Reinforcement of Scientific Literacy through Effective Argumentation on an Energy-related Environmental Issue

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ABSTRACT

This study designed a teaching unit in a chemistry course to engage students in discussing the complex issue of renewable energy development. In the 11-week learning activities, 66 ninth-grade students experienced individual exploration, group collaborative learning, and the operation of a web-based instant response system. Their learning outcomes were measured by the scientific conceptual test and the scientific literacy questionnaire, while their decision-making and argumentation processes were recorded using the instant response system. Results indicated statistically significant gains on the scientific concepts regarding solar cell and energy sources, as well as on the scores of scientific literacy. Likewise, students performed a substantial increase in argumentation skills, especially for those related to evidence-based arguments. Different science achievers showed a mixed pattern in proposing evidence to support their arguments. Using web technology in teaching argumentation on environmental issues is promised to raise students' interest in acquiring scientific knowledge to deal with relevant issues.

Keywords: solar energy, socioscientific issue, conceptual knowledge, argumentation, scientific literacy

INTRODUCTION

Energy Crisis and Environmental Issues

The burst of world population gives rise to the urgent demand for energy (Cheong, Johari, Said, & Treagust, 2015). The depletion of energy in the world has increased over 10 times during the 20th century, mainly from fossil fuels and partly from nuclear power electricity (Twidell & Weir, 2015). World marketed energy consumption driven by the growth of the economy from developing countries is expected to grow 49 percent from 2007 to 2035 (U.S. Energy Information Administration, 2010). The production and consumption of energy along with that of the concentration of carbon dioxide (CO_2) in the troposphere has increased by 30% from the initial stage of the industrial age until now.

Nowadays, the gradual depletion of fossil fuels causes the escalation of prices in all kinds of energy, and the use of renewable and sustainable sources of energy would be the solution for the energy crisis (Bodzin, 2012; Obama, 2017). The efficiency of energy and reduction of energy use, for some purpose, can promote the sustainability of economic growth (Fouquet, 2017). Therefore, citizens around the world must pay more attention to the environmental issues related to the use of energy with regards to their lives (Gambro & Switzky, 1999). It could be beneficial to elaborate on how people evaluate and judge the value of the use of renewable energy by deliberating on the pros and cons to the environment and welfare in human beings (American Association for the Advancement of Science, 1989; Cheong et al., 2015; Laugksch, 2000). The younger generation must be equipped with a basic knowledge of energy so as to make a judgment when facing the energy-related environmental issues in the future (Chen, Huang, & Liu, 2013; DeWaters & Powers, 2011; Laugksch, 2000). If students have a sufficient

Contribution of this paper to the literature

- The knowledge acquisition, argumentation skill, and collaborative action on the environmental issues should be integrated into formal science curriculum that aims to improve scientific literacy.
- The designed instruction involving conceptual knowledge regarding solar cell, argumentation, dyadic discussion, and web-based system is evidenced to improve low-achieving students' ability to generate evidence-based arguments.
- With adequate assistance of computer-based platform in making arguments on a complex issue, low science achieving students are capable of creating evidence-based arguments as good as their high-achieving counterparts.

knowledge base to understand the content of the issue, this would broaden their perspective and consideration while arguing to make a decision toward the issue (Sadler & Donnelly, 2006; Zeidler, Applebaum, & Sadler, 2011).

Scientific Conceptual Knowledge, Argumentation, and Scientific Literacy

Scientifically literate individuals can be aware of science-related public issues, such as health, food, energy, resources, and environment (Shen, 1975). They are equipped with the adequate scientific conceptual knowledge to actively participate in the decision-making process on such issues (Krajcik & Sutherland, 2010; Sadler, 2004). Science teaching should provide students with opportunities to actively construct the knowledge, understanding, and applications of scientific concepts and processes. Thereby, students would construct and share their ideas from communicating and interacting with peers through group discussion and argumentation (Osborne, 2010; Osborne, Donovan, Henderson, MacPherson, & Wild, 2016). Equipping students with the scientific conceptions and skills to engage in scientific discourse is one of the goals in science education. It is vital to elaborate and articulate toward issues in the discourse of argumentation activities (Kuhn, 2010; Kuhn, Zillmer, Crowell, & Zavala, 2013).

Socioscientific issues (SSI) are characterized as ill-structured social dilemmas based on the practice of scientific principles with contention and open-ended problems (Zeidler, 2014). Environmental issues, by definition, are one kind of SSI that involves controversies (Acar, Turkmen, & Roychoudhury, 2010) from various aspects of information related to science, technology, moral value, human welfare, and so on. Sadler & Fowler (2006) proposed a model indicating an intimate relationship between the scientific knowledge and argumentation quality of SSIs. Some empirical studies have implied that teaching argumentation may enhance students' content knowledge and argumentation skills (Dawson, & Venville, 2013; Venville & Dawson, 2010; Zohar & Nemet, 2002), while other studies suggest that increasing students' scientific knowledge could improve their engagement in argumentation (Lewis & Leach, 2006; Sadler & Zeidler, 2004). In generating arguments, the capability of making evidence-based arguments is not only an indicator of science learning performances (Venville & Dawson, 2010) but also an essential process in developing scientific literacy (Balgopal, Wallace, & Dahlberg, 2017; Bybee & McCrae, 2011; Choi, Lee, Shin, Kim, & Krajcik, 2011; Fives, Huebner, Birnbaum, & Nicolich, 2014; OECD, 2016). Hence, for future citizens, having good understandings and being able to clearly articulate arguments regarding resource management and environmental quality in the context of SSI are necessary (Bybee, 1993; Mun, Shin, Lee, Kim, Choi, Choi, & Krajcik, 2015).

Because the utilization of energy resources and the discussion of environmental issues are key segments of scientific literacy, it is vital for all citizens to be scientifically literate about resources and the environment (Bybee, 2008). Since energy topics were intrinsically included in science learning, being scientifically literate in the context of energy resources and the environment now is the goal to achieve in science education (Bybee, McCrae, & Laurie, 2009). Besides, the orchestration of instructional strategies would influence the outcomes of students' learning in argumentation and high-level thinking, which could inform contemporary science teaching strategies for all students (Belland, Gu, Armbrust, & Cook, 2015; Lin & Mintzes, 2010; Rivard & Straw, 2000; von Aufschnaiter, Erduran, Osborne, & Simon, 2008; Zohar & Dori, 2003).

In the present study, we designed a teaching unit composed of three phases and aimed to develop students' (a) understanding of scientific conceptual knowledge; (b) argumentation quality; and (c) enactment of action plans.

LITERATURE REVIEW

Scientific Knowledge in SSI for Scientific Literacy

The Program for International Student Assessment (PISA) defines scientific literacy as the ability to apply scientific understandings to life situations involving science (OECD, 2016). The goal of science education is to develop students' scientific competency that allows them to deal with problems in the context of personal, social,

and global levels (Bybee et al., 2009). As Roberts (2007) stated "students can't be scientifically literate if they don't know any science subject matter" (p. 735), science content knowledge still takes an overt position in scientific literacy. The advocacy of science-technology-society (STS) during the 1970s and 1980s has clarified the characteristics of decision-making on contemporary environmental issues, based on scientific concepts, skills, and values (DeBoer, 2000). Students were expected to be able to realize science as a social force and further to take social actions (Shen, 1975).

In Khishfe's (2014) conceptualization of scientific literacy toward the environment, in addition to incorporating scientific conceptual knowledge into the framework of scientific literacy, SSI were deemed the essential pillar in constructing the framework from the interaction among STS. Through argumentation, students would make informed decisions about SSI. The importance of integrating SSI into the science standard should be implemented to strengthen the knowledge and thinking skills for K-12 graders to make informed decisions and to be responsible citizens. This echoed Bybee's (2008) statement that "A scientifically literate individual has more than knowledge of resources and environmental issues" (p. 568). From the framework of PISA, it meant that, besides knowledge, the development of other competences (i.e., argumentation and decision-making) were also crucial for being scientifically literate. Therefore, with adequate development on the understanding about resources and the environment, it was helpful for students to empower their competences in personal decision-making and to participate in public policy formation.

The Need for Scientific Knowledge and Argumentation Skills in Dealing with SSI

Bodzin (2012) designed a 39 multiple-choice-item assessment to measure eighth graders' notion concerning: (a) energy acquisition, (b) energy generation, storage, and transport, and (c) energy consumption and conservation. Findings showed that students had insufficient knowledge and understanding of basic scientific facts and issues of energy resources as well as the influence of development and use of energy resources on society and the environment. Cheong et al. (2015) developed a diagnostic instrument to identify secondary school students' conceptual understanding of alternative energy resources. The content of the instrument included sources of the energy, greenhouse emission, costs, as well as disadvantages and advantages of alternative energy. It showed that students lacked understandings on the alternative energy, which involved apprehending the science of energy production, the costs and benefits of economics, and the effects of power generation on the environment. The results urged teachers to plan and implement lessons that intertwined the concepts of energy resources with environment issues.

For comprehending issues that occurred in our daily life (i.e., SSI), argumentation was considered to be the key skill in dealing with them (Khishfe, 2014; Lin & Mintzes, 2010; Osborne, Erduran, & Simon, 2004; Tsai, 2018). Venville and Dawson (2010) investigated whether the intervention of the argumentation skill and the discussion on SSI could increase students' genetics conceptual knowledge and argumentation levels. The results demonstrated positive effects and suggested that integrating argumentation skills into the science curriculum to enhance the learning of the scientific concept and argumentation skills still needs to be investigated under different SSI. Drewes, Henderson, and Mouza (2017) trained teachers to teach the topic of climate change in a professional development program. In this case, climate change was infused into the unit of the Earth's history with an argumentation activity in a two-week course. After conducting the course, students' scores of two categories on the causal human activity impact and the greenhouse effect mechanism improved with significance, but the mitigation and adaptation strategies did not have significant gains, and even the item of climate change effects had a negative effect. Instead of overemphasizing science on the casual mechanism and environmental effects, arguing with SSI and implementing social action would be an effective way to ameliorate the outcome.

Enhancing Scientific Literacy through Knowledge and Argumentation Integration

Mun et al. (2015) investigated secondary students' scientific literacy among different grade levels and genders and found students lacked interconnection with their environment and life, responsibility to global environment protection, and confidence in making decisions. A significant disparity existed in 9th graders who held the lowest scores among 7 to 12 grades. However, the researchers provided no explanation on the phenomenon of the significant decline, especially in the dimensions of character and values and science as human endeavor. Besides, the middle school students had lower scores than high school students. A similar condition also occurred in Taiwanese grade 9 students with significantly lower scores on the attitude in dealing with energy issues and decision-making, as well as on the action to effectively participate in energy selection and conservation in their everyday life as future citizens (Yeh, Huang, & Yu, 2017).

As a result, this study targeted at designing a teaching unit to enhance the grade 9 students' scientific literacy. Since SSI provided a more authentic context to construct meaningful knowledge (Dawson & Venville, 2009; Lee, Yoo, Choi, Kim, Krajcik, Herman, & Zeidler, 2013), students would be able to build up their knowledge about the

authentic issues when they wrote down their own arguments and communicated with others (Balgopal et al., 2017), and to enact their actions toward solving the problem. In addition to exploring the changes, either positive or negative, of the students' scientific conceptual knowledge, argumentation quality, and scientific literacy, the ability to generate evidence-based arguments was also analyzed according to students' prior achievements.

RESEARCH DESIGN

This study was based on the mixed method research design. SSI were integrated into the teaching unit on the topic of introduction of cells/batteries in the formal school science curriculum in an innovative way. The activities of argumentation and action were designed according to SSI. Students' scientific conceptual knowledge and scientific literacy were assessed before and after the teaching unit. The quality of students' argumentation toward the issue of solar cell utilization in Taiwan was also evaluated during this teaching unit.

Participants

Sixty-six grade 9 students (14 to 15 years old), 32 male and 34 female students, coming from two classes of a suburban public school in central Taiwan participated in this teaching unit. More than two-thirds of the students came from the school district, and the others entered the school in compliance with the government regulation.

Instructional Design

The teaching unit was based on the issue of the synergy between the energy resources and the environment. We developed the content and worksheet, which were verified by the Taiwan Ministry of Education and Education Bureau of the Taichung City Government. In order to conform to the content validity of the course, the content was examined by two science education academics and one experienced junior high school teacher in the domain of science and technology. The teaching unit, composed of three phases, is described in the following:

Phase 1: Production of energy and utilization of electricity

As the importance stressed by Roberts (2007), the goal of Phase 1 contained the structure and principle of the cell, including the Voltaic pile. In order to obtain basic scientific conceptual knowledge and important ideas for the application in the next phase (Lewis & Leach, 2006; von Aufschnaiter et al., 2008), the cells/batteries often seen in students' lives were introduced, like the carbon-zinc cell, alkaline battery, lead storage battery, or solar cell. Students were encouraged to look into the structure of the cells/batteries deliberately with the hands-on process. At the end of Phase 1, the teacher invited students to speak up to their peers individually for the explanation of the structure and utilization of their cells/batteries brought from their homes.

Phase 2: Argumentation on usage of energy resources in the context of SSI

Categorization on all sorts of energy exploited today was the first step, including the outline of the renewable / nonrenewable energy and the utilization of electricity. Then, the information about production and exploitation of solar cell enterprises leading to the advantages and disadvantages of people's lives in Taiwan would be informed. The employment of the Instant Response System (IRS) played an important role in the argumentation on the issue of the appropriateness of solar cell utilization in Taiwan. The IRS was adopted to select two students as a group for creating a high quality of argumentative reasoning (Kuhn, Shaw, & Felton, 1997). The personal and dyadic argumentations were implemented in turn before the instruction on the solar cell topic. The dyadic and personal argumentations were also held gradually after instructing the topic.

Phase 3 Decision-making of environmental issues in daily lives

Following previous instruction on energy utilization, the commencement of this phase was on the topic of "global warming" with the representation of the cause and effect of human beings' activities, and then the following discussions were carried out. Next, the content of the practice of "energy saving" and "carbon reduction" (Chen et al., 2013) with common symbols and tags appearing in everyday lives was instructed and discussed. Then, grouping was executed by the IRS according to students' dispositions to decide on one topic ranging from dieting, clothing, accommodation, transportation, and education & recreation. Each group (numbers > 2) collaboratively investigated the chosen topic for two weeks and expressed their understandings and findings from executing their plans by practical action, such as by oral representation (Jensen, 2002), drama, movie, etc. Finally, the teacher gave comments on the pros and cons about their ideas and presentations, and then praised students for the merits on their presentations.

Table 1. The scoring rubric of argumentation quality

Level	Description
0	Blank or irrational argument
1	Students could only generate **either**: (1) a simple argument (warrants followed by a claim) **or** (2) a simple counterargument (warrants followed by a counterclaim).
2	Students could generate **either**: (1) both an argument and a counterargument **or** (2) evidence or a qualifier followed by either an argument or a counterargument.
3	Students could construct **either**: (1) evidence or at least a qualifier followed by both an argument and a counterargument **or** (2) both evidence and at least a qualifier followed by an argument or a counterargument.
4	Students could construct both an argument and a counterargument **either** (1) with evidence and at least one qualifier **or** (2) with evidence and at least one rebuttal.
5	Students could construct a sound and coherent argument which comprise an argument, counterargument, evidence, and at least one qualifier and one rebuttal.

The IRS, CloudClassRoom (CCR, Chien & Chang, 2015), was introduced at the beginning of the course, substantially utilized in Phase 2, and then employed as a guideline for grouping in Phase 3. CCR, a web-based system which was applied in the process of the instruction with instant responses in smartphones, laptops, and PCs, assisted teachers in implementing the interactive course and grouping. Teachers could log in by an internet-capable device without any program installer and present true-false, multiple choice, or open-ended questions to students. Simultaneously, students would respond to the question by clicking options or typing sentences. Then, CCR would aggregate students' answers to allow the teacher to know whether the students understand the learning unit as well as to show adequate responses to all students for public voting.

For the accommodation of the progress in collaborative discussion, in light of our goals and the effect of discourse on student-student interactions (Osborne, et al., 2004), the group number of students increased from single, dyad, to group (group number > 2) learning in Phase 1, Phase 2, to Phase 3 respectively.

Instruments

For the purpose of realizing to what extent students achieved scientific conceptual knowledge, quality of argumentation, and scientific literacy in this unit, we adopted three kinds of instruments as follows:

Energy resources & environment (ER & E) conceptual knowledge test

This test was adapted from "energy-related content knowledge" (Hsieh, Liu, & Chen, 2013), and then verified by two science educators and one teacher (see instructional design) to confirm the content validity. The item distribution of the conceptual knowledge in three phases of the teaching unit corresponded to the two-way specification table. It was an 18 multiple-choice-item test. Item difficulty and discrimination equaling to .58 and .63 individually were established from 198 students excluded from participants in this study. Also, the internal consistency of reliability (KR 20) in the test was .86, which was adequate to apply.

The quality of argumentation on the utilization of solar energy in Taiwan

The rubric of the evaluation on the quality of argumentation was adopted from Lin (2014) with a minor modification to analyze students' levels of argument (**Table 1**). In our case, a level 0 was added into the original 5-level scheme because students sometimes could not generate any ideas or had answered unrelated to the guiding question. The highest level, level 5, was determined when their arguments had been composed of the warrant, evidence, qualifier, and rebuttal and must be solid, relevant, and coherent. Both level 4 and level 5 represented an evidence-based argument construction. The coding criteria were checked by the authors. The inter-rater reliability was conducted by randomly choosing one-fourth of the students' responses for both authors to independently analyze. With constant comparison applied, agreements were achieved until all of the discrepancies were discussed and solved. The first author applied the rubric to the remaining responses.

Students often abbreviated their responses in their replies, as we wanted to elicit their accurate responses in the positions they held. Therefore, misunderstanding students' uncertain expressions in the web context sometimes occurred. Therefore, for the clear-cut judgements, they stated their positions by choosing support/oppose options, and we could analyze critical components of the ground containing the warrant (backing), evidence, and qualifier existing in their argument, counterargument, and rebuttal. While students could not make accurate statements in

Table 2. Paired t test of ER & E conceptual knowledge test for different achievement levels

Achievements	Pre-test		Post-test		*t* (21)	Cohen's *d*
	Mean	Std Dev	Mean	Std Dev		
High level	13.86	1.28	16.41	1.76	8.71*	1.65
Middle level	12.18	1.92	14.18	2.61	3.89*	0.87
Low level	9.23	2.51	11.09	3.49	2.54*	0.61

* $p < .05$

their rebuttals, they sometimes elaborated and added information from their previous arguments in attempt to rebut (Kuhn et al., 2013; Lin & Mintzes, 2010). We denoted those as elaborated and supplemental warrants.

3C (Competency, Cooperation, & Confidence) scientific literacy questionnaire

This questionnaire was developed from a research project in Taiwan with a large-scale investigation of over 3000 students, including those from 1-12 grades, in order to measure students' scientific literacy (Chang, Chen, Guo, Cheng, Lin, & Jen, 2011; Cheng, 2011). Dimensions composed of competency, cooperation, and confidence were verified by two science education academics. The individual subscales of competency, cooperation, and confidence were (a) scientific inquiry and communication; (b) responsibility and positive interdependency; (c) self-efficacy and self-esteem. Items were answered by the 5-point Likert scale, ranging from 1 "almost never" to 5 "almost always". The reliability coefficient (Cronbach's α) of the total questionnaire was .99 with each subscale achieving .95 at least, from the same 198 students, suggesting the questionnaire was reliable.

Data Analysis

Analyses of quantitative data in the scientific conceptual knowledge and scientific literacy collected were carried out by SPSS 22. For analysis of qualitative data obtained from the IRS database in Phase 2, the quality of argumentation was assessed by the established rubric, and the Sankey diagram (Gesmann & de Castillo, 2011) was applied. The Sankey diagram was a kind of a flow diagram with the width of each flow proportionally corresponding to the flow quantity. Its advantage in this study relied on the visualization of the flow patterns between different categories by having clear-cut patterns in the transition between the levels of argumentation quality before and after the instruction. In order to make comparisons on students' performances during this instruction, students' prior science GPA in their seventh, eighth, and first semester of ninth grade were used to calculate mean scores. The selection criteria for high and low achievers were then according to the mean scores on top and bottom 33%. For example, student 33H meant student number 33 who was categorized in high achieving group (M: middle and L: low)

RESULTS

ER & E Conceptual Knowledge Test

The mean scores on the ER & E conceptual knowledge test from the pre-test and post-test were 11.76 and 13.89 with a standard deviation equaling to 2.73 and 3.46, respectively. The outcome revealed that students acquired knowledge significantly on the concept of electricity, energy and environment after instruction with a medium to large effect size of 0.69 (Cohen's *d*). Furthermore, we also wanted to know the effect of the instruction for different achievers labeled as high, middle, and low. Following the same procedure, the results in **Table 2** illustrated that the high-achieving, middle-achieving and low-achieving students had the mean scores changes with the effect sizes of large, large, and medium to large respectively. In a word, the higher achievements they had in science course, the more improved scores they obtained after this teaching unit.

The Quality of Argumentation

The variation of argumentation quality could be seen from the application of adequate argument elements in the argument, counterargument, and rebuttal. The Sankey diagram (**Figure 1**) showed the pattern of argumentation quality from high to low quality in turn as follows: level 5 (green), level 4 (blue), level 3 (orange), level 2 (yellow), level 1 (gray), and level 0 (pink). The outcome on the transition of the argumentation levels from left to right meant that students' argumentation quality change from the pre-test to post-test. Students' responses, which were defined as level 0 at the pre-test, could transfer to all levels, such as one student to level 5, three to level 4, two to level 3, two to level 2, one to level 1, and one still to level 0 after the instruction. The increase in the numbers of students in level 4 and level 5 from the pre-test (18.18%) to post-test (56.06%) was substantial, which concurred with the excerpts presented later in this section.
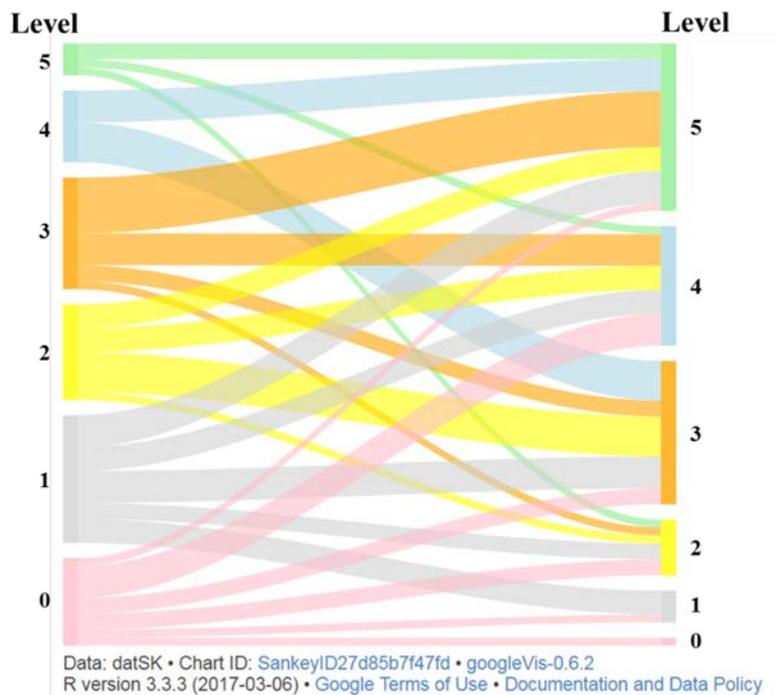
Figure 1. The transitions of students' levels of argumentation quality from the pre-test (left-hand side) to post-test (right-hand side)


| (a) | (b) | (c) |
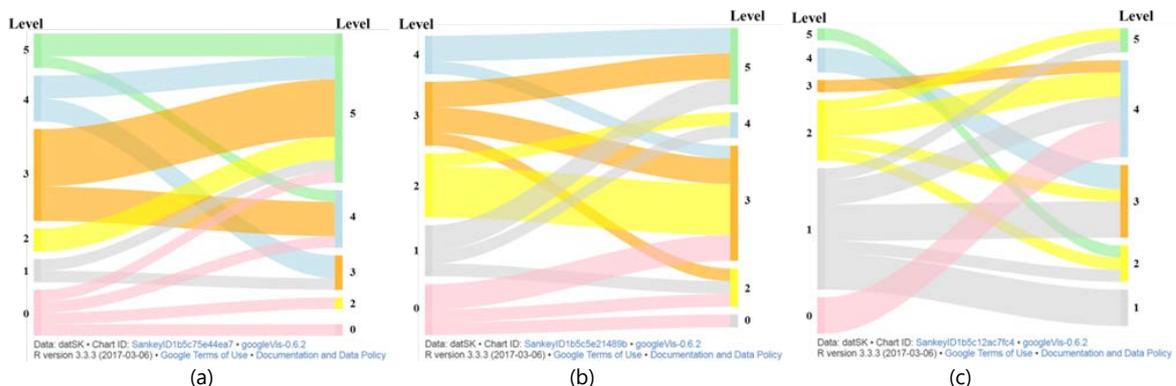
Figure 2. The transition of students' levels of argumentation quality from the pre-test (left-hand side) to post-test (right-hand side) by: a) high-achieving, b) middle-achieving, and c) low-achieving students

With regards to different achievers, the variation of achievers from the pre-test to post-test was depicted in **Figure 2**. After instruction, the high-achieving students were more likely to reach level 5 (13 students) than those middle- and low-achieving students (six and two students, respectively). Nevertheless, the same trend was not aligned with the category of generating evidence-based arguments. The number of the low-achieving students who attained levels 4 and 5 (10 students) exceeded that of the middle-achieving students (eight students) in the post-test. The pattern was distinct from the previous conceptual knowledge test as well as from that of the questionnaire (see the next section).

As shown in our results in **Figure 1** and **2**, most students improved after instruction in each achievement level. As a result, we chose students who improved after instruction in each achievement level to understand the changes of their argumentation quality. Their responses toward the SSI on the topic of the utilization of solar energy in Taiwan were presented as follows:

Student 33H

Pre-test (Level 4)

Argument: *I support it. When the sunlight is sufficient and the sun does not disappear* (Qualifier 1), *the resource of solar energy is infinite and does not produce much pollution* (Warrant 1 & 2)*. The sunlight is inexhaustible and does not need to take time to go through a cycle like water* (Evidence 1 & 2).

Counterargument: *When the sunlight is not sufficient* (Qualifier)*, the sunlight is hardly to be converted to a lot of electricity* (Warrant)*, even lower than the electricity generated from hydropower* (Evidence)*.

Rebuttal: *The destruction of the sun would take a long time* (Elaborated warrant).

Post-test (Level 5)

Argument: *I oppose it. It is estimated that for each ton of polycrystalline silicon produced, there will be 3-4 tons of silicon tetrachloride, which will cause huge damage to the environment* (Qualifier)*. The production process produces toxic silicon tetrachloride, which is a great hazard to the environment* (Warrant)*. When this highly corrosive and toxic liquid encounters moist air, it immediately decomposes into orthosilicic acid and highly toxic hydrogen chloride, which can irritate the eyes, skin and respiratory tract* (Evidence 1)*. When it encounters a spark, it will explode* (Evidence 2)*. The land used to dump or bury silicon tetrachloride will become barren, and trees and grass will not grow* (Evidence 3).

Counterargument: *If there is enough money* (Qualifier), *you can try to recover silicon tetrachloride, so that the environment will not be polluted and the solar energy will be more environmentally friendly* (Warrant).

Rebuttal: *It cost a lot of money to recover silicon tetrachloride. Few people want to do it* (Warrant).

Student 13M:

Pre-test (Level 4):

Argument: *I oppose it. Because the government does not give us subsidies* (Qualifier), *the solar panels are too expensive* (Warrant)*. The use of solar panels in Taiwan is not prevalent* (Evidence).

Counterargument: *Sometimes the government subsidizes the solar panels* (Warrant).

Rebuttal: *If there are no sunny days* (Qualifier 1), *solar panels cannot generate the electricity* (Supplemental warrant 1)*. And if there is a breakdown of solar panels* (Qualifier 2), *costs for repairing should be expensive* (Supplemental warrant 2).

Post-test (Level 5):

Argument: *I oppose it. The solar photovoltaic system needs an approximately 10 square meters area for setting, and, in the inclined roof setting conditions, it is about 7 to 8 square meters (cited from the Energy Bureau of the Ministry of Economic Affairs in Taiwan). Each family has a limited area to live. If people live in the apartment, the original upstairs space may be occupied. It is more suitable for people with a large house* (Qualifier 2), *because not everyone has the money or the space to install it* (Warrant 1 & 2)*. The government does not provide equipment subsidies for general solar photovoltaic power generation systems (cited from the Energy Bureau of the Ministry of Economic Affairs in Taiwan)* (Evidence 1) *and the cost of a single installation is also very huge* (Evidence 1)*. If people who rent the house want to install solar panels and if they want to move out within 10 years, they will lose their money from the installation of solar panels* (Evidence 1).

Counterargument: *The energy from the sun is inexhaustible (energy resources)* (Warrant).

Rebuttal: *For people who consume electricity substantially, solar panels are not suitable for them* (Warrant)*. Although the sun always exists all the year, the electricity that solar panels generate is limited* (Evidence)*.In the case of the replacement rate of solar panels every 10 years* (Qualifier)*, people actually need to have a long-term settlement that would not waste money and resources* (Elaborated warrant).

Student 11L:

Pre-test (Level 1):

Argument: *I support it. The sunlight is free, and the sun would not burst until hundreds of millions of years* (Warrant).

Counterargument: (None)

Rebuttal: *There is sunlight in eight out of ten days in Taiwan* (Supplemental warrant).

Table 3. Paired t test of 3C scientific literacy for different achievement levels

Achievements	Pre-test		Post-test		*t* (21)	Cohen's *d*
	Mean	Std Dev	Mean	Std Dev		
High level	3.80	0.57	3.88	0.45	0.75	0.16
Middle level	3.28	0.65	3.56	0.52	2.18*	0.48
Low level	3.13	0.57	3.56	0.67	2.87*	0.70

* *p* < .05
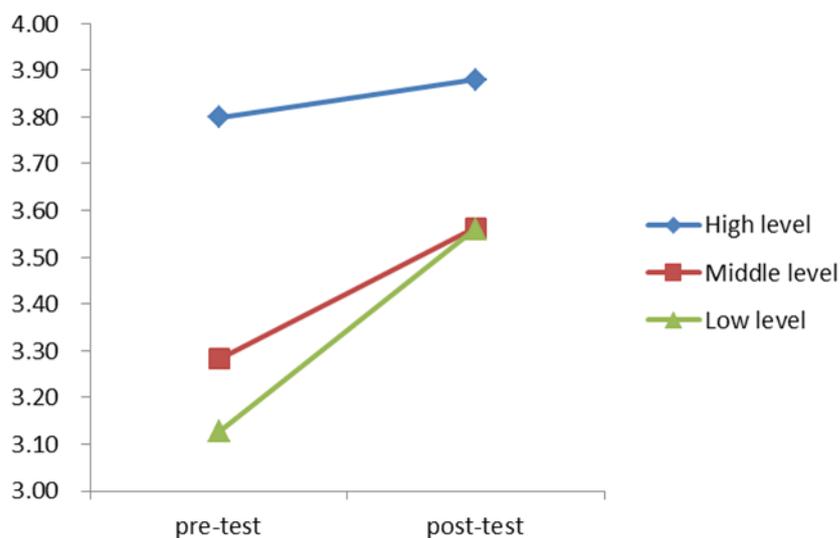
Figure 3. Gains on 3C scientific literacy from the pre-test to post-test for different achievement levels

Post-test (Level 5):

Argument: *I support it. The waste from solar energy production causes little pollution to the Earth* (Warrant).

Counterargument: *In the condition of the plum rain season* (Qualifier 1), *each day is cloudy* (Warrant 1). *If each day is cloudy, would the solar panels be useful* (Evidence 1)? *Solar panels need a large area* (*to produce electricity*) (Warrant 2).

Rebuttal: *There are other sunny days during the plum rain season* (Warrant). *The plum rain season would not necessarily tell you that you cannot see the sun* (Evidence).

In brief, qualitative changes could be inspected from the replies students gave in argumentation activities, which were displayed in the Sankey diagram. Students increased their argument elements and perspectives in a more coherent form regardless of their achievement levels.

3C Scientific Literacy Questionnaire

The mean scores of the 3C scientific literacy from the pre-test and post-test were 3.40 and 3.67 with the standard deviation equaling to 0.65 and 0.56, respectively. The result indicated that scientific literacy was statistically enhanced through the teaching unit with nearly a medium effect size of 0.43 (Cohen's *d*). As described in the previous section on three kinds of achievers, **Table 3** illustrated that the changes of the high-, middle-, and low-achieving students' mean scores from the pre-test to post-test with the phenomenon that the low-achieving students obtained almost the same scores as the middle-achieving ones did in the post test (**Figure 3**). The effect sizes of the high-, middle-, and low-achieving students' scores were presented as low, medium, and medium to large respectively in **Table 3**. However, the phenomenon revealed an opposite pattern in contrast to the conceptual knowledge test. To sum up, compared to high achievers, the low achievers gained more on the questionnaire scores, but less on the test scores, and vice versa.

DISCUSSION

Each phase of the teaching unit played an influential role on the ground of forging scientifically literate individuals. In the following paragraphs, we will inspect how the embedded elements dominated in each phase.

ER & E Conceptual Knowledge Test

The teaching unit effectively promoted students' knowledge of scientific conceptions about energy resources and the environment. Sadler and Fowler (2006) indicated that students would not engage in meaningful argumentation unless they had been equipped with a basic understanding of the content. Hence, the teacher instructed basic knowledge to students about the cells/batteries during Phase 1 for students to prepare for the next phase. Students needed to understand basic conceptual knowledge (Sadler & Donnelly, 2006) related to the composition of cells and the principle of electricity generation so that they would know the meaning and application of electricity generation and energy storage, and then judge the correctness of the information obtained from different sources. After finishing the worksheet based on the teacher's instruction, we encouraged students to speak up to their peers about what they thought of the concept and application of cells/batteries and energy storage devices in their daily lives. If they could, they were to try to state what properties made the cells/batteries adequate for their purposes, and to think about the role of science (Fives et al., 2014). It was an important process on how to elaborate their observation and reasons based on their prior experience and scientific knowledge (von Aufschnaiter et al., 2008) and to attempt to articulate their ideas about their theoretical assumption and practical usages.

The Quality of Argumentation

Through the instruction of solar cell production and exploitation, students' quality of argumentation obviously improved. Scientific knowledge played an indispensable role while confronting the SSI which existed in the authentic world (Kuhn, 2010). The enrichment of students' scientific knowledge could reflect on the quality of argumentation on SSI (Sadler & Donnelly, 2006; von Aufschnaiter et al., 2008). In our study, students originally could not construct their ideas well about the issues concerning the utilization of solar energy. After the discussion in dyad, students generated more argument elements and perspectives and reached a higher quality of argumentation. For example, student 13M in the post-test proposed a consideration about spaces for the setting of solar panels in addition to mentioning the government regulation about the setting in the pre-test. Student 11L had the similar perspective regarding space limitation and provided additional comments on pollution. Further, student 33H altered his view from less pollution of solar energy to the potential damage to humanity and environment generated in the production process of the solar cell. The instructional strategy allowed students to deliberate the problem, elaborate their reasons, confirm their beliefs, and reach consensuses through argumentation processes. The incorporation of the dyadic argumentation process would be beneficial to the learning outcome, resulting from strengthening the effect of the interlocutor and recognizing the discourse of countering to the opposite side (Kuhn et al., 1997; Kuhn, 2010).

As shown in the improvement on the quality of argumentation, direct instruction on the knowledge, computer-scaffolding information search (evident from responses of student 33H and 13M), and social interaction in dyads fostered students in complex cognitive skills in Phase 2 (including argumentation data collection). Unlike the setting in Zohar and Nemet's (2002) study adopting a long-time instruction, we implemented a short-term instruction (three lessons) to make efficient instruction of argumentation similar to the studies of Venville and Dawson (2010), and Dawson and Venville (2013). However, the difference that existed in our study was that explicit instruction of argumentation structure was not adopted. From the result of argumentation quality change, scientific knowledge could effectively promote students' level of argumentation in a short-term instruction (student 33H). While other factors indeed contributed to the quality of argumentation in this study, such as by discussion and argumentation in dyad as well as by a computer-supported system (Kuhn, 1997; Kuhn, et al., 2013; Nussbaum, Sinatra, & Poliquin, 2008), those factors were often adopted as strategies to the deployment of argumentation instruction. As a result, this study differed from other research focusing on explicit argumentation structure instruction by stressing the importance of scientific conceptual knowledge in enhancing students' argumentation quality.

Although there was a positive result on the change of argumentation levels, there still existed some decline in some students. It was noted that seven students had high argumentation quality at first, but showed slight retrogression after instruction. By closer examination of their responses, it was found that these students did not properly apply the evidence or information about pollution that they had just learned in class, or they changed their position on the issue without addressing sufficient and coherent warrant, evidence, qualifier, or rebuttal. On the other hand, students with level 0 in the pre-test could transfer to all levels, which meant the argumentation skill was originally present in students without having been properly developed (Kuhn, 1991). If there were some opportunities to invoke, students actually had the competence to improve considerably regardless of either conceptual knowledge or argumentation skills instruction (Kuhn et al., 1997; Lewis & Leach, 2006; Venville & Dawson, 2010; Zohar & Nemet, 2002).

The framework for the quality of argumentation had a definite boundary in levels 3 and 4 based on the use of evidence (Lin, 2014). In the pre-test, only about 20% of students' responses could be coded to have an argumentation level in level 4 or above, but over 50% of students in the post-test could reach the levels showing the ability to

generate an evidence-based argument. When students sought and used evidence for their arguments, they strengthened their argument in a more powerful way to persuade others (Kuhn, 2010). Most students who attained to level 5 indicated that they were equipped with the critical competence in thinking to create a sound and coherent argument in the context of SSI. The ability of using evidence to support or rebut arguments and applying evidence-based arguments to SSI issues were key components of scientific thinking (Bybee & McCrae, 2011; Choi et al., 2011; Fives et al., 2014).

3C Scientific Literacy

Scientific literacy was the ability for students to apply knowledge and skills to the variety of situations. Students' scores in all dimensions of scientific literacy had significant increases in all subscales. The enhancement could be observed over the teaching unit, particularly from their increasing quality of arguments as well as in their usage of evidence-based arguments.

The improvement could be inferred from the design of the teaching unit. The first dimension, "competence" was cultivated through searching information (student 13M) and making inquiries about the authentic issues (Bybee, 2008; Bybee et al., 2009). Communication skills were also enhanced through reaching consensuses and constructing arguments, especially in the dyadic discourse (Cavagnetto, 2010; Kuhn et al., 1997). Second, in the "cooperation" dimension, interdependency was developed when the dyad or group members shared a common goal. The positive result on this subscale showed that students were able to attain a high-level quality of argumentation and were willing to spend more time in achieving group work. Some students even devoted their after-school time to making videos and rehearsing their roles in the drama cooperatively, indicating that they were engaging and taking responsibility for their learning. In the third dimension, students with more confidence in talking to the class, engaging in argumentation in pairs, and in role playing in groups, which invoked respect and evaluation of others, had a promoted feeling of self-esteem (Maslow, 2013). Furthermore, students who had organized and implemented their action depending on their decision and will perceived more self-efficacy by accomplishing the action (Bandura, 1997). Student-centered learning activities which focused on weighing pros and cons as well as on taking actions from group work by the decision-making process provided a firm basis on acquiring confidence (Schusler, Krasny, & Decker, 2017).

Achievement Differences

The results of the ER & E test indicated that the teaching unit had a positive influence on the students' conceptual knowledge, especially for the high-achieving students. One explanation was that the ER & E test contained some scientific facts and concepts that students had learned from direct instruction. While we incorporated other instructional strategies like argumentation and decision-making into our teaching unit to foster students' critical thinking, the direct instruction technique prepared students with sufficient scientific conceptual knowledge for implementation in the other activities (von Aufschnaiter et al., 2008). Scientific knowledge is the prerequisite to taking action toward the environment issue (Jensen, 2002) and is also beneficial for engaging in argumentation (Lewis & Leach, 2006). The instruction did not hinder the high-achieving students' learning, but helped students discern and integrate scientific conceptions with argumentation and action in the authentic world, which corresponded to their structure of assimilating knowledge (Roelle & Berthold, 2013). Hence, students with more prior knowledge would be benefited more than low-achieving students.

Students' argumentation quality falling in the levels 4 and 5 meant they could use evidence to support their arguments. Most of these students were science high achievers (19 students). They also performed better on the ER & E test than middle- and low-achieving students. However, it was surprising that slightly more low-achieving students were able to reach high argumentation quality than middle-achieving students (ten versus eight, respectively). While we focused on the evidence-based argumentation, a different outcome would be obtained from the whole argumentation quality with various levels of achievement (Lin & Mintzes, 2010; Sadler & Fowler, 2006; Zohar & Dori, 2003). The pattern concurred with Zohar & Dori's (2003) study which showed that low-achieving students improved more than middle-achieving students in the moral dilemmas while teachers used explicit instruction of the argumentation skill in each dilemma. Rivard and Straw (2000) argued that low-achieving students gain more from the process of talking and that of talking and writing in learning science. Peer interactions were more beneficial for low achievers for knowledge construction. Evidence-based arguments would be constructed from low achievers' communication with other groupmates (Belland, Glazewski, & Richardson, 2011). Another explanation was that computer-based scaffolding would have more of an impact on low-achieving students than for high-achieving ones in creating evidence-based arguments of SSI (Belland et al., 2015). With adequate motivation and ease in assisting students to engage, it was promising for low-achieving students to improve as high-achieving ones in creating evidence-based arguments. In this study, SSI discussion in dyad was conducted on the CCR website and classroom, and students talked to each other whenever they wanted in addition to writing

responses. Consequently, low-achieving students could benefit from dyadic discussion and computer-assisted learning. The argumentation instruction in this study could make low-achieving students generate more evidence-based arguments.

Low-achieving students grew more than high-achieving students in scientific literacy with four times as large from the effect size evaluation. The ceiling effect (Belland et al., 2015) might be the reason that the high-achieving students were obstructed from improving significantly. While scientific literacy had multi-faceted competences as discussed in previous literatures (Mun et al., 2015; Osborne et al., 2004; Roth & Lee, 2004; Sadler & Donnelly, 2006; Santos, 2009; Venville & Dawson, 2010), the instruction should not only have relied on scientific conceptual knowledge, but also on the process of negotiation, argumentation, decision-making, and action enactment. The key competence of proposing evidence-based arguments might be an omen for scientific literacy as it incorporated more factors in generating arguments. Therefore, low-achieving students' enhancement in scientific literacy was worth noting. More research is needed to be done to explore the factors embedded in scientific literacy.

CONCLUSION

In this study, the teaching unit covering the topics from the fundamental scientific conceptual knowledge to the higher order thinking skill was aimed to foster the development of scientific literacy in the context of energy resources and environmental issues. We equipped students with sufficient knowledge to have the competence to elaborate their ideas about energy storage devices, and to collaboratively propose their arguments, counterarguments, and rebuttals on the topic of utilization of the solar cell. The development of argumentation skills enhanced the ability of decision-making for action on energy saving and carbon reduction in their daily lives. By some instructional strategies like dyadic discussion and computer-based support, students were able to improve the quality of argumentation, including generating evidence-based arguments, especially for low-achieving students. Through the teaching unit, the reverse trends in the growth of scientific conceptual knowledge and scientific literacy between high and low achievers are worth noting. The work to explore the factors behind the result still needs to be done in different research contexts.

IMPLICATIONS

Roth and Lee (2004) proposed that scientific literacy should be reframed under the collective praxis of social situations. Scientific knowledge is one form of various kinds of knowledge. Students could become scientifically literate by collectively participating in community issues. Likewise, Santos (2009) and Lee et al. (2013) advanced that rethinking of scientific literacy would be achieved via incorporating SSI to promote students' competency and willingness to dialogue, and then engage in sociopolitical action. As environmental problems provided a context of acquiring knowledge and solving problems (Roth & Lee, 2004), SSI about energy resources and the environment would be appropriate contexts for teachers to wield in the formal science curriculum. Students would learn more in applying what they learned in the science curriculum to the problems which occur in the real world (i.e., community), then, integrating what they learned in and out of school. In this way, students would become scientifically literate as future citizens.

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