. These results mean this lesson module not only fosters critical thinking but also promotes another component of citizenship competence.

Our data suggest that this lesson module can foster students' critical thinking. In the process of raising the critical questions, analysing the problem from various perspectives and referring to a more credible information source, students' critical thinking is strengthened. Nevertheless, in the analytical disposition of critical thinking, students did not show a

profound improvement in analysing controversial statements in the articles of pre- and post-tests.

These findings are consistent with the hypothesis that we set out at the beginning of the paper - SSIBL is a promising pedagogy for fostering students' critical thinking. Similarities can be found in previous research conducted by Bencze (2014), in which he implemented GMO food actors as SSI to develop 7th- and 8th-grade students' critical thinking skill through the STEPWISE framework.

In conclusion, the hypothesis is testified by the findings of this research. The setting up of the lesson module played a critical role in this success. Each section of the lesson module is closely related to foster different dispositions of critical thinking, and each additional learning material is closely linked with the learning goal, critical thinking. Therefore, students were able to give a more critical answer in the post-test and the semi-structured interviews.

Limitations

There exist some limitations in this research. Firstly, the lesson did not follow the original plan strictly, since two unexpected changes in school timetable interrupted the original teaching scheme. Moreover, four lessons (4hours) were relatively short that it

required students to do much work at home. The work was challenging to finish at home because the summative assessment was designed as a group assignment. In the interview, students also mentioned it would be better if they were given more time to prepare their posters.

Thirdly, given the topics of articles in the pre- and post-tests varied a great deal, students might have biases and hold different attitudes towards two topics. For example, in the pre-test, the topic about using plastics, students' opinions was closely relevant to policy, while in the post-test which used vegan issues as a topic, students would give more thoughts from self-interest as it was more relevant to themselves. Besides, many students showed insistencies on their arguments regarding vegan even if they acquired additional knowledge. It is because many factors are at play in students' preferences, ranging from their family, religion or social circle. With this being said, selecting vegan as a topic was not appropriate to measure the open-mindedness of critical thinking.

The last limitation is the lack of a control group. Many IB schools' teaching plans have already been arranged in the last year, which was a big problem for us because we started to find a control group in February of this year. Although we got one positive reply from

another IB school, they would teach heat and energy in late June which did not conform to our plans.

Recommendations

SSIBL is a useful educational framework, for students, teachers and policy-makers. It provides educators with a clear structure and suggestion on how to design a proper SSIBL lesson module. Feedbacks from teachers also indicated that this module encourages students to learn new scientific knowledge.

As for the implementation of SSIBL, this research paper suggests that the length of a whole module should be extended to five hours: one hour for raising authentic questions, two hours for finding out and two hours for taking action and summarising. Since both students and teachers mentioned they would like to have more time, an additional hour allows students to be more prepared for the poster and teachers to include more topics in the lessons. Thus, for the future use of SSIBL, the hours of lesson module should be moderately extended.

When it comes to teaching materials, in our case, teachers suggest that students can search for energy saving ways to save energy, instead of replacing the coal completely; or adding other concepts like heat and power could help students to recognise the full picture of science and to achieve a more in-depth understanding.

When employing the SSIBL pedagogy, we recommend starting the lesson module with a related case that can stimulate students' interest in the topic. In this lesson module, teachers began with demonstrating the electricity bill of their school and successfully grabbed students' attention. When students got interested in the topic, they generated more questions in the discussion sessions. As a result, their inquisitive disposition of critical thinking was improved, which was proved by the result of sub-question 1.

In the finding-out stage, we suggest that providing detailed guidance for students. This lesson module designed Worksheet 1 to guide students in their research process as well as organise their findings. Nonetheless, many groups did not use this worksheet for reference as it was not mandatory, which might explain why the analytical disposition of students was not improved as predicted. To avoid this issue, this stage should set more thorough guidance, along with control for students to analyse the controversy in SSIs, such as an intermediate inspection.

The final stage went as expected, with both results from pre- and post-tests and interview showed that students' critical thinking was improved. A summative assessment, which allowed students to share their points of view to others, was proved to be effective. Hence activities like this work well in engaging students to learn from each other and

becoming team-player. Not surprisingly, feedbacks of posters from both students and teachers are positive.

As shown in the results part, students not only fostered several dispositions of critical thinking but also became more active in participating in a global or local issue, the latter of which is crucial to obtain citizenship competence. Not all dispositions were fully investigated in this research, such as critical thinking self-confidence. In this aspect, we would recommend future research to analyse more on the learning outcomes of critical thinking derived from SSIBL pedagogy. At the same time, the skills of any other citizenship competences should be measured as the learning goals of SSIBL in future research.

Conclusion

We found that the SSIBL pedagogy can foster students to make inquiries, organise their thoughts, be motivated to find the truth and be able to find credible sources to support their argument towards SSIs. Each stage of SSIBL is necessary to improve the different dispositions of critical thinking. The asking stage can foster students inquisitive disposition, the finding-out stage helps students improve their truth-seeking disposition, and the acting stage helps students improve the maturity of judgement disposition of critical thinking. An additional but expected finding, not considered in the original research aim, was that students would be more motivated to change their current situation in a sustainable way. SSIBL should be taught in science education to improve students' critical thinking. Future work will investigate how SSIBL pedagogy can improve the skills of critical thinking and other citizenship competence.

Acknowledgements

I would first like to thank my supervisors Dr. Marie-Christine Knippels of the Freudenthal Institute at Utrecht University. The door to Dr. Knippels office was always open when I had a question about my research or writing. She consistently allowed this paper to be my own work, but steered me in the right direction whenever she thought I needed it.

I would also like to thank my second supervisor: Researcher, Michiel van Harskamp of the Freudenthal Institute at Utrecht University. Without his passionate participation and input, my research could not have been successfully conducted.

I would like to acknowledge Teacher Rein Dunki Jacobs at International School Eindhoven. I really appreciate he accepted the proposal of implementing my design in three classes and how he completed the teaching successfully.

I would also like to acknowledge Mardie Vermunt of the Freudenthal Institute at Utrecht University as the second coder of this thesis, and I am gratefully indebted to her for her very valuable comments on this thesis.

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APPENDIX

Appendix A

-Protocol and analysis of the prior investigative interviews with teachers and students.

1) The protocol of teachers' Interview

Table A 1

Subject	Core Questions	Sub-questions or Comment
Introduction	Researcher introduces the research and the goals of the interview.	Comment: During the interview, the researcher should use the word 'citizenship competences' many times, for triggering teachers' idea.
General interests in Sustainability education & critical thinking	1. What do you think of sustainable education?	1). Are you interested in sustainable education? Why and why not? 2). If yes, how do you use it? if no, would you like to use it in the future?
	2. The learning goals include critical thinking in the science guides of IB school, what do you think about it?	1). Do you feel it important and interested in teaching critical thinking?
Whether their current curriculum is relevant with 'sustainability'	1. Have you taught any science lessons that are related to 'sustainability'?	If the answer is Yes: 1) What was the lesson about? 2) Did your students like it?

		3) Have you encountered any problems when you teaching this lesson? What are the problems, why did it become a problem? If the answer is No, 1) Do you think the topic sustainability can be integrated into the current science lesson? Which one? 2) How do you think about using sustainability in science lessons? Are you willing to teach it in your class in the future? 3) Do you think your students will like it?
	2. Which other chemistry chapters/units/subjects do you think it is also important to link to sustainability?	
Whether their current curriculum/activity increase citizenship competence.	1. Do you have any science lessons or activities in the classroom that focus on improving students' critical thinking ability?	If the answer is yes, 1) What was the course/activity? 2) Do your students improve their skills in the end? 3) How did you evaluate their improvement? 4) Did you find it any problems when teaching this lesson? What is the problem, why would it become a problem? if the answer is no, 1) Why? 2) Would you like to use new lessons or activities that can improve students' critical thinking skills in the future?
	2. Which chemistry lesson do you think it	

	is also important/applicable to improve critical thinking skills?	
Self-efficacy	1. How will you feel if you teach sustainability education in science lesson? is it hard or difficult?	If the answer is Yes, why? how to solve this difficulty? If the answer is No, why? which experience/how to help you to use it easily.
	2. Would it be very hard for you to improve students' critical thinking ability?	If the answer is Yes, why? how to solve this difficulty? If the answer is No, why? which experience/how to help you to use it easily.
Conclude	1. Any idea, questions for me? 2. I am also interested in how students think about it; May I interview some students to better know their ideas? 3. Can I ask more questions by email/phone for following-up information? 4. Next step in my research is designing curriculum, we have already some frameworks, you can see it from the website, would you try in your class? ideas)	

2) The protocol of students' Interview:

1. What does the term 'sustainability' bring to your mind?

(if they can't answer, give a different term, for example, the environmental friendly activity, what can we do to environment that can help our next generation live, taking care of the environment, the goal is not to ask literal definition, but to ask their explanation, interpretation.)

2. Did you know this term 'sustainability' from school or home/television?

I. If you learn it from school, which course do you think it is related to sustainability? Do you like it?

II. If you learn it from home, how do you know this word? Do you think it is interesting?

3. How do you think sustainability has influenced your life / how will it influence your future?

4. Tell me an interesting thing in your daily life that is related to sustainability.

5. What do you think if you study sustainability in the science(chemistry) courses, is it interesting for you?

I. If it is, why?

II. if it is not, why not?

6. What questions do you have about sustainability, which question are you curious to find out?

7. If you are learning the topic about 'sustainability' in a science course, which of the following topics you are most interested in?

A. Plastic and how it affects our ocean *how does it go to the ocean, how long does it last, how it impacts human/animals?*

B. Plastic soup, *what is plastic soup, where is it, how does it form….*

C. The use of different metal in (environmental) Industry (f*or example: In England, ikindle eggs, wrapped with aluminium paper, where the metal comes*

from]

D. What is biofuel, *what is the differences between traditional fuel? Fuel from plants, living things*

E. Bioplastic, *what is it, what is the differences between plastic?*

F. How do people recycle in the neighborhood/our country/ in other countries?

G. Electricity generation/efficiency

H. How to view that fashion industry use recycling material more and more.

I. How can we design a chemical cloth to decrease air pollution?

J. Renewable energy, *Is renewable energy the best energy for peop*

3) Analysis of the prior investigative teachers' interviews: (Level of agreement from 1 to 5, 1 for Positive, 3 for neutral, 5 for negative)

Table A 2 The analysis of teachers' interviews

	Amaya	Riette	Ioana	Pete	Dirk	Flaur
Interested in Sustainability	1, very interested	1, essential subject, big topic	1, essential, relevant	1, global issues	1, absolutely interested	1
Interested in Critical thinking ability	1: most important	1: important to think critically; really really important.	2, essential, but it is higher thinking skills, students need lower thinking skills first.	1, definitely yes	2, of course interested	3, yeah, but…
Experience in teaching sustainability	2, have some relevant.	1, integrate into many level, and give many examples	1, many chemistry courses, organic.	1, used a lot in our unit	3, doing a bit	3, a few small things, like water usage
Experience in teaching Critical thinking ability	2, elaborate the report, feedback..	2, in the past, teach CPA implicitly, but now….	2, inquiry learning, interdisciplinary	3, lab report, revise and answer questions	2, I have lots of analysis related to it, but not explicitly, like a plastic report by themselves to discover a problem and analyse it.	3, teach implicitly, keep asking why.

Attitudes towards combining sustainability and critical thinking ability	1, absolutely, lots of topics related to sustainability and different perspectives…	2, existed project about sustainability and teach it from different country context	1, I would love to design and make it.	1, definitely doable.	2, I agree with that. It is a good question that you are asking and question science.	/
Self-efficacy (to teach sustainability)	1, study sustainability for phD.	3, mentioned several challenges, from content-based countries.	1, many topics, give many examples.	1, no different than other classes.	3, we don't cover enough content, not keen on	/
Self-efficacy (to teach critical thinking ability)	2, feel more responsible, check their progress, not for everyone	3, I won't say it is easy, it is not easy to teach someone think critically.	4, very very difficult	4, pretty difficult	4, I think yes	4, probably yes
Willingness to use SSIBL	2, approval to send following email.	1, I would love to use..	2, open to it but need more detailed	5, we don't want to change the current lesson.	2, we are open to it, but it should covering content, we don't have much time.	/

Appendix B

-Unit plan

-Clean energy or Conventional energy, which energy is more desirable?

Unit Description:

Students will work in groups. Each group will choose an energy source, collect information on the issues related to that source, and evaluate the possibility of that source to substitute their schools' original energy source.

By finding the differences between unrenewable energy and renewable energy, investigating and analyzing the consumption of energy in their school, and exploring the interconnectedness of political, economic, environmental and social issues, students will find out which energy source is the most desirable for their school and come up with the suggested ways to use different energy sources for a healthy and sustainable future.

Key concept: Change

Related concepts: Energy

Global concept: Globalization and sustainability: How is everything connected, Explore the interconnectedness of energy and communities, how local experiences can mediate the global.

Statement:

Exploring the heat exchange and energy transfer allows us to find a better solution in environmental and global issues related to the finite fossil fuel use.

These approaches to Learning Skills will be useful (ATL):

Communication skills:

- Negotiate ideas and knowledge with peers and teachers;
- Use appropriate forms for different purposes and audiences
- Take effective notes in class
- Structure information in summaries and reports.

Collaboration skills:

- Delegate and share responsibility for decision-making

Creative thinking skills:

- Use brainstorming and visual diagrams to generate new ideas and inquiries

Critical thinking skills:

- Critical thinking-gather and organize relevant information to formulate an argument.

Reflection skills:

- Consider ethical, cultural and environmental implications;
- Consider personal learning strategies;

Information literacy skills:

- Collect, record, verify and interpret data;
- Evaluate and select information sources and digital tools based on their appropriateness

to specific tasks.

- Present information in a variety of formats and platforms.
- Process data and report results.

Assessment opportunities in this chapter:

- Criterion A: knowing and understanding (ungraded)
- Criterion B: inquiring and designing (ungraded)
- **Criterion C: Processing and evaluating**

- Criterion D: Reflecting on the impacts of science (ungraded)

In this unit, we will…

Find out how the different energy sources are used in our daily life.

Explore the differences between renewable energy and un-renewable energy, and their relationship with society, environment, economy, and policy.

Take action to find out the best energy for our school, and develop a strategy to use the energy in a sustainable way.

Core questions/core information:

Factual:

1. How are renewable energy and unrenewable energy used in our daily life?
2. Does exothermic reaction or endothermic reaction occur when using the energy?
3. How is energy transferred and conserved?
4. What are the pros and cons of renewable energy and un-renewable energy?
5. How much does it cost to use the different energy sources? Which energy has the lowest/biggest economic cost?

6. How much carbon dioxide is emitted from different energy sources?

Concept:

How can we use scientific research to improve our community?

Debatable:

1. What are the social and economic consequences of renewable energy and un-renewable energy?

2. What are the limits of scientific research on this topic?

3. Who should take the responsibility to build a better environment for the next generation?

Assessments:

- Formative assessments: Worksheet 1 (for Criterion A and B, will not be graded.)

  Worksheet2 (for Criterion C and D, will not be graded.)

- Summative assessment: (to assess Criterion C, and it will be graded.)

Students will design and present their poster, by organizing the information they collected. In the poster, they will show how they carry out the research and how they evaluate the results, by using graphs or charts. At the end, they will understand how science affects their daily life and how they can contribute to improving the environment. Students will demonstrate their research skills, critical

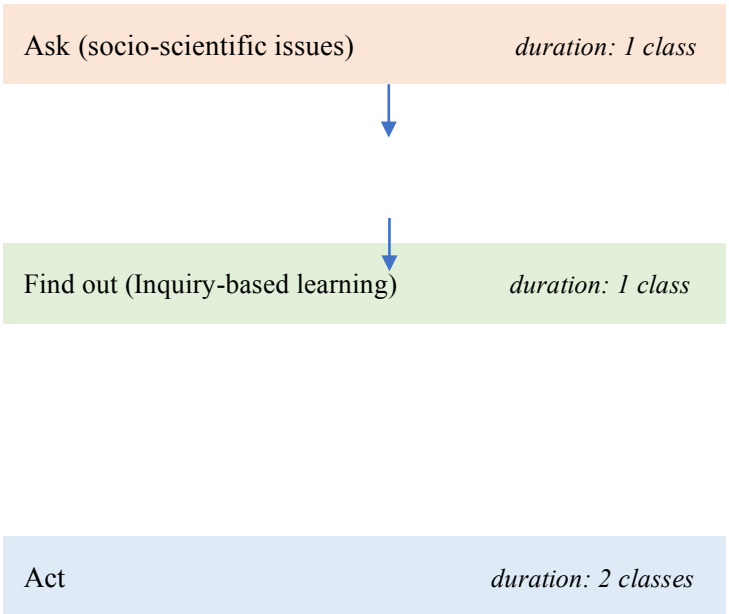
thinking skills and reflection skills. **Only** the content of the poster **will be graded** and the presentation skills will not be graded.

Unit Outline

Main idea:

MYP grade 9 students learn knowledge about energy, heat, combustion, endothermic and exothermic reaction, foster their research skills and critical thinking ability by making an inquiry into a socio-scientific issue.

Structure of Unit, based on the principle of SSIBL*:



Lesson 1: Ask an authentic question (60 min)

In this lesson, students will know the learning goals of the unit, activate their existing knowledge and learn new knowledge about energy. To engage students' interest, students will gain the energy bills of school and work in groups to analyze one energy source as the alternative for their school.

Learning objectives:

1. Students will be stimulated to explore the topic by themselves.
2. Students will activate prior knowledge and learn new knowledge.
3. Students will learn to design a comprehensive plan with specific goals.

Materials needed:

Computers, whiteboards, worksheet 1, Energy bills of school.

Table B 1The plan of the first lesson

Activities	Comment
1) **Stimulation and discussion** (5min) Brainstorm: Ask students to brainstorm a list of items that need the energy to operate in their school and record it on whiteboards.	Allow them to share their ideas with the class. Ask students: How much energy may be used for different items in school?
2) **List the energy** (15 min) 1. Allow students to think about which source of energy can be used for electricity. 2. Activate their prior knowledge about non-renewable energy and renewable energy. Extra activity: Browse the website: https://www.need.org/energyinfobooks	1. What is the definition of energy? 2. What is the non-renewable energy and what is the renewable energy? 3. What are the differences between them? 4. Categorize the energy into renewable energy and un-renewable energy.
3) Discuss the energy bill of school. 15 min Let students discuss what do they find from the energy bills.	Guide the discussion: 1. How much energy is used for different purposes? 2. Which kind of energy source is our school using?
4) Explain the learning goals of the unit, 5 min Inform students of the learning goals of the unit by using ICT tools.	Learning goals: Students should understand how their energy source is harnessed, developed, and distributed for their use and the issues associated with each of those processes. They can use research skills to solve practical problems and critical thinking ability to analyse the problems and come up with a proper solution.
5) Grouping & Knowing the homework/Task (10 min)	➢ Task:

1. Ask students separate into groups and choose one energy source from the list as their group topic. 2. The teacher explains the homework and the task for the next lesson 3. Ask if students have any questions for the homework and task. 4. Distribute Worksheet 1 to students.	Choose one energy source as the topic (it can be renewable energy or un-renewable energy, but every group's topic must be different) and find out the information to analyse if our school can use this energy source as the primary energy source. ➢ For the next lesson: 1) Find out the theoretical information about this energy source and compare it with the one our school is using (Worksheet 1). 2) Conduct arsearch and analyse the energy source from different perspectives: Scientific – nature of science and research that determine our understanding of natural phenomena Technological – applications of science relating to how the energy source is harnessed, processed, and distributed for use Societal – includes the health, cultural, and aesthetic aspects of human societies. Environmental – includes the relationships among organisms and the land, air, and water, for example: find out the data of how much carbon dioxide is emitted from the different energy sources.

	Economic – costs versus benefits, employment opportunities, competing for market share. Political – includes legislation, regulations, and permits that control development, and protect society and the environment. Public Opinions: take different positions as account: by interviewing the staffs in the market/ neighbourhood/ parents/ electricity workers… *Remind students: The collected information is important for the summative assessment.
6) **Plan** their activity, 10min. Make a plan for the project. Students make a practical plan for outdoor activity.	Students need to think about a feasible plan about how to conduct their research.

Homework & Research- Find out 1st

In this section, students will search for the information by themselves from various sources and verify its credibility. After all, they will come up with an answer.

Learning objectives:

1. Students will acquire new knowledge by themselves.

2. Students will know how science influences our daily life.

3. Students will gain insights from different perspectives.

4. Students will study how to collect, record and verify the data.

5. Students will learn how to conduct proper research by implementing a solid plan.

6. Students will find out how to use their chosen energy type appropriately.

During the research:

Students will implement their plan, write down their results on Worksheet 1, or even use the digital tool to record the results of the research.

After the research:

Teacher sends the requirement of their summative assessment by email.

Lesson 2- Find out 2nd (60 min)

If there is not enough time, students can finish the poster as a (homework) assignment.

In this lesson, students will design a poster to perform all the information they have searched, by following the requirement of summative assessment.

Learning objectives:

1. Students will present information in a variety of formats and platforms.
2. Students will process data and report results.
3. Students will learn how to interpret the research results to be easily understood by others, by using graph, pie, charts.
4. Students will strengthen their research skills and cooperation skills.

Materials needed: Marker pens, sticker, A3 or A2 poster paper.

Table B 2The plan of the second lesson

Activities	Comment
1) Check! 5min Check students' progress and make sure every group is on track.	
2) 55 min Make the poster	

Lesson 3-Act (2 *60min)

In this lesson, students will present their own work, get inspiration and learn new knowledge from other's work. Students will give feedback to each other. Students will choose the best energy source for their school together and vote for the best-suggested plan to use energy. The teacher will guide students to summarise the knowledge and the learning strategies of the whole unit.

Learning objectives:

1. Students will learn new knowledge from each other.
2. Students will learn critical thinking to comment on other groups' posters
3. Students will learn the critical thinking strategy from other groups' work.
4. Students will appreciate the impact of science on our lives.
5. Students will acknowledge that renewable energy is the solution to the finite fossil fuel.

Materials: Worksheets 2, board for displaying the posters, pens.

Table B 3The plan of the third lesson

Activities	Comment
1) Presentation, 52 min Distribute worksheet 2 (see more in Appendix B) at the beginning of class. Present the poster: 13 min *4	Worksheet 2 includes: 1) Feedback of others' presentation; What they learn from others' work;

	2) Choose their favourite one and give reasons; Explain why other's presentation convinces them.
2) Break 10 min	
3) Discussion in a new group using the Jigsaw Method, **15min.** Regroup the students: new groups consist of one student from each topic. Discuss with each other in the new group to decide which energy source is most appropriate for their school and the best suggested way to use this energy (the two results can from different groups.)	Jigsaw Method: A method of organizing classroom activity that makes students dependent on each other to succeed. It breaks classes into groups and breaks assignments into pieces that the group assembles to complete the (jigsaw) puzzle.
4) Share the results of their discussion**, 13 min.** After the discussion, every group shares the result and reasons for others and class would reach an agreement.	
5) Summary, 25 min. Summarize the knowledge with students: energy transferring, heat loss, energy conservation, electricity density, combustion, an exothermic and endothermic reaction, the pros and cons of different energy by giving notes or using ICT tool. Guide a discussion- how to make a careful study, which contains: ● How to use a reliable source to find scientific information. ● Why should we consider the problem from different perspectives; The problem from different perspectives may be different, and thus, the solution will be different. ● The Highlights in students' presentation, such as the approach and strategy students have used, that can be used in scientific research.	

The Electricity Bill of International School Eindhoven, 2018

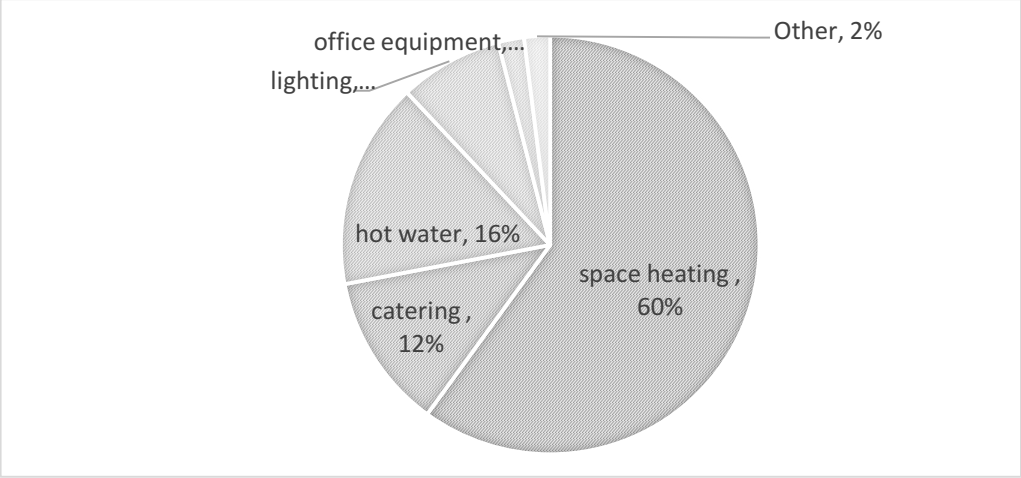
(This is a demonstration, which doesn't include VAT or any other fees)

Overview all-in year cost:

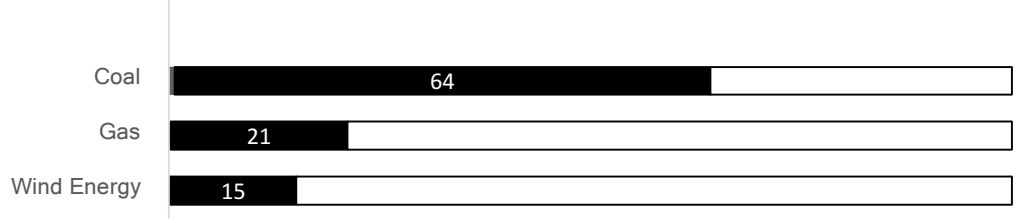
Electricity Units used	kWh rate	Charge
35,000 kWh*	€ 0.22	€ 7,700

kWh is a unit of energy, 1 kWh=1000 x 1J/s X 3600s/h = ?

Electricity composition



Percentage of electricity use:



The Criteria of summative assessment

Design a Poster

In groups of four people choose an energy source as a topic and design a poster in which you: Explain and discuss if we can use this source to substitute our schools' **original energy source** (Coal).

You will present the poster to the class in the next lesson on March 26th or 27th. You will have 8-10 mins for the presentation.

Only content in your poster will be graded, and the presentation skills will not be graded. You will be assessed on Criterion C (Processing and Evaluating).

The setting will be a 'meeting' with the school authorities and school council. You will present information about your chosen topic and ways of ameliorating the problem and deliver your messages in a most appropriate way to convince decision-makers.

The content of the poster should include:

1. Theoretical Background:

A clear explanation of the energy source (Cite the information source, explain the reason why you choose the source, and also evaluate its reliability of the source).

2. Progress:

What did you do, how did you interpret the results?

3. Result:

What is your research result, (Interpret it by graphs/pie charts/ diagrams...)

4. Discussion:

Based on the solid arguments, make a conclusion if it is appropriate to use this energy source for your school and suggest a way to use it properly in your own community. Besides, you can also discuss what you learned from this project, where you can improve next time, etc. ***use your Worksheet 1 as a reference** Keep your audience in mind! The goal of your poster is to convince your audience: your result/strategy is well-supported, keep your pitch or presentation elaborate, to-the-point, and relevant.

Worksheet 1a: Search

Our topic (energy source): _____

Based on the electricity bill, our school is using the energy sources: _____

Make a guess, between our energy source and our school's energy sources:

a. Which one has less energy waste?

b. Which one has a larger energy density?

c. Which one emits more greenhouse gas in the environment?

Keep in mind:

for each question, you need to be careful about the source you used for the answer. Is the source reliable?

1. What are the definitions of the energy sources that our school is using?

2. What is the definition of our energy source?

3. Do any reactions happen when using these energy sources?

(Endothermic? Exothermic? Combustion? Release greenhouse gas? Conversion? Conduction?...)

4. Other useful information:

5. What are the positive and negative issues related to production and use of this energy source, compared with the **main** energy source that our school is using (coal)?

Positive	Negative

6. With the evidence from your research, answer the question a, b, c again.

a: b: c:

Worksheet 1b: Measure and Record

1. Our research process (How we conducted our research)

2. Results:

(Use bar chart/line graph/pie chart/flow chart/table to show)

3. Conclusion (After our investigation, we conclude…)

1) We can/cannot use this energy source in our school, because:

2) Our suggested way to use this energy source in our community:

4. After searching the information and conducting your research, you can consider the problem from different perspectives and answer why would certain groups support or oppose developing this energy source?

PERSPECTIVE	REASONS	CONCLUSION
FOR EXAMPLE: ECONOMY	*It costs much more than fossil fuel…*	*We may not change our habits.*

Worksheet 2

Part A. Feedback (When other groups are presenting, please finish this part).

1. Besides our group, I like the group (topic: _____) most, because:

Compared with my group, their pros and cons are:

	Our group	The other group
Pros		
Cons		

2. The other groups *(it can come from different groups)* inspire me to do this differently next time:

(you can write about anything, such as strategy, content, research method, how to show the data…)

Part B. Open questions (After discussing in groups, please finish this part.)

1. Taken together, do you think it is feasible and desirable to change the school's current plan about energy sources? Why?

If the answer is yes, which part of the plan would you like to change?

2. Does one energy source (your own or one from another group) can cater to the need of

all aspects (economy, environment, policy, public opinion..)? Why/why not?

Appendix C

-Hypothetical Learning Trajectory(HLT) of the lesson module

1) HLT of the first lesson

Table C 1 HLT of the first lesson

Learning and teaching activity	Activities		Hypothesized learning results	Data source
	Teachers	Students		
1) Opening- stimulate students interests into the topic	Ask students to brainstorm a list of items that need the energy to operate in their school	Discuss it and record the results on Whiteboards.	Students get engaged in the subject. Emotions and interests are raised.	Video, audio, observation
2) Class discussion in energy source	1. Ask students to list which source of energy can be used for electricity; 2. Ask students questions about non-renewable energy and renewable energy.	Discuss and list the energy source on the whiteboard; Browse the website: https://www.need.org/energyinfobooks	Students' prior knowledge about non-renewable energy and renewable energy is activated.	Video, audio, observation.

3) Raise questions about energy bill and class discussion.	1. Distribute the energy bills of the school. 2. Let students discuss what do they find from the bills.	1. Read the energy bills. 2. Share their thoughts with each other.	☐ Students articulate their first questions about the topic ☐ Students understand the topic.	Video, audio, observation.
4) Introduction- General introduction to the lesson.	Introduces the topic of this unit and explains the learning goals.	Listen to the teacher, and ask if they have any questions.	☐ Students are aware of the topic of the unit and the learning goals.	Video, audio, observation.
5) Introduction- Homework and task.	1. Ask students separate into groups and choose one energy source from the list as their group topic. 2. Explains the homework and the task for the next lesson 3. Distribute Worksheet 1 to students.	1. Choose a topic in groups. 2. Listen to the teacher and ask if they have any questions. 3. Take the Worksheet 1.	☐ Students become engaged into the project by feeling the sense of ownership. ☐ Students know their task.	Video, audio, observation.
6) Plan the research.	Guide students to plan their research and offer help when needed.	Make a practical plan for the research.	☐ Students know how to conduct a feasible plan to carry out research.	Video, audio, observation.

2) HLT of the second lesson

Table C 2 HLT of the second lesson

Learning and teaching activity	Activities		Hypothesized learning results	Data source
	Teachers	Students		
1) Reviewing the last lesson.	Review the knowledge in the last lesson.	Catch up the prior knowledge.	Students get engaged in the subject and get prepared for the topic.	Video, audio, observation
2) **Finding out the information.**	Guide students and offer help when needed.	Conduct the research and search the relevant information by fulfilling worksheet 1.	Students learn new knowledge by themselves.	Video, audio, observation

3) HLT of the third lesson

Table C 3 HLT of the third lesson

Learning and teaching activity	Activities		Hypothesized learning results	Data source
	Teachers	Students		

1)	**Presentation.**	Distribute worksheet 2 at the beginning of class.	Present the poster in groups.	☐ Students reflect on the relationship between different stakeholder and their underlying values during their research. ☐ Students will learn new knowledge from each other. ☐ Students recognise another perspective and improve critical thinking by commenting on other groups' posters ☐ Students are aware of different strategies of other groups.	Video, audio, observation, Worksheet 2.
2)	**Class discussion.**	Ask students to form a new group and discuss the best plan together.	Discuss with each other in the new group to decide which energy source is most appropriate for their school and the best suggested way to use this energy (the two results can from different groups.)	☐ Students articulate their own values, gain insights from others ☐ Students become more aware of the differences in opinions.	Video, audio, observation.

3) Class discussion.	Ask every group to share their result and help the class to reach an agreement.	1. Every group shares the results and reasons. 2. Every student vote and come to an agreement.	Students will understand other's opinion and do an 'action'. Students recognise that it is necessary to act first to make a change.	Video, audio, observation.
4) Summary-class Reflection and Unit closing.	1. Summarized the knowledge with students. 2. Guide a discussion of how to conduct a reliable study.	Listen to the teacher, and ask if they have any questions. Discuss and reflect their learning process.	Students learn knowledge about energy. Students know the critical thinking is essential for science Students learn how to use it in daily life or science.	Video, audio, observation.

Appendix D

-Pre-test and post-test

1) Pre-test:

Please read the article, and answer the following questions

1.It is well known that Plastic waste is the main concern all around the world.

More than 6.3bn tonnes of plastic waste has been produced since the 1950s, more than half of which was produced in the past 16 years, and plastic production is expected to double again in the next 20 years. Despite higher recycling rates, large amounts of plastic leak into the environment. Estimates suggest there will be more plastic than fish in the sea by 2050 and there is evidence that it is present throughout the human food chain.

Based on this situation, the European Parliament has voted to ban a range of single-use plastics such as straws, cotton buds and cutlery and to ensure most bottles are recycled in a bid to curb ocean pollution.

Under the proposal, 10 single-use plastic products would be banned by 2021 and EU states are obliged to recycle 90% of plastic bottles by 2025.

2.But there are others who think that Plastics are great.

Because without plastic:

we would have no cell phones, laptops, smart watches, etc.

we would have no solar panels, cable/telephone wires, pacemaker batteries, electric vehicles, etc.

we would be severely limited in ways to generate and distribute power. Additionally, plastics enable making vehicles lighter in order to use less gasoline.

With plastics, we can live more comfortable, longer, and more connected lives.

I am tired to of people wanting to “ban plastics”, when really they just want to find a more environmentally responsible way of packaging and carrying goods, or alternatively, to encourage recycling of all materials (cardboard and metals clog landfills too). If you want to ban plastics it’s just a sign that you have no idea what they’re used for.

Your birth month: _ _

The last three digits of your mobile number: _ _ _

Your house number: _ _ _

1. How would you rate the argument after reading the second part of the article?

A = strong. It shows that the arguments for banning plastic are weak.

B = strong. The speaker is very clear about what he believes and why he believes it.

C = weak. The speaker probably owns stock in plastic industry.

D = weak. The speaker ignored the environmental argument entirely.

2. Does this test raise any questions for you? Which ones?

3. What are the arguments/controversies surrounding this issue?

4. What is your argument about this issue?

5. How would you find evidence/conduct a research to support your argument?

6. Which kind of information can make your argument more sense?

7. What could we do about this issue? What would be the effect of the decision?

8. How much would you stick with your argument, would any implication or result cause you to think differently?

9. Look back to Question 1 again, would you change your original answer?

2) Post-test:

Please read the article, and answer the following questions

1. Being vegan is a trend; it can help to save our planet.

Nothing will benefit human health and increase chances for survival of life on Earth as much as the evolution to a vegetarian diet. -- Albert Einstein

People are spending more money on vegan products, and plant-based diets are trending online. A vegan diet involves cutting out animal products like meat, fish, dairy and eggs.

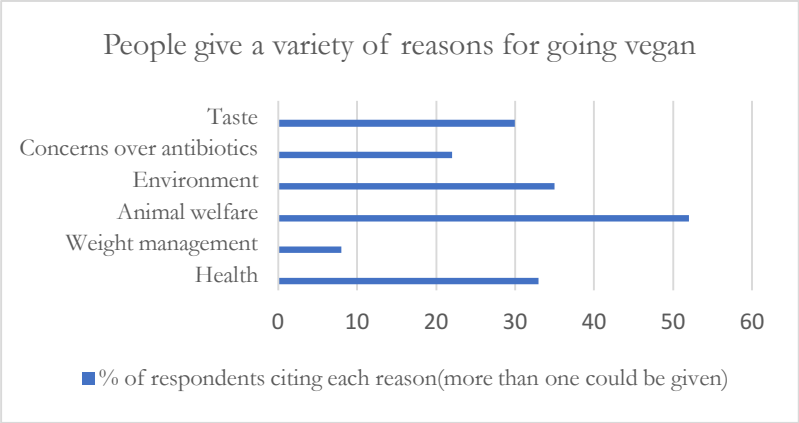


Figure D 1

Protecting the environment is one of the main reasons to go vegan. Because:

Food production accounts for one-quarter to one-third of all man-made greenhouse gas emissions worldwide, the main component of which is from the livestock industry. How our dietary choices affect climate change is often underestimated. In the US, for example, an average family of four emits more greenhouse gases because of meat they eat than from driving two cars - but it is cars, not steaks, that regularly come up in discussions about global warming.

2. There are also opposite voices against none-meat eaters.

If we stop feeding animal agriculture,

We would turn around one-third of the land on our planet to be useless, because they are too dry to grow plants.

Our body needs meat. We have canine teeth, which is the biological reason that we should crave meat. It tastes so good that any other vegetables cannot replace it.

More people would starve to death. People living in developing districts find it hard to survive without the meat, because imported vegetarian products can be expensive.

We need meat. There are ways to eat meat responsibly that are arguably better for the environment and for our food system than being a vegetarian or vegan.

Your class: MYP4_

Your birth month: _ _

The last three digits of your mobile number: _ _ _

Your house number: _ _ _

1. How would you rate the argument after reading the second part of the article?

A = strong. It shows the arguments for going vegan are weak.

B = strong. The speaker is very clear about what he believes and why he believes.

C = weak. The speaker probably owns stock in the livestock industry.

D = weak. The speaker ignored the environment argument.

2. Does this text raise any questions for you? Which ones?

3. What are the arguments surrounding this issue?

4. What is your argument/opinion about this issue?

5. How would you find evidence/conduct research to support your argument/opinion?

6. What kind of information can support your argument/opinion?

7. What could we do about this issue? What would be the effect of the decision?

8. Would you stick with your argument, or would any implication or result cause you to think differently?

9. Look back to Question 1 again, would you change your original answer?

Appendix E

-The protocol of semi-structured interviews with students and teacher

1) The protocol of semi-structured interview with students:

1. Overall comment on this unit

➔ What do you think about this unit?

- Like/dislike
- Why?

➔ Which activity do you like most/ are the most impressive?

- Why?

➔ Did you have any problems during the lessons?

2. Overall comment on this topic

➔ What do you think about the topic (measure attitudes: How do you feel about this topic?)

- Relevant
- Neutral
- Negative

(would it something affect your feeling?)

3. Self-measure/improvement

➔ What did you learn from this lesson?

➔ Can you describe what is sustainability, and how does it relate to energy?

➔ What was it like to hear the opinions of your classmates?

■ Useful

■ No opinion

■ Confronting

➔ What strategy would you use next time when you want to find more information about other issues?

■ Credible sources, how would you find information next time?

■ Different perspectives, which aspects you would consider next time?

4. Suggestion on the unit

➔ Would you like to change things about the lesson series?

■ Why yes / no?

➔ If you are the teacher, what would you like to change in the unit?

5. Do you have any questions/comments?

2) Protocol of semi-structured interview with teacher:

Lesson (for evaluation of the unit.)

1. What do you think about the unit? (overall comment?)

2. Did it go as expected?

3. Do you think the lesson has achieved its goals? (research skills, critical thinking, students care more about environment…)

4. Do you have any suggestions for the improvement? (Do you think it is too hard for students?)

5. Do you think students can use critical thinking to form an opinion about socio-scientific issues next time? Why and why now?

6. Does the unit content cover your original plan?

7. Would you like to use this unit next time/next year?

8. What have your learnt from this lesson approach?

9. Do you have any other questions or comments?

Teacher's tool:

1. Do you think materials are good for support?

2. What kind of teacher tool can be prepared next time?

3. Do you have any suggestions for improvements?

Background:

1. Have you had a class to improve students' critical thinking before? When?

2. Have you taught sustainability in your class before? When? What?

3. Do you think it is important to improve students' critical thinking in chemistry class?

4. Which learning approach do you prefer to use in the class?

Unit design:

1. Do you think the intro is good (begins with brainstorm)?

2. Do you think students are involved in the intro?

3. Do you think the summative assessment is good?

4. Do you think the summary part is useful?

5. Which part of the design do you think can help students develop their critical thinking?

6. Which part of the design do you think is unnecessary?

Appendix F

-Full transcripts of students' semi-structured interviews

1.what do you think about this unit?

Student A: Interesting, I can know how to protect the environment, and the current stage of environment, and how we can do to improve the environment.

Student B: it is very interesting, I learn more about, like for every energy sources, so like I thought nuclear energy was very harmful for the surroundings. Then I learnt that it doesn't even produce CO2 instead of radiates.

Student C: I like it very much, I just came into this school, so lots of information I could remember from my old school. Cause I did it in my first year of my secondary school. We did a whole unit on different renewable sources, and non-renewable. And we had a big test.

Student D: I think it is a good unit, because you will get to know what type of energy sources they are and it is a good way to think about the future. And about for instance, about the global warming and like carbon emission. Those are big problems, related on. We need to solve this problem. more else, it would be big problem that we are not able to solve. so, I think it is a good way to find other energy to replace the coal. it is a good topic to have research on.

Student E: it was very useful, first the introduction, and we got to know how to do the research on our own and the concept how we approach this unit, we have to make a poster on that, how we would change the energy sources. That was very nice, more like engaging.

Student F: I like this unit, I learnt more information from it. l have already known this subject but I didn't know for example, the cost and the property.

2.Which activity do you like most?/most impressive?

Student A: do the poster, find the information

Student B: like presentation.

Student C: I like working my groupmates, they all had different ideas and different sites. For example one of my teammates wants school to use nuclear energy. Other wants other energy and it was nice to have a discussion with them. Negotiation.

Student D: it was the part we have to do the research on certain sources about electricity. We have to research deeper inside to what it actually does and how it actually produced, and if there any waste after the process and the electricity is done. So the research was the most.

Student E: poster part.

Student F: I really like making the poster, because while I was making the poster, to make the poster, and I needed to make a research. while I was doing the research, I learnt more new information about it.

3.Did you have any problems during the lessons?

Student A: when I write the conclusion is the most difficult part. There are so many information, and I don’t know how to conclude them all together. I think the rubric can be more detailed, such as which information should be included in the conclusion.

Student B: it is also presenting, because I got very nervous when I presented.

Student C: no, but there was one teammate who didn't do anything, it was a bit harder. Some of the information was hard to find, such as how much money to calculate, we need to figure that out and find the calculation. and it was hard to change the units, scientific units.

Student D: it was management. So, for instance, our group was not ready and it was because our groupmates did not communicate that much during the research or anything. I do think we actually have to plan the research on certain things and certain date and point. we got to do the things in a rush and project, but we still managed to do it. we should be more responsible for what do use the time.

Student E: the topic I didn’t study on that I found it difficult. Not the knowledge part, usually teacher would explain everything and I would ask if I didn’t get anything.

Student F: for example, while presenting it, I couldn't tell everything that I did research. it was difficult to find the source, the source didn’t give you information very well. Some of them are not correct, I wasn't sure about all the information. So I researched one more time, if I get the same information again then I made sure the source was fine and I could use it.

4. What do you think about the topic (how do you feel about this topic?)

Student A: Biomass: it is ok, but I think it is hard to write how we can use this topic in our school? Previously, I don't know much about this topic, but my teammates think it is easy to write sth about biomass.

Student B: it is very new for me, l learnt some before, but not deep as this. So it was very useful and knowledgeable. I felt more relevant with this topic.

Student C: I like it. it actually is very relevant with our life, we do need to know in the future which type of sources we are using to create our energy and also to know how much it cost like in future, you want to buy a house you need to think which sources you prefer to use and also which one is more renewable, which one is more cost, which one is better for the environment. it is all good to know for the future.

Student D: I think it is a really interesting topic, I think it would also help in the future in the upcoming day. If you turn 18, you might also have to lead a house and build. It will be a way to learn which is the most efficient way and what is better for the environment.

Student E: it was nice.

Student F: this topic is very useful in my life, because I saw that, I understood that, some of the substances don't very useful but some of them are very helpful in our life, I learnt some of substances are not environmental.

5. What did you learn from this activity?

Student A: how to communicate with my teammates.

Student B: other groups use many graphs, which is very reliable so that it is useful to get the concept easily. And we can understand the concept;

Student C: I learnt a lot about the other things, since we went to the deeper in the nuclear energy, we know like geothermal, that group is really good and interesting from my opinion.

Student D: I also learnt that we had to use sources around us. So, like we should more concentrate in the EU part rather than the US part. Like the organisation from the EU and like proper sources, the website not ended with .com, but .org or etc.

Student E: cooperation, and time management, we should divide the work equally throughout the given time.

Student F: I don't know.

6. Can you describe what is sustainability and how does it relate to energy?

Student A: solar energy. If we can build more solar panels, and sun is always there, we can use energy from the sun.

Student B: solar is kind of not sustainable, it depends on various factors, it is not that sustainable. If you use it to replace some none sustainable energy like petroleum, coal, it is more sustainable but not evident.

Student C: it is related to our daily life, like houses, our school.

Student D: it is a balance in the environment as the economy as well. So sustainability of using natural resources with what they produce. It also related to energy, natural resources.

7. What was it like to hear the opinions of your classmates?

Student A: they did better than me. For example, nuclear energy, I thought there was a nuclear accident in japan which would cost lots to time to recover. But, after listening to my classmate's job, I think nuclear energy is not as dangerous as I thought.

Student B: they give me feedback, how to do better, we could use more graphs and plus, do the graph for the school.

Student C: they were all good, and I would change my impression about other energy sources after listening to their presentations, like with solar power, thermal energy was less good now, because they used a lot of the earth matter. It is good to learn from other groups.

Student D: they were more organized and they did more research on the cost or how it works. There wasn't that much information on hydroelectric, because it is basically turbine with the falling water, there is not much to say about how the hydroelectricity works. I think we could choose a more complex source.

Student E: I want to more in-depth about the information I know nothing about. I like their works and it is very relevant.

Student F: I like all the presentation, all the presentation gave me new information, about their substances. I would feel differently about the energy after hearing other's presentation.

8. What strategy would you use next time when you want to find more information about other issues?

Student A: how other people present their work; study how to get the points; think the questions from others' perspectives; but I still think environment issues is the important.

Student B: we could use more graphs to explain more, we just did some research's on the resources and effectivity. We should do more on what is the side effects and what is the consequences of it; we would cite the sources that is credible for the information next time.; like we should more pleasing and think about the needs more.

Student C: I think I will try to find the better sources, because we were presenting, we just talked straight and we didn't introduce anything or like said what we are going to talk about, it was a bit like hands on straight. And we didn't know whether the public could understand the topic in the very beginning. the sources we should use a better one. geothermal group they had different graphs and pie charts.

Student D: the type of website to use. I think it is the best to find the existing object that is surrounded by us. I think it would be the best way to start off. And to know what it is.

Student E: for group work, sometimes it goes well, sometimes I only know about the part that I research. I don't know the overall topic as much. So, the report is hard; next time, I would use more books, credible sources. And if I use other sources, I will make sure I cite them. and also the website, use .org.

Student F: I would like to change my explain to it, for example I show statistic, maybe it could be everything, while I show the table and graph. I can show the differences in them maybe. I like search

like that, for example, searching again and again to find the results. (give an example: if you want to know more about the issue of recycling, how would you know the solution about it?) I don't know.

9. Would you like to change things about the lesson series?(if you are teacher, which part of the unit you want to change?)

Student A: maybe we can build a model. it is more vivid for us and we can touch it and learn it.

Student B: we don’t have enough time to do our poster, the time should be longer to prepare the information.

Student C: be more prepared. When it comes to explaining, if it was not this question, I did not really remember, it was the harder to say. We should manage our time more carefully.

Student D: I don’t think I would change anything about it. but also try different kind of topic about sustainability instead of electricity. So you learn more variety of sustainable products.

Student E: before making the poster, we get more several examples to make the poster, sample of poster, alternative energy resources, different information the overall impression.

Student F: actually I like this unit, if I change, I don’t want to change so much, but maybe after students present the poster, if I would be a teacher, for example, I can explain all the substances one by one, I can compare these substances with students. immediately remind the knowledge and revise it a little bit.

10. Do you have any other comments?

Student B: it is a good experience and I learnt a lot.

Student D: it was really good to have this lesson because we don't really learn the side effects of this kind of things, in the science department. We don't learn the environmental, energy sources what it does afterwards. We need to find this information.

Appendix G

-Coding book and coding results of pre- and post-tests

1) Coding book:

Table G 1 Coding book of the pre- and post-tests

Question no.	Code	Examples from students' answers in pre-test	Examples from students' answers in post-test
1 (multiple-choices)	a	/	/
	b	/	/
	c	/	/
	d	/	/
2	Information source	asking about the author or the source of the text: who writes the text	asking about the author or the source of the text: who writes the text
	Social factor	how can people try to save the planet by banning the plastic?	how can people try to save the planet by going vegan?
	Text-related	why do so many plastics get used?	why do so many people go vegan and why it is hard to give up the meat?
	Science-related	is there any way to protect the environment without banning the plastics?	what would replace the meat if everyone goes vegan?
	Multiple perspectives	Mention two or more from above	Mention two or more from above
	NA	/	/
3	0	irrelevant answer	irrelevant answer
	1	one side about valid argument: using plastic is harmful to our planet and animals	one side about valid argument: eating meat is harmful to our planet and animals

	2	considering both sides of the plastics: plastic is endangering our environment but it is very useful in our daily life, we couldn't live without it.	considering both sides of the plastics: eating meat is endangering our environment but people are born to eat meat.
	NA	blank answer.	blank answer.
4	Nature/environment	people should know that plastic is endangering the animals underwater.	people should know that eating meat is harmful to the environment.
	Social	people should know to recycle the plastic and use less single-use plastic	people should consume less meat.
	Science	there should be more researches focus on developing alternatives to replace the plastics.	there should be more researches focus on developing alternatives to replace the meat.
	Economy	how can we find the best way to recycle the plastic at a low cost?	how can we find the best way to decrease the demand of meat at a low cost?
	Policy	government should enforce laws with this issue.	government should enforce laws with this issue.
	Impact	plastics is useful in our daily life but also it is dangerous to our health and to the environment.	people eat meat from their birth, but eating meat could be cruel to the animal and harmful to the environment.
	Self-interest	I wont change my behaviour.	I wont change my eating behaviour.
	NA	blank answer.	blank answer.
	Multiple perspectives	Mention two or more from above	Mention two or more from above
5	0	inaccurate/invalid/irrelevant answer	inaccurate/invalid/irrelevant answer
	1	look at articles on the internet;	look at articles on the internet;

	2	look at articles on the internet and do a survey	look at articles on the internet and do a survey
	3	look at articles on the internet, do a survey and ask for the expertise	look at articles on the internet, do a survey and ask for the expertise
	NA	blank answer	blank answer
6	Scientific data	facts/statistics	facts/statistics
	Social study	the results from questionnaire	the results from questionnaire
	Opinion from others	how experts say about it.	how experts say about it.
	Others	videos or pictures.	videos or pictures.
	NA	blank answer	blank answer
	Multiple strategies	Mention two or more from above	Mention two or more from above
7	0	no action or irrelevant answer;	no action or irrelevant answer;
	1	we need to throw plastic in certain bins.	we need to eat less meat.
	2	we need to throw plastic in certain bins so that they could be recycled effectively/ we should throw plastic into certain bins and educate the public to raise their awareness.	we need to eat less meat, so our environment can be protected to some extent/ we should eat less meat and also grow more beans in the farms.
	NA	blank answer	blank answer
8	Y	yes, I will stick to my answer	yes, I will stick to my answer
	N	no, I won't stick to it.	no, I won't stick to it.
	YE	yes I would stick to my answer, but if there is other research proves that plastic can use in a more eco-friendly way.	yes I would stick to my answer, but if there is other research proves that meat can be replaced perfectly.
	NE	Yes, I will stick to it and nothing will change my mind,	Yes, I will stick to it and nothing will change my mind,

		because it is such a big issue in the world.	because it is such a big issue in the world.
	NA	blank answer	blank answer
9	Y	/	/
	N	/	/
	NA	Blank answer	Blank answer

2) Coding results of the pre- and post-tests:

Table G 2 Coding results of the pre- and post-tests

Question no.	Code	Pre-test (n=35)	Post-test (n=39)	Change (%)
1 (multiple-choices)	a	2/35	5/39	6% → 13%
	b	29/35	25/39	83% → 64%
	c	1/35	7/39	3% → 18%
	d	3/35	4/39	9% → 10%
2	Information source	4/35	1/39	11% → 3%
	Social factor	9/35	10/39	26% → 26%
	Text-related	6/35	9/39	17% → 23%
	Science-related	7/35	12/39	20% →31%
	Multiple perspectives	2/35	3/39	6% → 8%
	NA	11/35	10/39	31% → 26%
3	0	4/35	1/39	11% → 3%
	1	19/35	23/39	54% → 59%
	2	12/35	12/39	34% → 31%
	NA	0/35	3/39	0% → 8%
4	Nature/environment	10/35	14/39	29% → 36%
	Social	13/35	15/39	37% → 38%
	Science	4/35	1/39	11% → 3%
	Economy	2/35	1/39	6% → 3%
	Policy	4/35	0/39	11% → 0%

	Impact	5/35	7/39	14% → 18%
	Self-interest	0/35	10/39	0% → 26%
	NA	0/35	1/39	0% → 3%
	Multiple perspectives	3/35	10/39	9% → 26%
5	0	4/35	6/39	11% → 15%
	1	23/35	16/39	66% → 41%
	2	8/35	15/39	23% → 38%
	3	0/35	1/39	0% → 3%
	NA	0/35	1/39	0% → 3%
6	Scientific data	22/35	26/39	63% → 67%
	Social study	3/35	4/39	9% → 10%
	Opinion from others	1/35	8/39	3% → 21%
	Others	8/35	8/39	23% → 21%
	NA	3/35	3/39	9% → 8%
	Multiple strategies	2/35	7/39	6% → 18%
7	0	4/35	1/39	11% → 3%
	1	16/35	21/39	46% → 54%
	2	12/35	15/39	31% → 38%
	NA	3/35	2/39	9% → 5%
8	Y	11/35	23/39	31% → 59%
	N	3/35	4/39	9% → 10%
	YE	14/35	9/39	40% → 23%
	NE	6/35	3/39	17% → 8%
	NA	1/35	0/39	3% → 0
9	Y	5/35	3/39	14% → 8%
	N	28/35	33/39	80% → 85%
	NA	2/35	3/39	6% → 8%