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AIR POLLUTION-BASED SOCIO-SCIENTIFIC ISSUES SITUATED IN TETRAHEDRAL CHEMISTRY EDUCATION FRAMEWORK FOR FORM FOUR STUDENTS LEARNING ABOUT ENVIRONMENTAL EDUCATION AND SUSTAINABLE DEVELOPMENT

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Abstract: Environmental education (EE) is gaining attention among educators as it is an important approach to raise awareness on sustainability. According to a survey, students' environmental awareness needs to be moulded from school. The main purpose of this study is to examine the ability of Form Four students to identify some air pollution-based socio-scientific issues (SSI) that occur daily through comics. This study was carried out during the 2021 academic year and about 34 students from five schools in Terengganu participated in this activity. Based on the collected data, four main types of air pollution were identified from the comics, namely local area, stationary, mobile and natural sources. The paired *t*-test revealed there was statistical differences in the students' awareness shift towards air pollution-based SSI ($p<0.000$). In addition, students showed high degree of satisfaction towards the activity based on their reflective essays. Based on their comic drawings, participants showed understanding that humans are part of the environment and they are affected by the air pollution as other living organisms and anthropogenic activities are the main cause of air pollution.

Keywords: Air pollution, comics, environmental education, tetrahedral chemistry education, sustainable development.

Introduction

Over the past decades, air pollution has been a worldwide problem. The increasing human populations and the impact of globalization and industrialization has made air pollution a major environmental issue (Shaddick *et al.*, 2020) that can affect human health. The World Health Organization (WHO) predicts that nine out of ten people could be affected by high concentration of pollutants in the air (WHO, 2018). A survey in 2019 revealed that air pollution caused mortality in nearly 500,000 infants in the first few months of life (Zhang *et al.*, 2021). In general, air pollution can fall into either outdoor or indoor categories, with outdoor air pollution levels affecting the indoor air quality and vice versa (Shrestha *et al*., 2019).

In recent years, environmental education (EE), which is part of education for sustainable development (ESD) is viewed as one of the promising approaches to mitigate the environmental degradation caused by the interaction of humans with ecosystem (Locke *et al*., 2010). According to Basil (2000), students' knowledge and attitudes towards the environment needs to be moulded starting

from school. In achieving this goal, Erhabor and Born (2016) states that environmental education themes should be incorporated into subjects at primary and secondary schools so that children develop positive attitudes towards the environment. Examples of early intervention EE programmes in schools includre the Shaver's Creek Outdoor School (SCOS) programme (Mullenbach *et al*., 2019), the use of Arduino technology for teaching environmental issues caused by globalization and anthropization (Alò *et al*., 2020), using extracurricular activities for promoting EE in Moroccan Middle Schools (El-Batri *et al*., 2019), bird feeding in the school compound (White *et al*., 2018), environmental programme on the paper and food waste management in school (Schmitz & Da Rocha, 2018), in-class sharing of environmentalism (Liu *et al.,* 2018) and so on. All these efforts were aimed to establish learners' environmental experience, which equipped our future generation with environmental literacy and becoming a civic citizen.

On the other hand, students' understanding of a specific chemical phenomenon or concept relies on their ability to imagine at the three levels of representation: Macroscopic, molecular and symbolic. These three aspects can be depicted in a triangle called Johnstone's triangle (Figure 1 (a)). Over the years, educators have employed this framework to explain chemical phenomenon or conduct research in chemistry education (Carvajal, 2020; Luviani *et al*., 2021). Mahaffy (2006) proposed that economics, politics, environmental and socio considerations can also be incorporated into the Johnstone's triangle as the fourth vertex of representation (Figure 1 (b)), which is termed the "Human" aspect, so as to enrich students learning experience in chemistry. In this way, it will be much easier for students to understand their lessons and it will be related to the real world (Indriyantri *et al.,* 2020). Moreover, the emphasis on the "Human" aspect is expected to show the connection between chemistry and their daily lives, thus, enhancing their motivation for deeper understanding of the macroscopic, molecular and symbolic aspects of chemistry. One of the earliest approaches in science learning that incorporated the humanistic perspective is socioscientific issues (SSI) education. Under the tetrahedron chemistry education framework, the SSI involving air pollution can be chosen as the context-based chemistry instruction to promote chemistry concept learning, argumentation skill, critical thinking and other higher order thinking skills (Rahayu, 2021). This is why the current study employed Mahaffys' chemistry tetrahedral model as part of the theoretical framework in this study. To date, limited research has been done on the EE embedded in Mahaffy's chemistry tetrahedral framework. To the best of our knowledge, this study constitutes the first research employing this framework to teach air pollution in school chemistry.

Drawing has been recognized as an alternative learning tool in school under the theory of "drawing to learn". According to this theory, students' art works represent their knowledge of the world (Anning, 1999). Educators employ the drawing approach to understand students' feelings, interest in a subject and make representation and reasoning on the world they intend to explore (Tytler *et al*.,

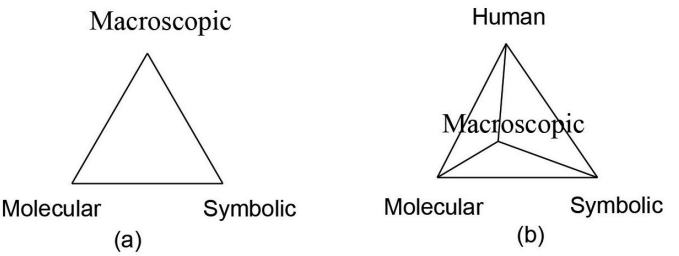

Figure 1: (a) Johnstone's triangle, (b) Mahaffy's chemistry tetrahedral education

2020). Constructivist educators accept t drawing as a valuable instructional tool for educators to examine students' understanding via their art works (Van de Pol *et al*., 2020). There have been numerous reports that drawing comics can make science learning more motivating and meaningful by making complex science concepts instantly understandable (Becker, 2000; Vebrianto & Thahir, 2021). When comics meet science, comics make science more alive and provide scientific literature to the general public that do not have access to it.

In Malaysia, Kamaruddin *et al*. (2018) revealed that there is no specific subject that teaches EE in the Malaysian school syllabus, thus, resulting in poor awareness and low civic consciousness among school students on environmental protection. According to a similar study, it was found that school students lack of understanding and exposure on environmental issues. Considering the fact that no specific curriculum is available for teaching EE in Malaysian schools and there are scarce pedagogical methods available to educators for teaching EE, the current study has selected the secondary school chemistry subject as a model for conducting EE via comic drawing on air pollution-based SSIs. The current work is of importance as it not only precipitates the students' understanding of current air pollution-based SSIs, but it also provides a potential pedagogy and a more interesting way for educators to teach EE among school students.

In this activity, the comics drawing activity was directed to Form Four chemistry students at five schools in the state of Terengganu, Malaysia. Participants were invited to generate a comic regarding air pollution-based SSIs, which attracted their attention and the facts must be based on the information described in newspaper or scientific journals. In the past, air pollution-based SSI is one of the themes integrated in the ESD for students sharing their perspective on how to prevent haze and air pollution (Rosman *et al*., 2019). Including comic drawing into science helps students not only in the learning of ESD but also provides students active participations and reduces stress and boredom. In this regard, the aims of this research are:

(1) To examine whether participants can convey the air pollution-based SSI together with the three elements, namely the macroscopic, molecular and symbolic aspects in their comic drawing.

(2) To investigate the change of participants' awareness before and after implementation of the current activity using the participants' awareness test in air pollution-based SSI.

(3) To investigate participants' perception towards current activity based on the survey and their reflective essays.

The current activity is important, as it promote ESD among students, so as to create an early environmental awareness and responsibilities at school level. Furthermore, it will enhance students' knowledge on various types of air pollution, civic consciousness and high environmental awareness among students.

Methodology

Participants

At the beginning of academic year 2021, 34 form four participants (18 females and 16 males) who were studying chemistry in five schools in Terengganu, Malaysia, participated voluntarily in the current activity (Table 1). Participants were required to draw an air pollution-based SSI comic based on what they have read in the newspaper and scientific journals. Apart from this, students were required to explain the science behind the air pollution-based SSIs, via the three aspects as depicted in Jonstone's triangle in their comics drawing.

Procedure

The form four chemistry course comprises three one-hour lessons per week for 40 weeks. Before the commencement of comic drawing activity, participants were told that their comic drawing will be analysed for research purposes and the possibility of publication in the future.

Table 1: Participants of the current study

	Sekolah Menengah Sains Setiu	Sekolah Menengah Kebangsaan Kompleks Gong Badak	Sekolah Menengah Kebangsaan Kompleks Mengabang Telipot	Sekolah Menengah Kebangsaan Agama Kuala Abang	Sekolah Menengah Kebangsaan Pengkalan Berangan	Total
Male	6	2	2	3	3	16
Female	8	4	3	1	2	18
Total	14	6	5	4	5	34

After obtaining the consent from schools and the participants, the corresponding author introduced the activity in week 14 of the school term and explained the definition of air pollution-based SSIs and their connection to ESD.

In week 22, a questionnaire on the awareness of the air pollution-based SSIs was directed as pre-survey to the participants. Additionally, participants were required to register their air pollution-based SSI topics via the Google form. Next, participants were briefed on the free online comic drawings software which they can use to generate comics (Toondoo, Strip Generator, Powtoon and so on). In addition, participants who participated in the comics drawing were given a gift notepad, as token of appreciation for participants who took part in this activity.

In weeks 28 and 30, students prepared their comics according to what they have read in the literature and which were of interest to them. They were required to explain the science concepts behind the air pollution-based SSIs, via the three aspects depicted in the Jonstone's triangle. The progress for preparing the comics was monitored via WhatsApp group chat and feedback was given to students' comics to improve the quality of the comics they drew.

At weeks 32 to 36, participants uploaded their comics and reflective essays in the Google Forms. The comics will be uploaded in the Padlet by one of the authors, so as to be followed by the participants. To evaluate changes in participants' awareness on air pollution-based SSIs, the Questionnaire on Awareness of Air pollution-based SSIs and the Questionnaire on the Perception of Comics Drawing Activity were directed to participants at week 37. Table 2 summarises the research process for the current activity.

Questionnaires

In this study, two questionnaires were directed to participants, namely the Questionnaire on Awareness of Air pollution-based SSIs and the Questionnaire on the Perception of Comics Drawing Activity. The former was utilized as a questionnaire for the pre- and post-surveys to examine participants' awareness of air pollution-based SSIs. In addition, paired *t*-test was carried out to compare students' awareness change between pre- and post-surveys. For the Questionnaire on the Perception of Comic Drawing Activity, it consists of four five-point Likert type items that required participants to rate their intellectual changeability, effectiveness in learning air pollution-based SSIs, effectiveness in promoting self-directed learning and effectiveness of the current activity to promote ESD.

Reflective Essay

Participants who had gone through this activity were required to submit a reflective essay, immediately after the administration of the pre- and post-surveys. In this reflective essay, participants were required to described what they learnt from the literature and their perception towards the implementation comic drawing activity. Previously, the reflective essay was utilized as an instructional tool for

Table 2: Research process and timeline implemented in this activity

	Students	Lecturer
Week 14	Introduction to comic drawing activity in air pollution-based SSIs	• Briefing and seeking consent for current activity. • Explaining ESD.
Week 22	Participants received pre-survey and briefing on the digital tools for comics drawing	• Participants register their air pollution-based SSI topics via the Google Form. • Participants received *the Questionnaire on the Awareness of Air Pollution-based SSIs* (Caspers & Roberts-Kirchhoff, 2003) prior to comic drawing activity. • Briefing on the free online comic drawing software and explain the assessments that the participants will undertake. • Explaining the deadlines for specific tasks executed in the current activity.
Week 28-30	Preparation of comics	• Monitoring participants' comic drawing progress via WhatsApp group chat.
Week 32-36	Comics and reflective essays submission via Google Form	• Participants' comics and reflective essays uploaded in the Google form were checked. • Inviting participants to view others works on the Padlet.
Week 37	Participants received two post-surveys	• The post surveys consisted of *the Questionnaires on the Awareness of Air Pollution-based SSIs* and *the Questionnaire on the Perception of Comics Drawing Activity* were administered to participants at the end of this activity.

students to express, reflect and clarify their ideas on their learning experience (Cha *et al*., 2016). For the analysis of participants' reflective essays, it was systematically reviewed by two of the authors who examined qualitatively their writings to classify the elements provided by the participants on the air pollution-based SSI topics selected by students, as well as their feedback on current activity. After getting consent and categorization from all authors, the manuscript was prepared. The inter-rater reliability is about 90%.

Results and Discussion

Evaluation of Students' Comics Based on the Air Pollution-based SSIs

Explaining the chemical processes of air pollution-based SSIs requires students to understand the key concepts of science or chemical phenomenon and make representations of what they read from the newspaper or literature into the comic drawing. Over the years, a growing body of evidence showed that the balance emphasis on the mascroscopic, molecular and symbolic aspects in chemistry learning can lead to a better learning gain and performance in the chemistry subject (Sanchez, 2017). In this work, to maximize students' chemistry concept learning and also to address the problem of the lack of relevance of chemistry learning in school chemistry education (Spencer *et al*., 2021), the author has invited Form Four chemistry students from five schools in Terengganu, Malaysia, to participate in the air pollution-based SSI comics drawing activity in the tetrahedron chemistry education framework (Mahaffy, 2006). Participants mostly chose their own comic drawing, without much guidance from the author. This is to maximize students'

opportunity for reading and creativity, in their comic drawing.

Between weeks 32 and 36, about 34 comics were received from participants. Three of them were rejected as they did not include the three elements associated with the Johnstone's triangle. The approved comics were then codified according to four main types of air pollution stationary, area, mobile and natural sources (Hahad *et al.,* 2020) by two of the authors. Overall, about 48% of the submitted air pollution-based SSI comics were associated with acid rain (stationary source), 19% of featured open burning (area source), 16% on greenhouse gases emitted by vehicles (mobile source) and 10% on a combination of acid rain and greenhouse gases emitted by vehicles. Finally, about 7% of the comics were based on the topic of emission of greenhouse gases generated from wildfires (natural source). The topic of interest chosen by the participants are shown in Table 3.

In the cognitive domain, the activity allowed students to deeply understand the scientific concept of air pollution-based SSIs. This is evident, when participants revealed their understanding about the air pollution topics they have chosen in their reflective essays. For instance, a participant revealed in the reflective essay that acid rain could damage man-made materials and structures (Table 4, Student 3). Another student revealed that the open burning could release toxicants to the environment, which further deteriorate the soil, water and human food conditions (Table 4, Student 8). Additionally, one of the participants who chose the topic on emission of greenhouse gases generated from vehicles revealed that the use of fossil fuel such as gasoline is one of the main contributors to greenhouse gases that leads to global warming (Table 4, Student 19). One of the reflective essays indicated that about 8 billion tons of carbon dioxide are released per

Table 3: Topics of interest chosen by participants

Topic Chosen	Number of Students
Acid rain (stationary source)	15
Opening burning (area source)	6
Emission of greenhouse gases from vehicles (mobile source)	5
Acid rain (stationary source) + emission of greenhouse gases generated by vehicles (mobile source)	3
Emission of greenhouse gases generated from wildfire in the forest (natural source)	2
Total	31

Table 4: Example of participants' quotes about the air pollution-based SSIs as depicted in their reflective essays

Issue	Representative Quotes
Acid rain	"*I learnt that acid rain is a local issue but later on it has tuned into global concern that damage man-made materials and structures.*" [Student 3]
Open burning	"*Opening burning could release dangerous compounds, such as the nitrogen dioxide, methane and other particulates that could cause soil, water and food contaminations*." [Student 8]
Emission of greenhouse gases from vehicles	"*Vehicles on the road causing greenhouse gase like carbon dioxide. This is one of the reasons why we have global warming in the earth.*" [Student 19]
Emission of greenhouse gases from wildfire in forest	"*Burning of vegetation in forest will introduce soot and other greenhouse gases in the air, which causes global warming. In addition, it is estimated around 8 billion tons of carbon dioxide released per year for the last 20 years*." [Student 30]

year for the past 20 years, caused by wildfires (Table 4, student 30). Overall, most participants were able to produce the instructed comics and showed their understanding about air pollution-based SSI. The activity enabled students to perform literature search and determine the best way to convey the message, when drafting their comics based on the air pollution-based SSIs.

Finally, the comic drawing activity also enriches the participants with the opportunity to reflect on the current SSIs in a more playful way (Ntobuo *et al*., 2018). Figures 2 and 3 show some of the comics that were memorable to the author. It was included into the manuscript after obtaining participants' permissions.

Figure 2: Example of participant's comic on the air pollution caused by the acid rain (stationary source) and emission of greenhouse gases by vehicles (mobile source) (adapted with permission)

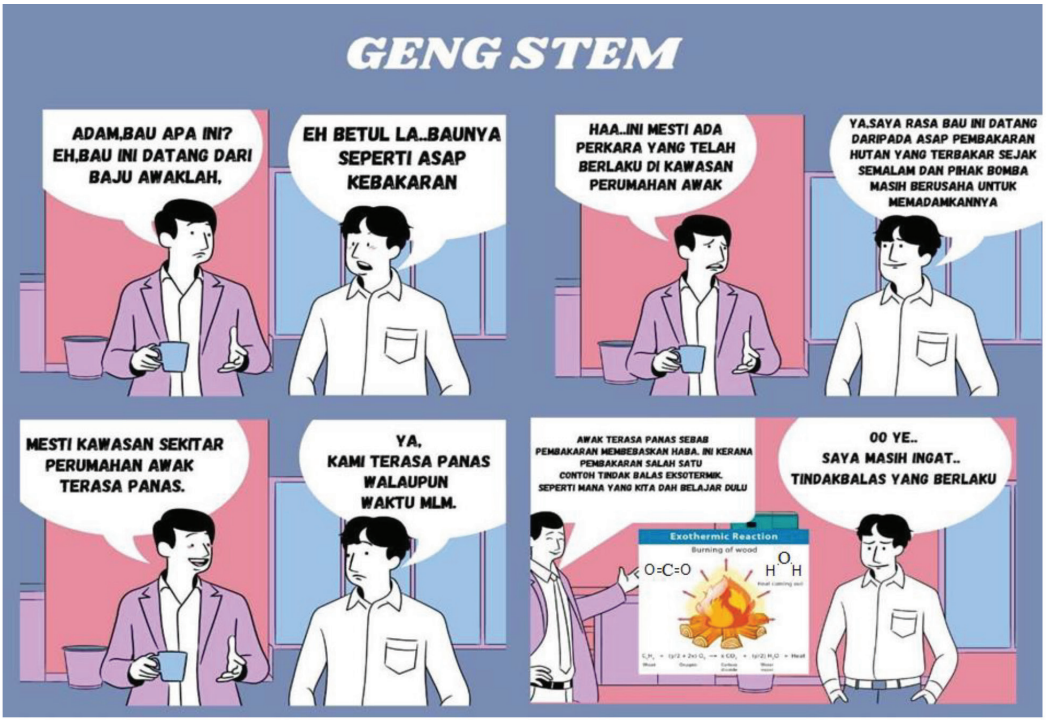

Figure 3: Example of participant's comic on the emission of greenhouse gases generated from the wildfire in forest (natural source)

Evaluation of Students' Awareness of the Air Pollution-based SSIs

After received all the comics drawing and screened through by two of the authors, participants' comics were uploaded in a virtual bulletin board called Padlet. This was to allow participants to learn from each other and also deeply understand other air-pollution based SSIs. Moreover, this setting will also enable the examination of the participants' development in their familiarity of the air pollution-based SSIs. For this reason, participants were subjected to the Awareness of Air Pollution-based SSIs questionnaire. Based on the pre-survey result, the average scores on four topics were found to be below "familiar" before the implementation of the activity (Table 5 and Figure 4). However, participants revealed that they were more acquainted with air-pollution-based SSIs after the end of this activity, with the average scores recorded higher than before activity. In addition, the paired *t*-test results indicated that there were statistical differences in the students' awareness change towards the study of air pollution-based SSIs ($p<.000$). Thus, these results indicated that participants were more familiar about the air pollution-based SSIs, after their involvement in this activity. Moreover, the comic drawing activity is capable of engaging students in the communication of scientific matters and SSIs (Pursitasari *et al*., 2019). It is noteworthy that the current activity provides an alternative instructional method for teaching EE, by taking advantage of comics to deliver scientific information.

Table 5: Survey result on participants' awareness change on air pollution-based SSI

Topic	Mean ± SD (*N* =31)		*t*	*p*
	Before Course	After Course		
Acid rain (AR)	3.0 ± 0.50	4.8 ± 0.50	-12.702	.000
Open burning (OB)	2.8 ± 0.67	4.9 ± 0.30	-13.248	.000
Greenhouse gases emitted from vehicles (GGV)	3.0 ± 0.59	4.7 ± 0.43	-11.418	.000
Greenhouse gases emitted from natural wildfire from forest (GGWFF)	1.8 ± 0.75	4.6 ± 0.62	-9.539	.000

*Likert five-scale, 1 = None, 2 = Limited, 3 = Somewhat familiar, 4 = Familiar, 5 = Very familiar

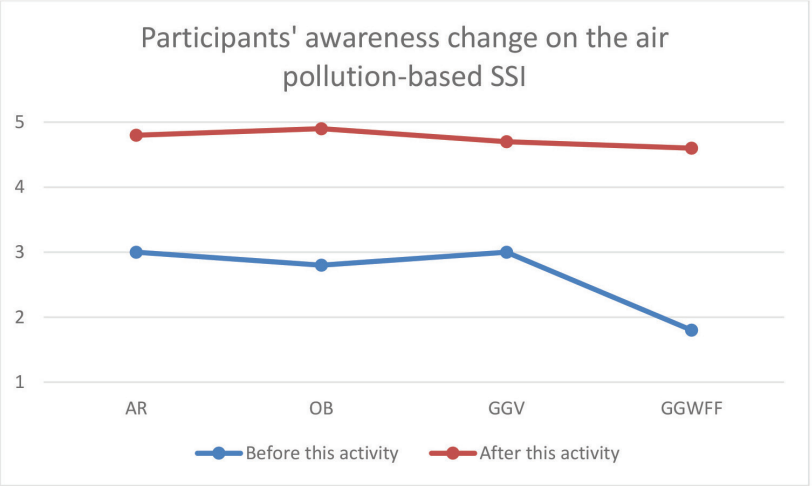

Figure 4: Participants' awareness change on the air pollution-based SSI

Participants' Perception toward the Air Pollution-based SSI Comics Drawing Activity

Our findings also provide some insight into the student's attitude towards the implemented activity. As shown in Table 6, participants feedback was found to be positive in response to the implementation of air pollution-based SSI comic drawing activity. Our survey result revealed that the activity posed an intellectual challenge to participants (M = 4.37). In fact, educational research has shown that there is a need in today's science curriculum to incorporate intellectually challenging material to engage students' interest and commitment to study real-world problems (Kan *et al*., 2015; Simamora & Saragih, 2019). In addition, participants admitted that the activity enable them to learn more about the principles of chemistry via the air-pollution based SSIs comic drawing (M = 4.63). In this activity, participants felt that they developed their autonomous learning skills through proposing and drafting their own comics (M = 4.48). Finally, the survey results also indicated that the current activity was effective in promoting ESD (M= 4.41). Overall, the current findings show the potential of incorporating air pollution-based SSIs comic drawing activity in promoting EE and ESD studies in the science curriculum. Undoubtedly, we have also identified several limitations during the implementation of this study. Firstly, the sample size was relatively small (N = 31), in which only a small population of students could benefit from this activity. Besides, the study was directed to only science major students, with none of the students from non-science major being assessed for the effectiveness of this study. In future, this study can be extended to these students to create early awareness on EE and ESD.

In order for the author to learn about the participants experience and the level of satisfaction towards the implemented activity, the reflective essay was directed to participants and some of their comments were shown here:

Instructions at school are boring and the comic drawing is so much fun. [Student 16]

Incorporating elements of Johnstone triangle in comic drawing broadens my knowledge in chemistry. [Student 5]

It's a great activity! We can know more about air pollution and how dangerous is air pollution! [Student 21]

The current activity increased my understanding of air pollution and it has relevance with chemistry learning. [Student 26]

Conclusion

The study employed comic drawing activity situated in Mahaffy tetrahedral chemistry education framework to instil early awareness in Form Four students in air pollution-based SSIs. Based on previous literature, learning of science concepts will be more effective if it

Table 6: Participants' feedback on the current activity for academic year 2021 (N = 31)

Question	Rate*					M (SD)
	1	2	3	4	5	
Rate the intellectual challenge posed by current activity	0	0	5	7	19	4.37 (0.79)
Rate the effectiveness of the current activity in the learning of chemistry	0	0	2	6	23	4.63 (0.63)
Rate the effectiveness of the current activity to promote autonomy learning	0	0	2	10	19	4.48 (0.64)
Rate the effectiveness of the current activity to promote the ESD	0	0	3	10	18	4.41 (0.69)

*Likert five-scale, 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree

can be connected to real-life situations. This study utilized air pollution based-SSIs as an instructional tool in EE and ESD learning, as well as to promote specific science concepts learning and other higher-order thinking skills. The pre- and post-surveys indicated that the activity challenged participants intellectually and at the same time enabled the study of chemistry concepts and ESD. In addition, the activity promotes the autonomous learning, as revealed from the participants' survey result. Moreover, students became more familiar with the air pollution-based SSI topics as indicated from the survey result in the current research setting. The activity has potential as an instructional tool to instil ESD among students from the non-science major to learn about the ESD, so as to create an early environmental awareness and responsibilities at school level.

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