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The effect of online argumentation of socio-scientific issues on students' scientific competencies and sustainability attitudes

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ABSTRACT

One focal point of science learning is to develop students' ability to actively participate in discussions of socio-scientific issues (SSIs) in their daily lives. This study proposed the SSIs-Online-Argumentation Pattern (SOAP) to develop a pedagogical strategy enabling students to participate in online argumentation of SSIs. Two quasi-experiments were conducted to investigate the variations in scientific competencies and sustainability attitudes of students following the SOAP strategy. The participants were 127 senior high school students and 68 undergraduates respectively. Students' scientific competencies and sustainability attitudes were assessed using quantitative methods. The results showed that the SOAP strategy led to differences in high school students' scientific competencies. The mean scientific competency of the experimental group was higher than that of the comparison group in the post-test and in the delayed test. Specifically, for the constructs 'identifying scientific issues' and 'using scientific evidence', the difference between the two groups did not reach significance in the post-test and in the delayed test. The results showed that the SOAP strategy resulted in differences in undergraduates' sustainability attitudes. In the post-test, the mean sustainability attitude of the experimental group was higher than that of the comparison group. Specifically, for the constructs of 'economic' aspect, the post-test difference between the two groups did not reach significance. Finally, this research proposed suggestions and implications for future studies related to SSIs and science education.

1. Introduction

The objective of science education is to cultivate scientifically literate citizens (Dillon, 2009; Holbrook & Rannikmae, 2009; Lin, Hong, & Huang, 2012; Sadler, 2004; Wang, 2014), and this is also the goal pursued by the reforms and standards of science education in United States (NGSS Lead States, 2013) and Taiwan (Ministry of Education, 2014). In particular, the education reform in Taiwan set the goal of constructing literacy-based curricula (Ministry of Education, 2014). In the modern era of information technology, a scientifically literate person is expected to be able to exercise independent judgment and critical thinking rather than blindly obeying authority. A scientifically literate citizen is also expected to identify scientific phenomena surrounded with filtered information and participate in public discussion (Hofstein, Eilks, & Bybee, 2011). Such a

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viewpoint emphasizes the cultivation of "participatory" scientific literacy as the objective of science education (Forbes & Davis, 2008; Hofstein et al., 2011), where the focal point of learning is to develop students' ability to actively participate in the discussions of socio-scientific issues (SSIs) as well as make prudent decisions and propose feasible solutions regarding these issues in their daily lives (Lin & Mintzes, 2010). Such socially controversial issues are related to science. They are characterized as ill-defined and open-ended structures and have multiple potential solutions (Kolstø, 2001; Ratcliffe & Grace, 2003). Recent related studies have focused on whether the application of SSIs in education has a positive effect on students' academic achievements and scientific literacy (Chin, Yang, & Tuan, 2016; Eastwood, Sadler, Sherwood, & Schlegel, 2013; Kolstø, 2001; Lin & Mintzes, 2010; Saunders & Rennie, 2013).

The Programme for International Student Assessment (PISA) organized by the Organization for Economic Co-operation and Development (OECD) has emphasized that students' scientific literacy include several aspects, namely, identifying scientific issues, explaining phenomena scientifically, and using scientific evidence (OECD, 2012). Holbrook and Rannikmae (2009) maintained that scientific literacy includes four dimensions: intellectual, attitudinal, societal, and interdisciplinary. Such a definition of literacy considers the wide-ranging aspects and links science and technology to economy, politics, culture, and society on both individual and global scales. The PISA test framework considers scientific competencies to include the scientific literacy as defined by Holbrook and Rannikmae (2009) and recognized the necessity of possessing environmental responsibility, the ability to acknowledge the importance of individual actions, and the will to adopt measures to protect natural resources. In other words, a person is expected to be responsible and conscious of the environment and resources and possess a certain degree of sustainability attitudes (Lee et al., 2013). The discussion above indicated that the essence of contemporary scientific literacy implies an individual's scientific competencies in debating SSI in a rational and reasonable way and express concerns regarding these issues.

SSIs reflect issues encountered by industrialized countries in the development of science and technology (Levinson, 2006) and integrating them into the school curriculum may promote students' scientific literacy (Chin et al., 2016; Lin & Mintzes, 2010). Contemporary research trend indicates that scientific literacy includes reading and writing (Chin et al., 2016). In the context of science education, reading refers to scientific reading (Yore & Treagust, 2006), whereas writing is most widely applied in argumentation (Tsai, 2015). Therefore, related studies (Acar, Turkmen, & Roychoudhury, 2010; Böttcher & Meisert, 2013; Lin & Mintzes, 2010; Sadler & Donnelly, 2006; Wang, 2014; Zeidler, Sadler, Simmons, & Howes, 2005) have suggested to integrate argumentation pedagogy into SSI education. Students may develop informal reasoning, argumentation ability, and higher-order thinking as a result of debate with classmates during argumentation of SSI (Lin & Mintzes, 2010; Lindahl & Folkesson, 2016; Sadler & Zeidler, 2005). The above shows students may develop argumentation ability and scientific competencies in the processes of coming up with feasible solutions to these issues. Moreover, SSIs often involve moral reasoning regarding socio-ethical dilemmas, which is lacked in traditional science education (Morris, 2014). Saunders and Rennie (2013) suggested considering the cultivation of sustainability attitudes in SSI instruction.

Related studies have proposed SSI as an important strategy to improve students' scientific literacy (Levinson, 2006; Ratcliffe & Grace, 2003; Sadler & Donnelly, 2006; Sadler & Zeidler, 2005; Sadler, 2011). However, the practical application is rare due to the difficulties in implementing SSI in classes (Hofstein et al., 2011). SSIs are merely introduced into classrooms as a formal subject (Saunders & Rennie, 2013). Sadler (2011) asserted that scholars should further contribute into the SSI research to provide suggestions for curriculum improvement, which also reveals the importance and necessity of research on SSI practice. In addition, some scholars have stressed the importance of the integration of SSIs and argumentation (Acar et al., 2010; Böttcher & Meisert, 2013; Lin & Mintzes, 2010; Sadler & Donnelly, 2006; Wang, 2014). However, few studies have proposed explicit models for guiding the instructions to be issued for SSIs and argumentation. Moreover, with regard to in-class implementation, argumentation was suggested as an SSI strategy and the Internet was stated to be an effective tool for conducting argumentation learning and activities (Choi, Hand, & Norton-Meier, 2014; Lin, Hong, & Lawrenz, 2012; Tsai, Jack, Huang, & Yang, 2012; Yu & Yore, 2013). The synergistic effect of SSI and online argumentation on students' scientific literacy should be further investigated. Thus, this study proposed the SSIs-Online-Argumentation Pattern (SOAP) and investigated the effect of this instructional strategy on students' scientific competencies and sustainability attitudes.

1.1. Socio-scientific issues

SSIs are controversial social issues which are science-related and such issues are normally interdisciplinary and related to socio-ethical dilemmas (Kolstø, 2001; Ratcliffe & Grace, 2003; Sadler & Zeidler, 2004). SSIs have an open and interdisciplinary nature and include the influence of different social factors. For example, construction of nuclear power plants in Taiwan is related to economic and political factors. Therefore, when discussing such issues, students have to evaluate the arguments from different aspects, integrate relevant information, assess feasible plans, and select an optimal solution (Eggert & Bogeholz, 2009; Liu, Lin, & Tsai, 2011; Papadouris, 2012). SSIs also involve scientific process and moral reasoning dilemmas (Kolstø, 2001; Ratcliffe & Grace, 2003; Sadler & Zeidler, 2004; Zeidler et al., 2005), one example of which is genetic engineering technologies. Disputes are a result of a value conflict among people with different standpoints regarding some issues. Consideration and judgment of merits and drawbacks of technology application and appropriateness of actions touches upon considerations of ethics and social responsibility (Zeidler et al., 2005). SSI implications involve the relationship between science and mutual influence of humankind, society, and the environment.

Integration of SSIs into the classroom can solve the problem of alienation of traditional science learning from the social reality. Traditional science learning focuses on acquirement of scientific knowledge and textbooks often fail to link the knowledge with the application of science and social responsibility (Hofstein et al., 2011; Morris, 2014; Tytler, 2012). The current science curriculum puts emphasis on students' learning of scientific knowledge rather than training of students' thinking skills (Hanegan, Price, & Peterson, 2008). Students may not link what they learned in the classroom to the real world and solve issues confronted in daily life using their scientific knowledge (Tsaparlis, Hartzavalos, & Nakiboglu, 2013). Some studies showed that as a result of excessive scientific knowledge in classroom, students are limited only to the learned knowledge in their thinking, fail to consider broader aspects, and lack critical thinking (Hofstein et al., 2011; Liu et al., 2011). Moreover, researchers indicated that application of science in real world is closely linked to society, culture, economy, and human actions (Forbes & Davis, 2008; Papadouris, 2012; Ratcliffe & Grace, 2003; Sadler & Zeidler, 2004) and advocated the integration of SSIs into scientific curriculum in order to reform traditional education (Hofstein et al., 2011; Morris, 2014). To sum up, SSIs comprise multi-faceted dimensions and are problematic and controversial. Solutions of such issues are characterized by constrained conditions. When they applied in society, the issue of moral reasoning has to be considered. Implementation of SSIs is an educational method that can link real society and science learning. Development of decision-making abilities through discussions and exercises with classmates may enable students to make reasonable and objective solutions to SSIs and become scientifically literate citizens (OECD, 2013).

1.2. Scientific competencies

Scientific competencies refer to "*the capacities to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity*" (OECD, 2013, p. 9). Thus, contemporary science education has been focusing on helping students improve their argumentation regarding scientific issues, as well as their critical thinking skills (Osborne, Erduran, & Simon, 2004; Simon, Erduran, & Osborne, 2006). These scientific competencies are *identifying scientific issues*, *explaining phenomena scientifically*, and *using scientific evidence* (OECD, 2012). Such competencies in PISA framework focus on examining students' abilities in solving issues, communication competencies in delivering scientific concepts, and ability to apply them with regard to issues encountered in daily lives.

Lin (2010) referred to research on scientific literacy and developed an assessment framework based on scientific competencies that is applicable to public in Taiwan. These scientific competencies include *identifying scientific issues*, *explaining phenomena scientifically*, *using scientific evidence*, and *solving problems technically*. Propositional planning for this assessment framework used daily life and various contexts to package basic competencies, knowledge, and attitude required in a certain field into grouped-questions. Such daily contexts included *health*, *natural resources*, *environment*, *hazard*, and *frontiers of science and technology*. Tests developed based on this framework can be used to examine public scientific competencies (Tsai, Li, & Cheng, 2017).

Scientific competencies comprise a set of specific constructs (Lin, 2010; OECD, 2012, p. 108): (1) *Identifying scientific issues*: This construct includes the recognition of questions that would be possible to investigate scientifically; and the recognition of the key features of a scientific investigation. (2) *Explaining phenomena scientifically*: This construct includes the application of scientific knowledge in a given situation; description or interpretation of phenomena and prediction of changes; and identification of appropriate descriptions, explanations, and predictions. (3) *Using scientific evidence*: This construct includes the accessing of scientific information and construction of arguments and conclusions based on scientific evidence. (4) *Solving problems technically*: This construct includes the application of techniques to solve problems; application of technical tools and methods; collection and analysis of data; and development of solutions for problems.

The comparison between test frameworks of Lin (2010) and PISA (OECD, 2012, 2013) showed that Lin's (2010) framework added a new construct of "solving problems technically," while the other three criteria were similar. Moreover, Lin's (2010) definition of contexts, knowledge, and attitude was similar to that in PISA framework. The assessment framework proposed by Lin (2010) recognized PISA framework and focused on the development of scientific competencies as necessary skills in adult life (Tsai et al., 2017).

Earlier studies on scientific literacy mainly focused on assessment of static scientific knowledge. However, Turner (2008) questioned the inclusion of only scientific knowledge into scientific literacy and mentioned the research trend of scientific literacy from the cognitive deficit model to the contextual model. This paradigm shift implies the importance of students' possession of scientific competencies to contribute the debate of individual and policy issues (Lin, Hong, & Huang, 2012).

1.3. Sustainability attitudes

Sustainability literacy refers to one's knowledge, competence, and values supporting sustainable development (Parkin, Johnston, Buckland, Brookes, & White, 2004). Sustainability literate individuals have an understanding of, competence in, and attitude toward actions aimed at long-term benefits for themselves and others (Diamond & Irwin, 2013; Parkin et al., 2004; Sahin, Ertepinar, & Teksoz, 2012). Sustainability attitudes are individuals' inclination toward and value of sustainable development and developed behavioral habits, feelings, and ideas (Sahin et al., 2012). In other words, sustainability attitudes are an individual's positions with regard to sustainable development. Subjective opinions developed with respect to sustainable development may shape an individual's behavior. This shows an active and important role of sustainability attitudes in sustainability literacy (Arbuthnott, 2009; Michalos, Creech, McDonald, & Kahlke, 2011; Sahin et al., 2012). With regard to the context of sustainability attitudes, above studies showed sustainable development of an effective society.

From an integrative perspective, environmental, social, and economic aspects were seen as the three main aspects of research on sustainability attitudes (Lee, Chang, Choi, Kim, & Zeidler, 2012; Michalos et al., 2011; Parkin et al., 2004; Sahin et al., 2012). The environmental aspect covers natural resources (water, energy, agriculture, and biodiversity), climate change, rural development, sustainable urbanization, and disaster prevention. The social aspect covers human rights, peace and human security, gender equality, cultural diversity and intercultural understanding, health, and governance. The economic aspect covers poverty reduction, corporate responsibility and accountability, and market economy (Michalos et al., 2011, pp. 393–394). A sustainable society is characterized by its economic development, protection of the natural environment, and development into a fair society.

Studies on science education (Diamond & Irwin, 2013; Ellis & Weekes, 2008; Lee et al., 2013; Parkin et al., 2004) pointed out the importance of possession of a sustainability attitude by students and called teachers' attention to the necessity of informing students to face conflicts and contradictions in economy, technology development, and the environment. For this, recent SSIs, on which no compromise has been reached yet, can be used for students' reflection and discussion. Such on-site authenticity can directly affect students' values and provide them with understanding of relationship between technology development and society (Lee et al., 2013; Sadler & Zeidler, 2005). Economic and technological developments have led to inevitable changes in the surrounding environment. Therefore, teachers may develop global citizenship in students and consider sustainable development issues from different perspectives (Lee et al., 2013).

The above shows the agreement between sustainability attitude improvement and SSI-related instructions. Sustainable development curriculum can link students and communities and increase their future interest in society and concern for economic and environmental development (Lee et al., 2013). The SSI instruction has an open-ended nature and does not have certain answers as in a traditional classroom. Students are supposed to rely on their knowledge and values for comprehensive reflection and judgment. In this learning process of SSIs, students may shape personal viewpoints and beliefs.

1.4. Argumentation of SSIs, scientific competencies, and sustainability attitudes

Argumentation activities are currently one form of interaction in scientific community. Hypotheses are supported through development of arguments and proposition of evidence, during which an individual's conception may be constructed (Kuhn, 2005; Osborne et al., 2004; Smith, Kiili, & Kauppinen, 2016). Nowadays, scientific literacy emphasizes that students can inspect evidence for a scientific issue and develop rational arguments so that they can apply argumentation skills in daily lives (Lin, Hong, & Huang, 2012; OECD, 2013; Osborne et al., 2004; Tsai, Lin, Shih, & Wu, 2015). Teachers can design learning with SSI that would include dilemmas and controversial contexts and provide argumentation experience (Sadler, 2011). Based on the above, students not only receive experts' explanations but also can apply argumentation skills to comprehension SSIs.

Integration of SSI discussion into curriculum may develop students' understanding of current controversies in science and technology, as well as reasoning skills of scientific competencies. When discussing SSIs, students can clarify contradictions between social culture and science and make decisions via the argumentation process (Zeidler et al., 2005). Students' viewpoints are evaluated based on evidence, reasoning, and conclusions of these decisions, which reveals one's scientific competencies (OECD, 2012). Students can examine development of social phenomena from multiple perspectives and develop attainments of participating in related public debates. Thus, application of SSI is considered to be an important strategy to improve students' scientific literacy (Levinson, 2006; Ratcliffe & Grace, 2003; Sadler & Donnelly, 2006; Sadler & Zeidler, 2005; Sadler, 2011). Issues that are close to students' life experience can be incorporated into scientific curriculum in order to increase their interest and turn them into active learners. This learning process may encourage students to engage in critical dialogues and train their scientific competencies.

Previous studies also asserted that the SSI learning environment can improve students' social participation and their attitudes toward science (Hanegan et al., 2008). Some studies (Lee et al., 2013; Saunders & Rennie, 2013; Tytler, 2012) reminded that when instructing SSI, teachers may guide students to solve issues while considering the responsibility and sustainability attitudes. Lee et al. (2013) integrated SSI into high school curriculum and investigated the improvement of students' values required for global citizenship. The results showed that SSI instruction had a significant positive effect on students' social and moral compassion, and socio-scientific accountability. Students admitted to have certain sense of responsibilities with regard to environmental protection but hesitated to the action. No significant difference was observed in the ecological worldview. Lee et al. (2013) attributed the outcomes to students' considerable knowledge about the ecological environment prior to SSI instruction. According to above discussion, the current study focused on sustainability attitudes and investigated the effect of SSI instruction on students' sustainability attitudes from different perspectives.

1.5. The SSIs-Online-Argumentation Pattern (SOAP)

The above discussions show the relationship among the argumentation of SSIs, scientific competencies, and sustainability attitudes. Integration of SSIs and argumentation has been proposed by several studies (Acar et al., 2010; Böttcher & Meisert, 2013; Lin & Mintzes, 2010; Sadler & Donnelly, 2006; Wang, 2014; Zeidler & Nichols, 2009; Zeidler et al., 2005). Effectiveness of argumentation on the Internet has also been confirmed (Choi et al., 2014; Lin, Hong, & Lawrenz, 2012; Tsai et al., 2012; Yu & Yore, 2013). This study integrated SSIs, Internet, and argumentation and developed the SOAP strategy (Fig. 1) to validate its effectiveness. Fig. 1 includes three instructional strategies, which are *SSIs*, *online*, and *argumentation*. The critical elements in

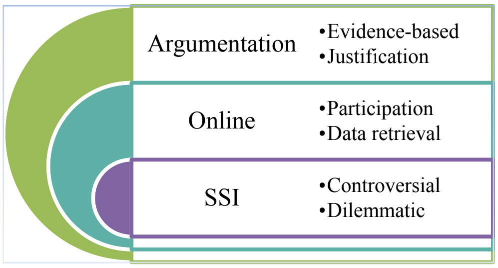

Fig. 1. The SOAP strategy.

the SOAP were constructed based on the definitions and findings of previous studies on argumentation and SSI domains. The details of each element are discussed in the following sections.

In the aspect of SSIs, Saunders and Rennie (2013) pointed out that SSIs exist at the interface of science and society and possess a controversial and dilemmatic nature. Related studies proposed that SSI instruction design may involve controversial issues that generate cognitive conflict in students (Böttcher & Meisert, 2013; Kolstø, 2001; Levinson, 2006; Saunders & Rennie, 2013), which may allow students to engage in argumentation training (Tsai, 2015). SSIs may push students to think about their own beliefs and values from contradictory perspectives and manage cognitive dissonance (Zeidler & Nichols, 2009), which is the source of attitude change (Sénémeaud & Somat, 2009). SSI instruction may also include putting students in dilemmas involving different positions (Böttcher & Meisert, 2013; Ratcliffe & Grace, 2003; Sadler, 2004; Saunders & Rennie, 2013; Zeidler et al., 2005), which may shape their science-related attitudes through social construction (Lee et al., 2013). As SSIs involve controversial and dilemmatic situations, students naturally divide into different groups to express their ideas and evaluate peers' opinions in SSI instructional practice.

With regard to the online strategy, online environments may allow students to be active learners and provide them with a diverse range of learning resources (Diamond & Irwin, 2013; Smith et al., 2016). Related studies suggested that SSI instruction design may promote students' active participation (Eastwood et al., 2013; Kolstø, 2001; Lee et al., 2013; Saunders & Rennie, 2013) and retrieval of evidence (Böttcher & Meisert, 2013; Kolstø, 2001; Sadler, 2011). Online participation enables students to engage in equal bidirectional communication, at any time and in any place, with peers who may have different viewpoints (Tsai et al., 2012; Wang, 2014). This kind of participation may provide learners with opportunities to train scientific competencies, such as the ability to explain phenomena scientifically. Data retrieval is another strategy that can be applied to train learners to determine what they can actively construct with their knowledge when online instructional activities connect global resources. This kind of data survey may provide learners with opportunities to train scientific competencies, such as the use of scientific evidence. Students can use the Internet to learn, to collect, and to obtain data; meanwhile, teachers can use the online environment for effective instruction (Fauville, Dupont, von Thun, & Lundin, 2015; Smith et al., 2016; Wang, 2014).

With regard to argumentation, it is described as a process of debate between people proposing different arguments which consist of assertions followed by evidence-based reasons and justifications (Jeong, Songer, & Lee, 2007; Sandoval & Millwood, 2005; Tsai et al., 2012). Related studies proposed that SSI instruction design may emphasize evidence-based reasoning (Lindahl & Folkesson, 2016; Ratcliffe & Grace, 2003; Sadler, 2011; Yu & Yore, 2013) and justification of personal opinions (Böttcher & Meisert, 2013; Sadler, 2004, 2011; Saunders & Rennie, 2013). In this process of SSIs argumentation, students continuously revise and adjust their arguments through discussions with evidence to train their scientific competencies (Tsai, 2015). During the argumentation process with a scientific community, they may gain a deeper understanding of these issues (Osborne et al., 2004; Smith et al., 2016), justify different viewpoints, and adjust their science-related attitudes (Lee et al., 2013).

According to the above discussion, an overarching question emerges. Does the SOAP strategy have any effect on students' scientific competencies and sustainability attitudes? This study thus integrated the SOAP strategy using an online platform. In the instruction process, instructor introduced SSI via online videos and data based on the SSI study by Solomon (1992) and conducted argumentation based on the argument-critique-argument approach proposed by Yu and Yore (2013). First, videos were used to introduce issues to students so that they could propose personal arguments. Students were then encouraged to evaluate others' arguments. Finally, individual arguments were reflected upon and synthesized. This study investigated whether students could develop related competencies and attitudes in the SOAP strategy. The designed items by Tsai et al.'s (2017) assessment are applicable to exams for high school students. On the other hand, an attitude change is generally a long-term process (Berg, 2005) and the high-school education system in Taiwan fails to provide this kind of long-term intervention. Sustainability issues are more widely used in the university courses in Taiwan. Therefore, the instructional experiment in this study separately discussed the effect of SOAP strategy on high school students' scientific competencies and undergraduates' sustainability attitudes. The first experiment investigated the effect of the SOAP strategy on high school students' scientific competencies. The second experiment investigated the effect of the SOAP strategy on undergraduates' sustainability attitudes.

2. Experiment 1

2.1. Research questions

Based on the above research background and review of important literature, this study mainly focused on investigating improvements in students' scientific competencies as a result of SOAP strategy in the online environment. The research questions (RQ) are addressed below:

RQ1. Was there any difference in the post-test of scientific competencies between students who participated in SOAP strategy and those who did not?

RQ2. Was there any difference in the delayed test of scientific competencies between students who participated in SOAP strategy and those who did not?

2.2. Participants

The participants in this study were students of a high school, located on the edge of city center in southern Taiwan. Four classes with a total of 127 students were randomly selected, among which two classes were the experimental group and two classes were the comparison group. Considering the administrative arrangements, students went through the experiment in the original class during the experimental period. That caused a situation in which the numbers of participants were quite unbalanced between the experimental and comparison group. The experimental group comprised 77 participants and the comparison group comprised 50 participants. No significant difference in the pre-test of scientific competencies was observed between the two groups ($t = 0.17$, $p > 0.05$), showing that students' scientific competencies were similar.

2.3. Research design

The quasi-experimental design was adopted as shown in Table 1. Prior to the experiment, *Scientific Competence Test* (section 2.5) were tested in both groups. Experimental treatment was applied to students in the experimental group and SOAP strategy was implemented in six classes that took a total of six hours (as section 2.6 and Table 3). Students in the comparison group went through the traditional textbook-based lecture which includes similar SSIs, such as genetically modified organism and nuclear power. The same Scientific Competence Test was conducted for both groups right after the experiment and one month after the experiment.

2.4. SSI scenarios

This study used SSI scenarios as a basis of students' argumentation activity that included contexts related to scientific competencies and controversial dilemmas. Science-related online news was used as sources for five local SSI scenarios, as shown in Table 2. After compilation of these scenarios, two science education experts were invited to evaluate the validity. For example, one of the experts suggested that the presentation of the SSI scenarios should take into account the balance of positive and negative reports. The SSI scenarios were revised according to these suggestions.

2.5. Scientific Competence Test

The instrument developed by Tsai et al. (2017) was used in this study. Assessment was comprised of five groups with a total of eleven items. A full score was eleven points. The constructs include the *identifying scientific issues* (item n = 3), *explaining phenomena scientifically* (item n = 3), *using scientific evidence* (item n = 2), and *solving problems technically* (item n = 3). The contexts within Lin's (2010) assessment framework revolved around important scientific issues in Taiwan. Five science educators reviewed the items to achieve expert validity. There were five contexts spanning various competencies; item were either multiple choice or true or false. In terms of validity assessment, Rasch analysis revealed that the mean square error (MNSQ) for indicator goodness of fit was between 0.94 and 1.05. T values were between −1.8 and 1.0. Separation reliability was 1.00. All of above indicate acceptable reliability and validity. Estimated difficulty was between −2.23 and 1.84; lower estimated values indicate the items were easier to answer correctly.

Table 1
The design of experiment 1.

Group	Pre-test	Treatment	Post-test	Delayed test
Experimental group	O_1	X_1	O_3	O_5
Comparison group	O_2	X_2	O_4	O_6

Note: O_1, O_2, O_3, O_4, O_5, O_6 were Scientific Competence Tests; X_1 was the SOAP strategy; X_2 was traditional instruction.

Table 2
Scenario and controversies of SSIs.

Context	Scenario	Controversy
Hazard	Flood detention pools	Neighboring residents raise questions and worry about the harm of flood detention pools that cannot effectively discharge and collect water, creating a place for propagation of mosquito vectors and increasing the concern about environmental health. (modified from http://www.ftv.com.tw)
Natural resources	Chlorination of tap water	Some scholars suggest that trihalomethanes, by-products of using chloride ion for disinfection, are carcinogenic, which is mainly due to activation of humic substances or precursors of trihalomethanes by chlorine during disinfection. (modified from http://www.water.gov.tw)
Environment	Technology factories	Civic societies suggest that when local governments support operation of factories by companies, in addition to the issue of rivers contaminated with discharge water, this can lead to unsuitability of neighboring fields for cropping. (modified from http://www.npf.org.tw)
Health	Genetically modified mosquitoes	Several scholars oppose to such release, suggesting that the experiment duration was too short. If genetically modified mosquitoes have a harmful effect after some time, it will be too late to improve the issue. (modified from http://e-info.org.tw/node/62857)
Frontiers of science and technology	Nuclear power plants	Civic societies opposing to this development project suggest that nuclear power generation can cause long-term contamination of land occupied by nuclear power plants and places where nuclear waste is stored can never be re-used. The most important is that Taiwan is located in an earthquake zone and there are concerns about quakeproof and safety of nuclear power plants. (modified from http://medialiteracy.pixnet.net)

2.6. SOAP strategy and activities

This study used the SOAP strategy (Fig. 1) to design instructional activities that included SSI, online, and argumentation. As shown in Table 3, the duration of each class activity was one hour, and a total of six hours of activity was arranged for the students. Scholars (Lin, Hong, & Lawrenz, 2012; Osborne et al., 2004; Tsai, 2015; Tsai et al., 2012) have found that Toulmin's Argument Pattern is an effective way to guide and evaluate the arguments of students. With respect to argumentation instruction, Toulmin's (1958) Argument Pattern was used as the framework for students to practice making arguments in an online forum. The sequence of the instructions was based on Tsai's (2015) study and started with simple, single component instructions which progressed to ones that were increasingly complex and consisted of diverse components. There were two classes (class 1–2 in Table 3) on argumentation instruction which was from the three-component argument, the four-component argument to the five-component argument. The instructor is a senior teacher with more than twenty years of experience teaching the sciences. He is also experienced in providing in argumentation instruction for students in high schools and universities.

For class 3–6, the implementation of the SOAP strategy used SSIs as the content of argumentation activities which followed the sequence in Fig. 2. Referring to the SSI study by Solomon (1992), this study used online videos and data to introduce SSI background and analyze SSI controversies and dilemmas (Table 2). In online practice, students in the experimental group participated in the argumentation activities and searching for relevant data online. During the experiment, teachers guided students to use their argumentation skills to discuss specific issues. The argument-critique-argument approach (Yu & Yore, 2013) continuously encouraged students to make use of their argumentation skills in discussion. Previous studies (Tsai, 2015; Tsai et al., 2015) have found that a similar sequence proposed by Yu and Yore (2013) was an effective way to conduct argumentation activities. Each student had to propose their initial evidence-supported argument, justify the arguments of others, and finally concluded with his or her own final argument. Students were given the opportunity to learn scientific concepts related to SSIs through an instructor's introduction to the SSI background. They were also able to broaden and deepen their thinking through online argumentation activities. In this regard, it could be effective to train and enhance students' reasoning skills.

Table 3
The objectives, examples, and related scientific thinking of SOAP instruction.

Class	Objectives	Argumentation example	Scientific thinking
1–2	Argument pattern	Three sisters of Ming have red hair (warrant). Hua is Ming's fourth sister (data). She may have red hair (claim) because red hair is hereditary in her family (backing), unless Hua's hair has turned grey due to old age (rebuttal).	Deductive and inductive reasoning
3–4	Draft arguments of a scientific issue can be conducted using the argument pattern	The south of Taiwan has long suffered from dengue fever epidemic. The *Aedes aegypti* mosquito is the vector of dengue fever. A British biotechnology company has developed genetically modified mosquitoes, seeking to control the spread of dengue fever. Arguments of which theory do you support? Why?	Argumentation skills
5–6	Draft arguments of a scientific issue can be conducted using the argument pattern	Family of A-Hua lives in the north of Taiwan, approximately 50 km away from a nuclear power plant that is being constructed. The government explained that nuclear power plants provide large-scale and stable power supply, which can reduce residents' electricity expenses. Arguments of which theory do you support? Why?	Argumentation skills

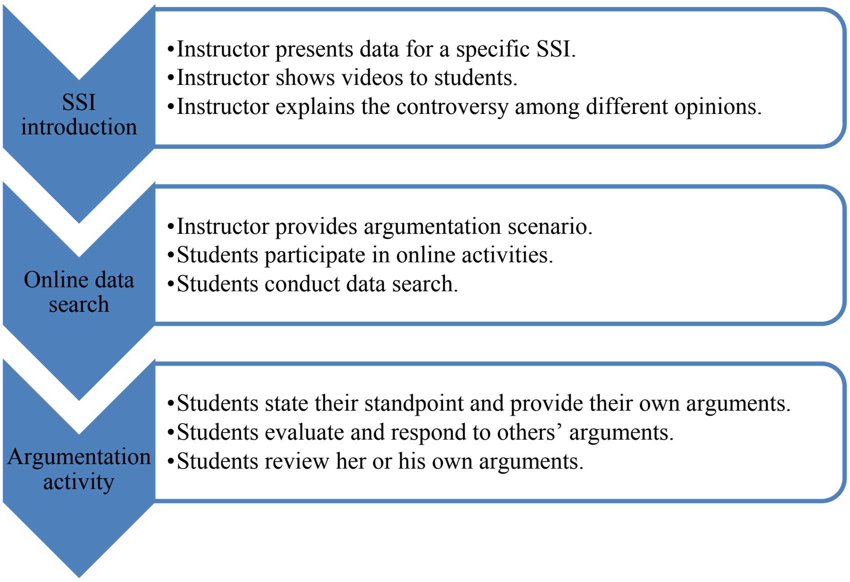

Fig. 2. The implementation of SOAP strategy.

2.7. Data analyses

This study used analysis of covariance (ANCOVA) to examine the effect of SOAP strategy on scientific competencies. The scientific competence pre-test was the covariate. It was examined whether two groups of students performed differently in the scientific competence. The tests for the homogeneity of regression slopes were first examined. Afterward, ANCOVA was used to examine differences in the post-test of students' scientific competence between two groups. Differences in the delayed test of students' scientific competence in two groups were also examined using ANCOVA.

2.8. Results

In the test of regression homogeneity slopes prior to ANCOVA, the results were $F(1, 123) = 3.17$ ($p > 0.05$) and $F(1, 123) = 2.66$ ($p > 0.05$), showing no significant difference. This indicates fulfilling the basic assumption of homogeneity. The linearity test between covariate and dependent variable reached significance ($F(1, 125) = 32.37$, $p < 0.05$; $F(1, 125) = 16.29$, $p < 0.05$). The skewness values of variables were between −0.46 and −0.18, and the kurtosis values of variables were between −0.74 and 0.08. These observed variables, in which the skewness and kurtosis were between −2.58 and + 2.58, were in line with the normality (Hair, Anderson, Tatham, & Black, 1998). Thus, the following ANCOVA can be executed.

The ANCOVA for scientific competencies in the post-test is shown in Table 4. The effect for students' scientific competencies was $F(1, 124) = 19.04$, reaching significance ($p < 0.001$), and the effect size was 0.39. According to Cohen's (1988), 0.10, 0.25, and 0.40 represent small, medium, and large effect sizes, respectively. The effect size of this experiment was close to large. This shows that experimental treatment had the effect on students' scientific competencies. The comparison in Table 4 shows that the adjusted mean post-test score for the experimental group was 8.13, which is higher than that of 7.11 for the comparison group.

The ANCOVAs for the various scientific competencies were then conducted. Under the constructs of 'explaining phenomena scientifically' and 'solving problems technically', the post-test difference between the two groups reached significance ($F(1, 124) = 7.35$, $p < 0.01$; $F(1, 124) = 34.78$, $p < 0.001$). The comparison of 'explaining phenomena scientifically' construct showed an adjusted mean post-test score of 2.55 for the experimental group, higher than the 2.26 obtained for the comparison group. The comparison of 'solving problems technically' construct showed an adjusted mean post-test score of 1.97 for the experimental group, higher than the 1.16 obtained for the comparison group. Under the constructs of 'identifying

Table 4
ANCOVA of post-test for students' scientific competencies.

Group	Pre-test *Mean(SD)*	Post-test *Mean(SD)*	Post-test *Mean'(SE)*	*F*	η^2	Cohen's *f*
Experimental group (n = 77)	7.29 (1.48)	8.14 (1.41)	8.13 (0.14)	19.04***	0.133	0.39
Comparison group (n = 50)	7.24 (1.42)	7.10 (1.52)	7.11 (0.18)			

Note: ***$p < 0.001$; *SD* = standard deviation; *SE* = standard error; Cohen's $f^2 = \eta^2/(1-\eta^2)$.

Table 5
ANCOVA of delayed test for students' scientific competencies.

Group	Pre-test *Mean(SD)*	Delayed test *Mean(SD)*	Delayed test *Mean'(SE)*	*F*	η^2	Cohen's *f*
Experimental group (n = 77)	7.29 (1.48)	8.01 (1.58)	8.00 (0.17)	11.25***	0.083	0.30
Comparison group (n = 50)	7.24 (1.42)	7.08 (1.61)	7.09 (0.21)			

Note: ***$p < 0.001$; *SD* = standard deviation; *SE* = standard error; Cohen's $f^2 = \eta^2/(1-\eta^2)$.

scientific issues' and 'using scientific evidence', the post-test difference between the two groups did not reach significance ($F(1, 124) = 0.15$, $p > 0.05$; $F(1, 124) = 1.64$, $p > 0.05$).

The ANCOVA for scientific competencies in the delayed test is shown in Table 5. The effect for students' scientific competencies was $F(1, 124) = 11.25$, reaching significance ($p < 0.001$), and the effect size was 0.30. The effect size of this experiment was medium. This shows that experimental treatment had effect on students' scientific competencies in terms of learning retention. The comparison in Table 5 shows that the adjusted mean post-test score for the experimental group was 8.00, which was higher than that of 7.09 for the comparison group.

The ANCOVAs for the various scientific competencies were then conducted. Under the constructs of 'explaining phenomena scientifically' and 'solving problems technically', the delayed test difference between the two groups reached significance ($F(1, 124) = 4.20$, $p < 0.05$; $F(1, 124) = 20.03$, $p < 0.001$). The comparison of 'explaining phenomena scientifically' construct showed an adjusted mean delayed test score of 2.49 for the experimental group, higher than the 2.27 obtained for the comparison group. The comparison of 'solving problems technically' construct showed an adjusted mean delayed test score of 1.82 for the experimental group, higher than the 1.16 obtained for the comparison group. Under the constructs of 'identifying scientific issues' and 'using scientific evidence', the delayed test difference between the two groups did not reach significance ($F(1, 124) = 1.59$, $p > 0.05$; $F(1, 124) = 1.06$, $p > 0.05$).

3. Experiment 2

3.1. Research question

Based on the above research background and review of important literature, this study mainly focused on investigating the effect of SOAP strategy on students' sustainability attitudes. The research question is addressed below:

RQ3: Was there any difference in the post-test of sustainability attitudes between students who participated in SOAP strategy and those who did not?

3.2. Participants

The participants in this study were students of a university, located on the edge of the city center in Kaohsiung, Taiwan. A total of 68 students were selected from two general education classes. The experimental class comprised 31 participants and the comparison class comprised 37 participants. No significant difference in the pre-test of sustainability attitudes was observed between the two groups ($t = 1.71$, $p > 0.05$), showing that students' sustainability attitudes were similar.

3.3. Research design

The quasi-experimental design was adopted. Experimental treatment was given to students in the experimental group and SOAP strategy was implemented in six classes that took a total of 18 h. Students in the comparison group went through the traditional general education course which covered similar SSIs, such as green energy, environmental pollution, and ecological conservation. A sustainability attitudes questionnaire (section 3.5) was conducted in two groups. Unlike Experiment 1, the delayed test was not conducted in this experiment since the semester ended after the post-test.

3.4. SSI scenarios

Same as in section 2.4

3.5. Sustainability attitude questionnaire

The sustainability attitude questionnaire was adopted from Michalos et al. (2011). Cronbach's alpha of the original questionnaire was 0.89 while in this study it was 0.80. Opinions toward sustainability attitudes were examined using 15 items in three constructs, namely, environmental aspect (item n = 4), social aspect (item n = 7), and economic aspect (item n = 4). For example, "The present generation should ensure that the next generation inherits a community at least as healthy, diverse and productive as it is today" (social aspect). Answers were given on a four-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = agree, 4 = strongly agree); scores ranged between 15 and 60 points.

3.6. SOAP strategy and activities

In general, the strategy and activities were similar to 2.6. As the general education course was implemented, each week took three hours. Since attitude change is generally a long-term process (Berg, 2005), each class in Table 3 was extended for 3 h and the experimental groups went through a total of 18 h. In this study, duration of SSI introduction via videos was longer and the instructor used longer time to analyze the controversies of SSIs.

3.7. Data analyses

This study used ANCOVA for quantitative data to examine the effect of SOAP strategy on sustainability attitudes. The pre-test of sustainability attitudes was a covariate. It was examined whether two groups of students performed differently in the post-test of sustainability attitudes. The tests for the homogeneity of regression slopes were first examined. Afterward, ANCOVA was used to examine differences in sustainability attitudes of students between two groups.

3.8. Results

In the test of regression homogeneity slopes prior to ANCOVA, the results was $F(1,64) = 1.63$ ($p > 0.05$), showing no significant difference. This indicates the basic assumption of homogeneity was fulfilled. The linearity test between covariate and dependent variable reached significance ($F(1,66) = 4.69$, $p < 0.05$). The skewness values of variables were between −0.52 and 0.01, and the kurtosis values of variables were between −0.79 and 0.40. These observed variables were in line with the normality (Hair et al., 1998). Thus, the following ANCOVA can be executed.

The post-test ANCOVA for sustainability attitudes is shown in Table 6. The effect for students' sustainability attitudes was $F(1, 65) = 9.76$, reaching significance ($p < 0.01$), and the effect size was 0.39. The effect size in this experiment was close to large. This shows that experimental treatment had the effect on students' sustainability attitudes. The comparison in Table 6 shows that the adjusted mean post-test score for the experimental group was 51.90, which is higher than that of 48.16 for the comparison group.

The ANCOVAs for the various sustainability attitudes were then conducted. Under the constructs of 'environmental' and 'social' aspect, the post-test difference between the two groups reached significance ($F(1, 65) = 6.65$, $p < 0.05$; $F(1, 65) = 8.67$, $p < 0.01$). The comparison of the 'environmental' aspect showed an adjusted mean post-test score of 14.61 for the experimental group, higher than the 13.59 obtained for the comparison group. The comparison of the 'social' aspect showed an adjusted mean post-test score of 24.26 for the experimental group, higher than the 22.50 obtained for the comparison group. Under the constructs of 'economic' aspect, the post-test difference between the two groups did not reach significance ($F(1, 65) = 0.15$, $p > 0.05$).

4. Discussion

4.1. Improvement of students' scientific competencies

In this study, SSI instructional experiments were conducted using online argumentation activities based on the SOAP strategy. The results of Experiment 1 revealed that high school students in the experimental group outperformed their counterparts in scientific competencies in the post-test and the delayed test. At the same time, medium to large effect size showed that SOAP strategy can lead to long-term improvement in scientific competencies. The above provides answers to RQ1 and RQ2. These results agreed with the findings reported by Chin et al. (2016) and Tsai (2015). Chin et al. (2016) involved students into in-class argumentation of SSI. Tsai (2015) involved students into online argumentation activities related to scientific competencies. This study integrated these research orientations into the SOAP strategy by including SSI, online, and argumentation strategies to provide insight into research on scientific competencies. Osborne et al. (2004) pointed out that SSI instruction has interdisciplinary nature; students can refer to their life experience, which increases their willingness to participate in a dialogue. Thus, the SOAP strategy may serve as a reference for improving scientific literacy.

The digital environment can support learning activities for individual and social argumentation (Lin, Hong, & Lawrenz, 2012; Smith et al., 2016; Tsai, 2015; Yu & Yore, 2013). The current study used the Internet for SSI argumentation. Students built their own arguments and evaluated arguments of others. In this process, students could search for and analyze related data online to address conflicting situations (Tsai, 2015). In argumentation processes, students justify reasons of scientific communities through interaction. This requires constant training of scientific reasoning and explanation skills. Online

Table 6
ANCOVA of post-test for students' sustainability attitudes.

Group	Pre-test *Mean(SD)*	Post-test *Mean(SD)*	Post-test *Mean'(SE)*	*F*	η^2	Cohen's *f*
Experimental group (n = 31)	46.97(4.29)	51.52(5.72)	51.90(0.87)	9.76**	0.131	0.39
Comparison group (n = 37)	48.57(3.42)	48.49(4.47)	48.16(0.80)			

Note: $^{**}p < 0.01$; *SD* = standard deviation; *SE* = standard error; Cohen's $f^2 = \eta^2/(1-\eta^2)$.

argumentation of SSI can promote students to use logic in reasoning and construction of optimal arguments to convince others (Tsai et al., 2012). When encountering an unfamiliar issue, students have to use online data and technology to solve it. These are practical manifestations of scientific competencies. Under the SOAP strategy, students underwent six classes of training, which enhanced their scientific competencies of 'explaining phenomena scientifically' and 'solving problems technically'.

However, the students in the experimental group did not outperform their counterparts in terms of the competencies for 'identifying scientific issues' and 'using scientific evidence'. Students experienced the most difficulties in PISA scientific competencies concerning 'identifying scientific issues' (Lin, Hong, & Huang, 2012; Tsai, 2015). Some studies on argumentation (Jeong et al., 2007; Lin, Hong, & Lawrenz, 2012; Sandoval & Millwood, 2005) have also showed that students faced difficulties in understanding the meaning of evidence and gathering appropriate and sufficient evidence. Moreover, the test items in 'identifying scientific issues' tested the students' ability to determine the experimental condition and control condition in the experimental design. The test items for 'using scientific evidence' tested the students' ability to justify the data in the tables or figures (OECD, 2012). These two kinds of competencies were not commonly used during argumentation practice involving SSIs. Tsai (2015) also found that scientific competencies might not improve if the argumentation activities were not addressed during training. Future studies may investigate these issues in a designed context.

The objective of science education for scientific literacy is to train students to become citizens willing to participate in public affairs, to serve in society, and to think critically (Dillon, 2009). Nowadays, the young generation often uses online information and news as the source of scientific knowledge. These sources need to be justified in a proper way that students developed for scientific competencies by discussing SSI. The argumentation process mainly trains students' deductive and inductive reasoning skills, as well as coordination skills for justification of the link between evidence and arguments (Kuhn, 2005; Osborne et al., 2004; Tsai, 2015). Careful reflection on SSI and provision of opinions shows that a student possesses a certain degree of scientific literacy (Zeidler et al., 2005). Scientifically literate citizens are able to apply scientific knowledge to explain scientific phenomena and draw evidence-based conclusions and can learn about science and technology to develop the cultural environment (OECD, 2013). The SOAP strategy may turn students into citizens willing to contribute to science-related issues and possessing scientific competencies.

4.2. Development of students' sustainability attitudes

The results of Experiment 2 showed that undergraduates in the experimental group outperformed their counterparts in the post-test of sustainability attitudes. At the same time, large effect size showed that SSI online argumentation can develop sustainability attitudes in students. The above provides the answer to RQ3. The results above are in concordance with the findings reported by Wang (2014) and Lee et al. (2013). The minor difference is that the instruction in this study included diverse SSIs (flood detention pools, water resources, construction of science and technology factories, genetically modified mosquitoes, and nuclear power plants). Such an approach was found to develop sustainability attitudes in students and provide other insight into related research. However, Fauville et al. (2015) used the Facebook platform and found that the Internet had a positive but limited effect on scientific literacy. Fauville et al. (2015) reported that users did not provide much feedback in response to the instructor's questions, which resulted in unidirectional knowledge transfer. This showed that, in order to fully manifest advantages of an online platform, instructors may use multiple instructional strategies in online learning to promote students' active participation and discussion. As proposed by Lee et al. (2013), involvement of students into SSI discussion can improve their social responsibility and willingness to act.

Online argumentation of SSI may provide several advantages for active learners to shape their attitudes. Diamond and Irwin (2013) pointed that e-learning can support student-centered learning and help to develop students' sustainability attitudes, including personal values and identity aligned with achieving sustainability. These values and identity are involved in situations related to students' lives. When searching for SSI-related data online, students draw from real-world situations. In contrast to didactic teaching, online learning is characterized by asynchronicity (Hou & Wu, 2011; Lee et al., 2011) and provision of multiple media (Smith et al., 2016). Such an active learning method may shape students' attitudes. In addition, Tytler (2012) stated that in SSI situations, students can clarify complicated concepts and deepen impression through interaction with classmates and teachers, and develop positive attitudes toward sustainable development. In the online argumentation, students who are bystanders can also derive different opinions and broaden their thinking by observing the discussions. Moreover, the more importance of online argumentation of SSI is that the teachers' role may transfer from a lecturer to a facilitator, giving the responsibility of learning to students and creating their own sense of responsibility for sustainable development.

In argumentation activities, students learn that SSIs include multiple aspects, such as science, technology, society, economy, and the environment (Acar et al., 2010), and involve controversial situations. SSI can foster students' thinking about sustainability issues, allowing them to reflect on the interaction between people, science and technology, and the environment (Lee et al., 2011; Sadler & Zeidler, 2005). The issues included into argumentation scenarios were used in this study, for instance, genetically modified mosquitoes and nuclear power plants, led to differences in proposals by different positions held by different communities. A large number of opinions have led to conflicting situations and cognitive dissonance (Sénémeaud & Somat, 2009). The undergraduates in the experimental group were found to have diverse attitudes in online argumentation but most of them gave priority to sustainable development. When solving SSI, undergraduates may justify personal decisions, which often involve personal values. Students' decision-making processes can reflect their personal responsibility (Lee et al., 2011), as well as consideration of the necessity of sustainable development.

After undergoing the SOAP strategy, experimental group students considered sustainable development from their viewpoints. When faced with the dilemma of profits and sustainability, they prioritized sustainable development factors such as environment and society. However, the experimental group students focused on the economic benefits for a company or a country. With regard to the data for the constructs of 'economy', the post-test difference between the two groups did not reach significance. The situation was also observed when instructions were being given. Lee et al. (2012) found that some students still tended to prioritize the economic profits of their own country after the implementation of SSIs. The prioritization of the profit at the individual or national level over global well-being reveals ethnocentric and egocentric perspectives (Lee et al., 2012). The above shows that students developed different viewpoints under the SOAP strategy.

4.3. *Research contributions*

Importance of integration of SSI and argumentation was attested in past studies (Acar et al., 2010; Böttcher & Meisert, 2013; Lin & Mintzes, 2010; Sadler & Donnelly, 2006; Zeidler et al., 2005). This study extended this SSI instruction orientation and developed SOAP strategy integrating features of the Internet. In the traditional in-class discussion of SSI, several active students may lead classroom discussions, while the proposed instruction method enables equal online participation of all students and has a broader effect on participants (Wang, 2014). Moreover, past studies (Chin et al., 2016; Kolstø, 2001; Saunders & Rennie, 2013; Wang, 2014; Zeidler et al., 2005) recognized the importance of SSI for students' scientific competencies. However, few studies have discussed such variables of scientific literacy as scientific competencies and sustainability attitudes. The data obtained in this study demonstrated the potential benefit for students and implications for research on SSIs. Finally, this study used the empirical method to examine the effect of SOAP strategy on students' scientific competencies and sustainability attitudes. The SOAP strategy was found to reach medium to large effect size. This showed that SOAP strategy can be further used in instructional practice.

4.4. *Research limitations*

This study adopted Scientific Competence Test (Tsai et al., 2017), based on the test framework proposed by Lin (2010). This framework focused on testing public competencies and adapted the item difficulty to those who have completed compulsory education. Test items developed are too easy for undergraduates. For example, high school students may not be familiar with the experimental design concept, but undergraduates in Taiwan often use this concept in their semester projects. Therefore, this study did not conduct the Scientific Competence Test among undergraduates. Future studies can adopted the framework and develop a scientific competence test applicable to undergraduates to conduct similar experiments. SSI studies may adopt mixed-method research by using both qualitative and quantitative data (Lee et al., 2013). Through this approach, future studies may confirm the findings of this study.

5. Conclusions and suggestions

This study conducted SSI instructional experiments with online argumentation activities based on the SOAP strategy. The results showed that SOAP strategy can improve high school students' scientific competencies and develop undergraduates' sustainability attitudes. However, SSIs were rarely used in scientific curriculum (Hofstein et al., 2011). Therefore, when encountering controversial events, many people expect that scientists can provide them with standard answers for policy formulation; however, even scientists cannot reach consensus on many issues (Ratcliffe & Grace, 2003). The SOAP strategy and life-related SSIs allow students to use their scientific knowledge in argumentation, to think about human-nature controversial issues, and to enhance their scientific reasoning and explanation skills. Science teachers can select SSIs that are suitable for students' level for them to discuss. This may improve students' understanding of the social nature of science disputes, as well as their evidence-based reasoning and critical thinking skills, thus, strengthening students' judgment and decision-making (Lin & Mintzes, 2010; Tytler, 2012). In the modern era of Internet, students are easily influenced by online information. Therefore, it has become crucial to be able to distinguish and evaluate information critically, which is an important skill of a scientifically literate citizen.

The SOAP strategy in this study used interactive instruction of SSIs. Increased interaction among teachers, students and their classmates can directly and indirectly improve students' engagement and participation (Rudsberg, Ohman, & Ostman, 2013; Tytler, 2012). Moreover, issues that can be frequently heard about in real life and derived from online news were used for discussion in this study. In this learning process, students are aware of the close relationship between what they learned in class and things that surround them in real life (Eggert & Bogeholz, 2009; Hanegan et al., 2008; Lin & Mintzes, 2010). As a result, students' social responsibility and sustainability attitudes might be trained. This also means that science teachers may use local issues to foster students' interest toward surrounding problems. What one learns can also be applied outside the classroom, which links school curriculum, life, and society (Forbes & Davis, 2008; Nielsen, 2012; Tsaparlis et al., 2013). In view of recent development of social media, school education may attach importance to training students' ability to discuss social issues from the perspective of global citizenship. Science teachers may change existing teaching models and be willing to contribute to such instruction.

The applications of SOAP could consider the training of the argumentation skills of students first. Guided argumentation instructions (Chin et al., 2016; Tsai, 2015) can be used. In the SSI introduction stage, an instructor may introduce local science-related issues which are controversial and dilemmatic. As SSIs have interdisciplinary nature, it is suggested that teachers from different disciplines design a course together when doing it for the first time. Videos of the local news are suggested for students to develop a better understanding about these issues (Solomon, 1992). Instructors may then give the students time to actively participate in online discussions and data retrieval. For such activities, computers would be required. For the argumentation activities, teachers can use online forums or social media as platforms for discussion (Smith et al., 2016). Students may be asked to present their own evidence-supported standpoint in the opening discussion. They can then justify their peers' arguments and have opportunities to think deeply about different standpoints. Finally, students may be asked to reflect on their own arguments (Yu & Yore, 2013).

Development of science education is always characterized by the contradiction between theory and practice (Hanegan et al., 2008). Despite the recognition of SSI role in improving students' competencies by learners, teachers, and the government, SSIs are rarely applied in classrooms (Hofstein et al., 2011). Moreover, due to the current examination system in Taiwan, teachers often do not pay attention to training these competencies and only focus on knowledge recited from textbooks. This study suggests using an authentic assessment method and integrating SSIs to assess students' critical skills and attitudes. SSI instruction challenges science teachers' existing habits. Teachers may guide students to express different viewpoints and provide a large space for discussion among students. The current and previous studies have showed the potential effect of SSI on improving scientific competencies and sustainability attitudes. With regard to educational policies, it is recommended to ensure the conformity between teaching and evaluation to train students for the global citizens' competencies.

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