Green Chemistry Letters and Reviews

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tgcl20

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To cite this article: Jeongho Cha, Hak Bum Kim, Su-Yin Kan, Wen Yu Foo, Xue Yi Low, Jing Yi Ow, Prasana Devi Bala Chandran, Gaik Ee Lee, Jean Wan Hong Yong & Poh Wai Chia (2021) Integrating organic chemical-based socio-scientific issues comics into chemistry classroom: expanding chemists' toolbox, Green Chemistry Letters and Reviews, 14:4, 699-709, DOI: 10.1080/17518253.2021.2005153

To link to this article: https://doi.org/10.1080/17518253.2021.2005153

Published online: 21 Nov 2021.

GREEN CHEMISTRY LETTERS AND REVIEWS
2021, VOL. 14, NO. 4, 699–709
https://doi.org/10.1080/17518253.2021.2005153

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Integrating organic chemical-based socio-scientific issues comics into chemistry classroom: expanding chemists' toolbox

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ABSTRACT

Over the past decades, there had been a growing concern for policy makers and scientists to implement the sustainable development (SD) agenda. To date, little efforts are made to instil early awareness and education for sustainable development (ESD) amongst the first-year undergraduates to become effective and responsible global citizens. As such, the learning of organic chemical-based socio-scientific issues (SSIs) within the scientific world is important to promote early awareness amongst chemistry undergraduates in SD. In this manuscript, for the first time comics drawing is being used as learning instruction to instil the ESD learning amongst first-year undergraduates at Universiti Malaysia Terengganu. In this activity, students made their own comics with regard to organic chemical-based SSIs they have read and shared their own comics, together with their reflective essays on the learning management system (LMS). Based on a survey result, students' involvement in the current activity has resulted in their familiarity with the organic chemical-based SSIs. In addition, they have expressed a high degree of satisfaction toward the implemented activity and the chemistry content they learnt in this course based on the reflective essay received by the course instructor in the LMS.

ARTICLE HISTORY
Received 13 July 2021
Accepted 8 November 2021

KEYWORDS
Basic organic chemistry; comics; education for sustainable development; stimulating awareness about pollution from organic chemicals; students' active involvement

1. Introduction

Education for sustainable development (ESD) is an approach initiated by the United Nations (UN) with the aim to improve the capacity of current and future generations to address the environmental and developmental issues that are plaguing in today's world (*1*). In addition, students or future citizens are viewed as stakeholders in the society who play an important role to shape a more sustainable future, which is aligned with the concept of sustainable development (SD) (*2*). As such, many reports were generated about the possibility of including ESD in the science curriculum as a mean to achieve the sustainable goals in schools and at higher education levels (*3*,*4*).

On the other hand, why do educators view the adoption of ESD in the school chemistry education can provide an effective platform to drive the future generation in achieving SD? According to published literature, this transformative approach emphasises on sustainability among the future generation by teaching proper stewardship of natural resources and evaluating the chemistry related-business or products, based on the lens of balanced, multi-perspective and also carefully reflected manner (*5*).

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Moreover, chemistry, which is often viewed as the main contributor of environmental pollution, can improve its much 'tarnished' image by transforming into the champion and driver of sustainable science in the twenty-first Century, via the adoption of ESD in the chemistry curricula (*6*).

To inspire the future generation about the importance of SD, there were a number of chemistry-related activities which targeted the undergraduates and school pupils. For example, the microplastic outreach programme (*7*), making a simple and sustainable paint activity (*8*), greening the high school laboratory (*9*), systems thinking and sustainability in general chemistry (*10*), sustainable pharmaceutical synthesis in the laboratory (*11*), and implementation of green and sustainable practice in pharmacy and medical programmes (*12*). It is noteworthy that all these efforts for implementing the sustainable practices in schools and university chemistry education are the consequences of increasing consciousness amongst stakeholders towards environmental pollution and degradation that we face in today's modern world (*13*,*14*), and the need for a more SD whereby they seek chemistry as one of the opportunities to achieve the SD goals.

1.1. Drawing as an instructional tool

The 'drawing to learn' theory is grounded based on the fact that students' drawings represent their knowledge of the world (*15*). In addition, it is also used as an instructional tool to understand students' feeling and interests in a particular subject. Apart from the standpoint of art, this type of instructional learning enables students to make representation and reasoning regarding the world they intend to explore via drawing and is the theory guiding the present study (*16*). Reformers see drawing as one of the opportunities to introduce more interactive and inquiry-based learning (*17*). According to a survey, students were motivated in science learning via drawing, as they were more able to explore and justify their understanding in science, compared to conventional teaching (*18*).

Apart from this, drawing is a useful instructional tool to aid learners in overcoming limitations in the presented materials, organize new knowledge more effectively by integrating new and existing knowledge (*19*,*20*). For instance, inviting students to draw what they have read and understood, requires them to make explicit understanding of the facts they understood in an inspectable form (*21*). Moreover, visual representation matches the visual-spatial demand in science learning, which further enhances constructive learning strategies (*22*). In short, drawing can be used to help students to discern key concepts, as well as prepare students for future learning and challenges of new tasks (*23*).

1.2. Using comics in education

The motivation and key argument in our current manuscript is that, based on our past experiences in chemical education (*24*–*26*), comics can be used as an interesting medium for students to learn about SD via socio-scientific issues (SSIs). Building on a previous evidence that showed when comics meet science (*27*), comics can offer opportunity for students to develop understanding in science, by making complex concepts instantly understandable. Apart from this, comics make science more alive and accessible to the public who have no access to scientific literature.

In a previous study reported by Zainordin et al. (*28*), the authors found that the undergraduates' exposure and emphasis on ESD is low. To create an early awareness on ESD for first-year undergraduates, an alternative, non-face-to-face activity, via the creation of the SSIs comic drawing was introduced to engage students with ESD learning in the basic organic chemistry course. Previous study revealed that the SSIs based on ESD can make chemistry learning more motivating and meaningful (*29*). In addition, this type of study provides the relevance of chemistry education in the sustainability context, and thus schools or universities chemistry education should also contribute to this area so that students can learn to be more responsible for themselves and the future generation (*30*–*33*). Moreover, the use of comics for teaching and learning is reported to enhance students' motivational and active participation (*34*).

1.3. Research goal

In this activity, students were invited to make a comic drawing about the organic chemical-based SSI which attracted their attention and it must be according to the current literature. Organic chemical-based SSIs are topics or course of actions associated with the use of organic chemicals in our daily life. Students were required to choose the literature and organic chemicals and connected these in their daily life, and where possible represent it through comic drawing as implemented in this activity. The use of comic drawing approach as an alternative instruction for students' learning of SSI not only allows the learning of ESD but also enables their active participations, and thus reduces stress and boredom in the learning process. As such, the purpose

of this research was set off as listed in the following context:

(1) To examine whether students can convey their ideas in the organic chemical-based SSIs by using comic drawing approach.
(2) To examine students' awareness on the organic chemical-based SSI issues before and after administration of the current activity by using the SSI awareness test in organic chemistry and students' reflective essays.
(3) To investigate student's attitude toward comic drawing activity based on the survey and their reflective essays.

2. Methodology

2.1. Participants

At the beginning of semester I (2018/2019 session) and semester II (2019/2020 session), 41 participants (14 males, 27 females) from the basic organic chemistry course participated voluntarily in this activity (Table 1). They were invited to draw an SSI comic based on the current literature on organic chemicals that they have read.

2.2. Procedure

The basic organic chemistry course comprised two one-hour lessons per week, for 14 weeks. Before the commencement of this research, students were briefed about their work which will be analysed for educational research. In addition, findings of the current research and their comic drawings will be used for publication in the future. The participants understood and agreed before their participation. Then, the course instructor introduced the activity in week 2 of the semester and explained the definition of SSIs and their relation to ESD.

In week 3, a questionnaire on the awareness of the organic chemical-based SSI was administered to the participants as a pre-survey. In addition, students were given a Google Forms to register their topic for the activity. Next, students were briefed about several comic drawings software which were available online for free, such as the Toondoo, Strip Generator, Powtoon and Make Belief Comix that can be used to make their comics. Although this activity was not assessed in this course, students who participated received a gift pen as a token of appreciation for voluntary participation.

Table 1. Participants of the study.

	Semester I (2018/2019)	Semester II (2019/2020)	Total
Male	6	8	14
Female	12	15	27
Total	18	23	41

During week 4 and week 7, students were drawing their own comic according to their selection of the literature. The lecturer monitored students' progress via WhatsApp group chat, where each student can also see other students drawing. The lecturer gave some feedback on students drawing to improve the quality of comics they drawn.

At week 8, upon their task completion, the students will upload their comics and reflective essays in the learning management system (LMS) chat room for display and to be followed by their peers. To assess changes in students' awareness of organic chemical-based SSI issues, the Questionnaire on Awareness of Organic Chemical-Based SSI and the Questionnaire on the Implementation of Comic Drawing Activity were administered to participants. Table 2 summarizes the research process for the current activity.

2.3. Questionnaires

In this study, two simple questionnaires were developed by the authors. They were the Questionnaire on Awareness of Organic Chemical-Based SSI and the Questionnaire on the Implementation of Comic Drawing Activity. The former was used for the pre- and post-surveys to monitor the students' awareness of organic chemical-based SSI. This questionnaire consisted of topics on organic chemical-based SSIs chosen by participants, and participants were asked to assess their awareness on these SSIs associated with the use of organic compounds, before and at the end of activity. Paired *t*-test was used for the comparison of students' awareness between pre- and post-surveys. The latter questionnaire consisted of four five-point Likert type items which required students to rate the intellectual changeability, effectiveness on learning organic chemistry, effectiveness in promoting self-directed learning, and effectiveness to promote ESD in this comic drawing activity.

2.4. Reflective essay

Apart from pre- and post-surveys, students who experienced the implemented activity were required to submit a reflective essay (Figure 1). Within the essays, students wrote what they have learned from the literature and how they felt during comic drawing activity. Undoubtedly, writing is an effective tool for students to organize, express, and clarify their ideas and thus reflect on

Table 2. Research process in this activity.

	Students	Lecturer
Week 2	Introduction of comic drawing activity and learning about SSI	• Briefing about the activities including seeking their prior permission and introduction of current activity • Explaining SSI
Week 3	Taking one pre-survey and guiding participants on how to draw comic with digital tools	• Administering the Questionnaire on the Awareness of Organic Chemistry-Based SSI (*35*) before the commence of this activity. • Explaining comic drawing software and assessments which will be conducted throughout this activity and deadlines. • Asking students to register their topic of interest of SSI via the Google Forms
Week 4~7	Drawing SSI comic	• Monitoring students' progress weekly via WhatsApp group chat.
Week 8	Online submission of comic drawing and writing reflective essays	• Checking students' comics and reflective essays in the LMS • Inviting students to view their fellow classmates' works on the LMS.
Week 10	Taking two post-surveys	• Administering the Questionnaires on the Awareness of Organic Chemistry-Based SSI and the Questionnaire on the Implementation of Comic Drawing Activity after the end of this activity.

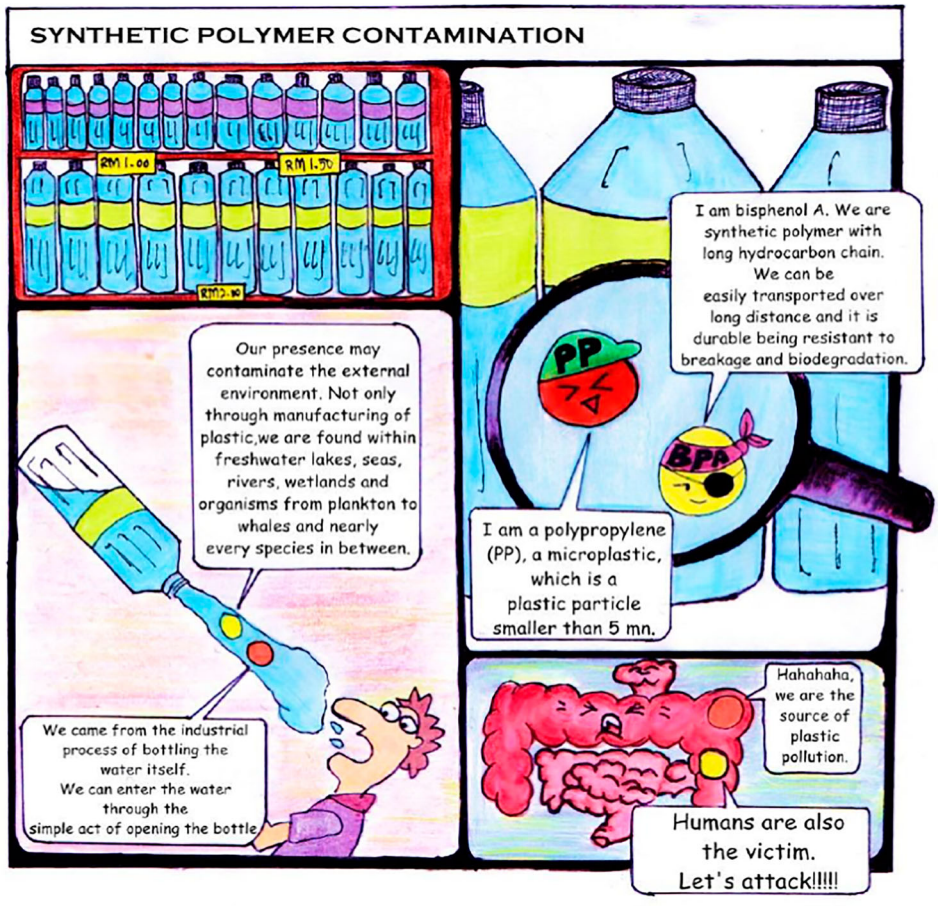

Figure 1. Example of student comic on the microplastic SSI (adapted with permission).

their learning experience as reported by a previous literature (*36*).

To analyze students' feedback on the implemented activity, students' reflective essays were examined qualitatively by two of the authors with the intent to classify the elements of SSI provided by students into the topic chosen by students by students. After getting consent on the categorization by all the authors, the manuscript was prepared. All reflective essays and data obtained from this study were systematically reviewed and categorized by two of the authors. After getting consent

Table 3. Topics of interest chosen by students.

Topic chosen	Number of students
Plastic pollution	18
Pesticides and the environment	9
Global warming	7
Antibiotic-resistant issue	1
Diethanolamine	1
Volatile organic compound (VOC)	1
Total	37

on the categorization by all the authors, the manuscript was prepared. The inter-rater reliability is about 95%.

3. Results and discussion

3.1. Characteristics of comics produced by students

After the announcement of comic drawing activity, students showed a positive response towards its implementation. This was evident when all students met the course instructor to have an insightful discussion before commencing the activity. Students were not presented with any articles in this activity, except for the course instructor's brief introduction to the SSI terms, and students had to choose a topic which attracted their attention in the current literature. This was to maximize their opportunity for reading and creativity. Therefore, students were mostly on their own when selecting a topic and drafting their comics. In an earlier report based on a comic project (*37*), comic activity was shown to be capable of instilling active learning and self-directed learning among students. This was one of the reasons comic format was chosen to introduce SSI, as many students faced disengagement in science, due to the passive role they play in a conventional classroom (*38*).

After four weeks of drawing, 41 comics were submitted. Amongst them, four comics were rejected because one of the comics was not related to the organic chemical-based SSI topic, and the other three failed to clearly deliver the SSI message. The rest of the students showed that they understood the organic chemical-based SSI as reflected in their reflective essays, and they gave their comments about the potential social-scientific issues caused by these organic compounds. The topic of interest and number of participants are summarized in Table 3.

To probe participants' ideas associated with organic chemical-based SSI, they were invited to draw the corresponding comics based on the SSI literature that they have read. In today's curriculum, it is widely perceived by educationists that comic is a potential educational tool to engage and motivate students for learning, as well as a visual representation about the science of ideas learnt. Moreover, by drawing a comic, students were needed to provide a justification for their own ideas and clarify the scientific thinking involved (*39*). Figures 2–6 are the representatives of the organic chemical-based SSI comics provided by participants. Various organic chemical-based issues were raised during the implementation of this activity, such as issues regarding plastic pollution (Figure 2), pesticides and the environment (Figure 3), global warming caused by the use of carbonfluorocarbon (CFC) (Figure 4), antibiotic-resistant bacteria (Figure 5), and volatile organic compounds (VOCs) (Figure 6).

In the cognitive domain, comic drawing enabled the students to study deeply about the scientific ideas or related issues. This was evident when participants showed their understanding about the SSIs involved in their reflective essays. For example, a student who had chosen the plastic pollution topic was overwhelmed by the quantity of microplastic particles produced within a year (Table 4, student 6). Moreover, participants also indicated that the use of certain pesticides can threaten biodiversity and the environment as revealed in their reflective essays (Table 4, student 2). In addition, based on participants' literature search, they found that the use of CFC-related organic chemicals could cause ozone layer deterioration (Table 4, student 26). In most cases, students were able to reveal their understanding toward the involved organic chemical-based SSIs, and some of their representative quotes are shown in Table 4. It is noteworthy that the current activity was effective in cultivating students to do literature search about the involved organic chemical-based SSI to draft a specific content and determine the best way to convey their comics. In addition to communicate scientific information, the SSI comics served to present information and conclusion that do not 'close them,' but enabled students, citizens and readers to further reflect, discuss and make interpretation in a more playful way (*40*). Some comics which were memorable to the course instructor were also included in the manuscript (Figures 2–6) after their permissions were granted.

3.2. Evaluation of students' awareness of the organic chemical-based SSI

As described earlier, students were required to register their topic of interest in the Google Form sent by the course instructor, upload their comics and reflective essays on the created LMS chat room. This was to enable other participants to engage with their peers,

Figure 2. Example of student concept cartoon on pesticide (carbamate) and the environment SSI (adapted with permission).

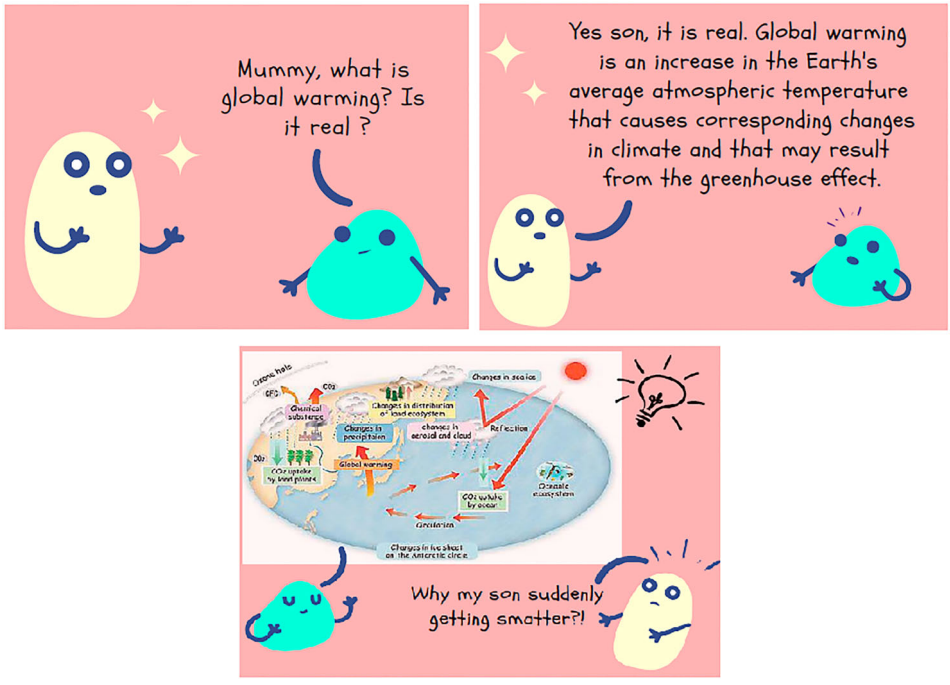

Figure 3. Example of student concept cartoon on the global warming caused by the CFC (adapted with permission).

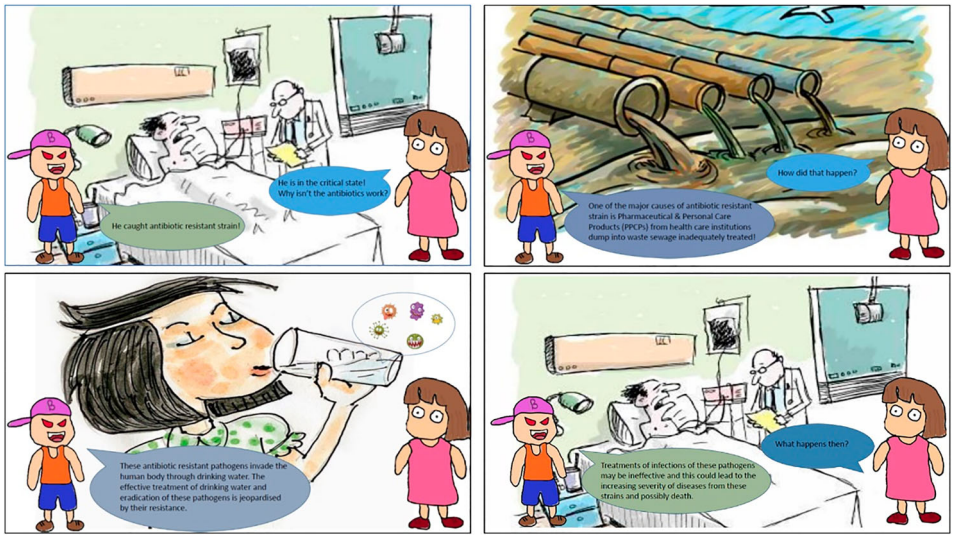

Figure 4. Example of student concept cartoon on the antibiotic-resistant SSI (adapted with permission).

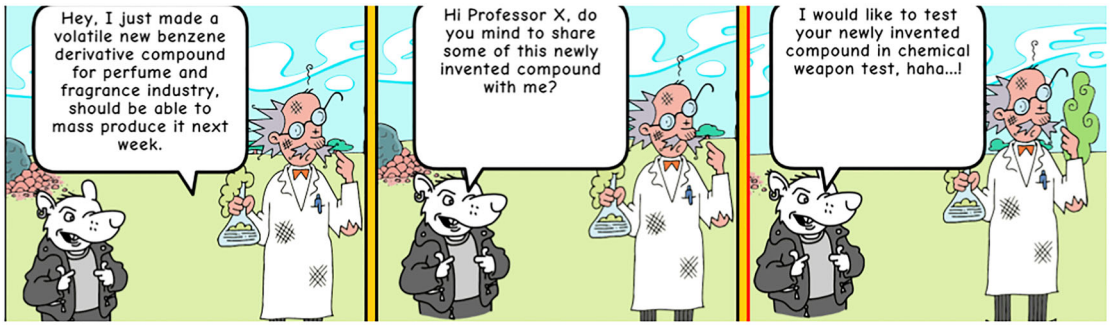

Figure 5. Example of student concept cartoon on the volatile organic compound SSI (adapted with permission).

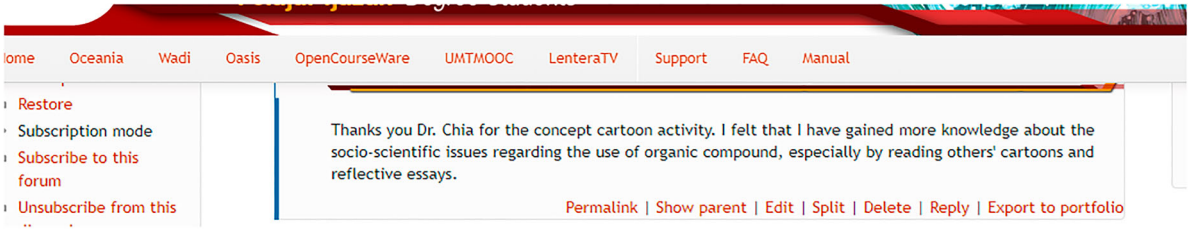

Figure 6. Example of student's reflective essay from the LMS.

Table 4. Representative quotes of students' understanding about the organic chemical-based SSI as shown in their reflective essays.

Issue	Representative quotes
Plastics pollution	'It was surprise to learn that mankind had consumed 39000–42000 microplastic particles per year.' [Student 6]
Pesticides and environment	'The danger of the use of pesticide should not be under-estimated as it causes environmental havoc and threatening the biodiversity.' [Student 11]
Global warming	'The use of CFC is one of the greenhouse gases that depleted the ozone level, thus causing the global warming.' [Student 26]
Antibiotic-resistant	'Among the so many pharmaceuticals, antibiotics have received special attention for their wide application in human therapy and livestock agriculture. Unscrupulous disposal of antibiotics into the environment can results in the emergence of resistant bacteria strains that results in public health concerns.' [Student 29]
Diethanolamine	'Diethanolamine may cause skin irritation and negative effect to liver and kidneys' [Student 40]
VOC	'VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects. Also, they could be used as potential chemical weapons in future.' [Student 32]

Table 5. Students' awareness change on the SSI-based ESD as shown in the 5-point Likert scale* survey form.

	Mean ± SD ($N = 41$)			
Topic	Before course	At end	t	p
Plastic pollution [PP]	2.7 ± 0.63	4.5 ± 0.64	−13.384	.000
Pesticides (carbamates, triazines, DDT, 2,4-D) and the environment SSI [PEST]	2.9 ± 0.79	4.8 ± 0.46	−12.608	.000
Global warming SSI [GW]	3.2 ± 0.70	4.6 ± 0.59	−9.853	.000
Antibiotic-resistant SSI [ANT]	2.0 ± 0.84	4.4 ± 0.67	−15.097	.000
Diethanolamine SSI [DE]	1.9 ± 0.83	4.2 ± 0.79	−14.676	.000
Volatile organic compound (Benzene) SSI [VOC]	1.5 ± 0.60	4.1 ± 0.84	−14.154	.000

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

learn from each other through their SSI-based ESD comics, as well as to understand deeply about the current SSI chosen by their fellow colleagues. In addition, the participants' familiarity change on the organic chemical-based SSI could be studied in the current setting, since their topics of interest were known the first hand. To achieve this, the Questionnaire on Awareness of Organic Chemical-Based SSI was subjected to participants, before and after administration of the activity. Based on Table 5 and Figure 7, the average scores of six topics were below 'familiar' before the administration of activity. Participants felt that they had gained more after their involvement in the activity, with the average scores after activity higher than before. Moreover, the results of paired t test showed there are statistical differences on the students' awareness change towards the topics of SSI ($p < .000$). The current surveyed result showed that

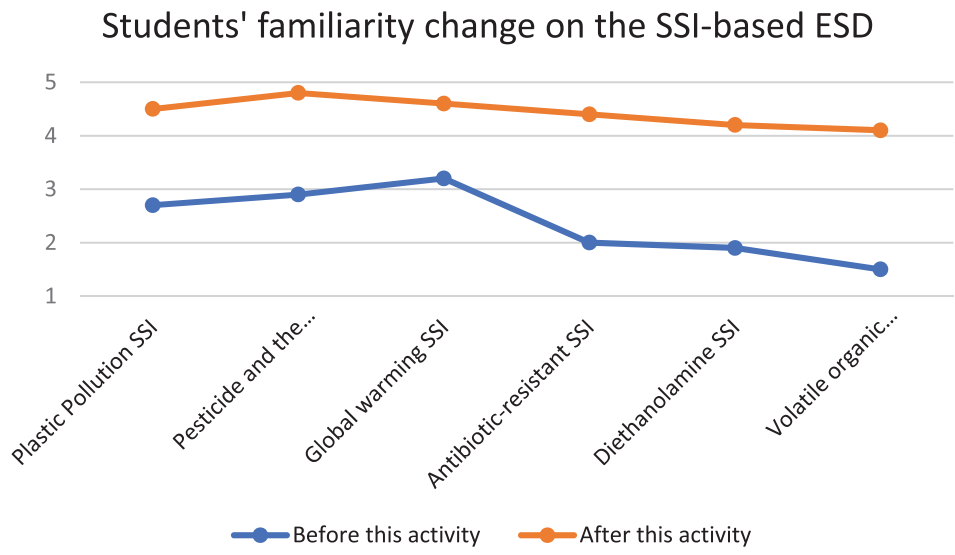

Figure 7. Students' familiarity change on the SSI-based ESD.

students were more aware about the SSIs of the organic chemical-based setting. Besides, the comic drawing activity presented here was capable of engaging students in a topic and enabled the communication of scientific matters between peers, which was in agreement with a recent article (*41*). Moreover, the use of reflective essays could be a potential way to enhance peers in understanding a studied topic, as implemented in the current study setting. The current implemented activity was considered to play a crucial role, especially in promoting environmental awareness attitude amongst participants.

3.3. Students' attitude toward comic drawing activity

The purpose of this activity was to create students early awareness in the ESD by using the comics as a way for them to communicate about scientific matters. In addition, students were required to think critically about the topics and ideas, before the creation of comics. Nevertheless, the current implemented activity was aligned to ESD, whereby it involved topics of every day's organic compounds and societal issues. Moreover, by taking advantage of the organic chemical-based SSI comic, the current activity provided an alternative method to teach sustainable education which differed from previous methods, whereby most of methods involved ESD implementation, either in laboratories or classroom settings.

Toward the end of this activity, students showed a highly positive response toward the activity (Table 6). In the first place, students admitted that the current activity was an intellectual challenge to them (M = 4.56). The author felt that it was indeed very important and needed in many of today's curriculum to nurture undergraduates' thinking capabilities and instil their reasoning skill. In addition, students felt that they could learn more about the principles of basic organic chemistry via the implemented activity (M = 4.51). For autonomy learning, students felt that the current activity could train them in developing their personal skill, through proposing their topics of interest and making their own comics (M = 4.59). Finally, students felt that the current activity was effective in promoting ESD (M = 4.83). Overall, the findings of this survey showed that the potential of incorporating the comic drawing activity which emphasized on the SSI in promoting ESD in the future. Undoubtedly, the current activity required a lot of thought and critique from students when crafting the comics on SSI. Nevertheless, the present work provides students with an opportunity to practice these

Table 6. Students' response on the implemented activity for semester II 2018/2019 and semester I 2019/2020 (N = 41).

	Rate[a]					
Question	1	2	3	4	5	M (SD)
Rate the intellectual challenge posed by current activity.	0	0	0	18	23	4.56 (0.50)
Rate the effectiveness of the current activity in the learning of organic chemistry.	0	0	0	20	21	4.51 (0.50)
Rate the effectiveness of the current activity to promote autonomy learning.	0	0	0	17	24	4.59 (0.49)
Rate the effectiveness of the current activity to promote the ESD	0	0	0	7	34	4.83 (0.37)

[a]Likert five-scale; 1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = Agree; 5 = strongly agree.

skills, and at the same time, by drawing comics it enhances students' gain in science learning (*42*). For future work, the comic drawing activity is useful to engage school students to learn about sustainability. Besides, the comic drawing activity can also be implemented in conjunction with a guideline (*43*) to maximize students' learning in sustainability issues. In addition, students can learn better and engage actively on the SD issues, if the activity was properly designed and conducted online, as indicated in this work and also reported by a previous literature (*44*). Finally, as pointed out by one of the reviewers, the comics of SSIs related to the use of chemical compounds were solely based on the understanding of participants. In future, course coordinators can play a role to clarify further on the current knowledge or progress of the SSIs chosen by students by having a group discussion, after the administration of this activity.

In the students' reflective essays, students also expressed their level of satisfaction towards the implemented activity. Some participants' comments were included here:

> This activity is interesting, and I hope the course instructor will keep this activity for the future class. [Student 1]

> In my opinion the most precious things that I've learn in this course is the knowledge in handling the chemical. Both chemical in the laboratory and chemical that we always used in daily life. Since my parent run the businesses that involved certain dangerous chemical like WD 40 and VOCs household product like paint, paint stripper, aerosol spray, and so on, it makes me felt more interesting in this course, so I can remind my parent and myself also to become less ignorant and be more aware with the chemicals we are dealing with because I've learned so many bad effect if we do not handle it properly. Besides that, this topic motivate me to become a good and knowledgeable chemist in the laboratory rather than a chemist that only mastering in calculation and theory. [Student 17]

> I really enjoyed the activity, thanks Dr. Chia! [Student 19]

> In short, I enjoyed the process creating the comic yet it may be frustrating and baffling as well but in the end I gain some knowledge and experience which will bring me a great impression toward it. [Student 25]

The instructor has been teaching the basic organic chemistry course since 2013 till date. From the perspective of the course instructor, the implemented activity was challenging to students, but at the same time enjoyable and effective in promoting ESD, judging from the survey result. Moreover, the current setting of activity in the basic organic chemistry course enabled students to think more critically about the chemicals they handle, so as to train them to become more environmentally conscious and a responsible citizen contributing to SD, which had never been experienced by the previous classes that were not exposed to this activity. In the current activity implementation, several limitations were identified by the course instructor. The sample size was relatively small ($N = 41$) and impact of the activity could not be felt by a larger group of students. In addition, the benefit of this activity is to create early awareness amongst undergraduates. However, it does not guarantee that the participants will apply the SD practices in their future lives. In the future, the SSI-based comics could be incorporated into machinima technique (*45*,*46*) to engage students active learning in SD.

4. Conclusion

The use of animated comics could enhance young students on their knowledge and understanding of specific science concepts, which are normally difficult to comprehend by using the traditional teaching method. The purpose of this activity was to create students early awareness in the ESD by using the comics as a way for them to communicate about scientific matters. In addition, students were required to think critically about the topics and ideas, before the creation of comics. Nevertheless, the current implemented activity was aligned to ESD, whereby it involved topics of every day's organic compounds and societal issues. In the current research, the pre- and post-surveys on the current activity implied that the students were intellectually challenged and satisfied with the activity which led to the learning of principles in the basic organic chemistry course. In addition, students agreed that this activity promoted autonomy learning and was effective in promoting ESD. With the current research setting, students felt more familiarized with the SSI topics regarding the use of some organic compounds, as shown in the survey result. In future, this activity will be adapted in teaching of SSIs in other fields, as well as to motivate students about ESD so that it can create an early environmental consciousness and responsibilities of every citizen on the earth's SD.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research was supported by Daegu University, 2018.

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