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Improving Students' PISA Scientific Competencies Through Online Argumentation

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The scientific competencies advocated by the Programme for International Student Assessment (PISA) focus on the abilities needed in students' adult lives. This study investigated how such scientific competencies could be improved by using online argumentation. One hundred and thirty-eight 8th grade high school students took part in the study, with 69 in the experimental group and 69 in the control group. A quasi-experimental design was adopted and qualitative and quantitative analyses were used. An online argumentation system served as an aid for argumentation instruction and activities among experimental group students during the experiment. The results showed that using online argumentation could improve the students' scores for the PISA scientific competencies. The experimental group students outperformed their counterparts in terms of overall mean scores for the scientific competencies. On the one hand, the individual competencies of 'using scientific evidence' and 'identifying scientific issues' of the experimental group were higher than those of the control group. On the other hand, the experimental group students did not outperform their counterparts in terms of competency in 'explaining phenomena scientifically'. Using an online environment to complement argumentation instruction and organizing argumentation activities focused on related topics may be a potential direction to consider for improving students' PISA scientific competencies.

Keywords: *Argumentation; Online argumentation system; PISA; Scientific competencies; Scientific literacy*

Introduction

The Programme for International Student Assessment (PISA) sponsored by the Organization for Economic Co-operation and Development (OECD) reviews

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students' competencies in reading literacy, mathematics literacy, and science literacy every three years. Each survey focuses on a single subject, with the other two serving as supplementary subjects. The objective of the PISA is to understand how 15-year-old students from the participating countries apply knowledge and abilities in their handling of daily issues before completing their compulsory education (Bybee, 2008; Bybee & McCrae, 2011; Fensham, 2009; Lin, Hong, & Huang, 2012; Olsen & Lie, 2011; Sadler & Zeidler, 2009). Nowadays, whether or not public debates about governmental policies on socio-scientific issues lead to informed decisions depends largely on the scientific literacy of citizens (Lin, Hong, & Huang, 2012). With that in mind, not only does the PISA measure the students' understanding of school curricula, it also measures the important knowledge and abilities required in modern society for their future (Bybee, 2008; Bybee & McCrae, 2011; Lin, Hong, & Huang, 2012; Nentwig, Roennebeck, Schoeps, Rumann, & Carstensen, 2009; Yeh & She, 2010).

PISA uses the term 'literacy' within each subject area to indicate a focus on the application of knowledge and abilities (Bybee, 2008). It is not possible for students to acquire in school all the knowledge that will be required in the future when they become adults. School education has to build solid abilities for lifelong learning. Thus, the PISA scientific competencies emphasize that students need to prepare for the abilities needed in their future adult life and equip themselves with the basic literacy necessary in modern society. PISA features three competencies that are far more process oriented: (1) identifying scientific issues, (2) explaining phenomena scientifically, and (3) using scientific evidence (OECD, 2009; Sadler & Zeidler, 2009). Bybee (2008) stated that a student who is more developed in terms of such literacy will demonstrate the ability to create or use conceptual models to make predictions or give explanations, to analyze scientific investigations, to relate data as evidence, to evaluate alternative explanations of the same phenomena, and to communicate explanations with precision. Enhancement of these abilities corresponds with a rationale in which scientific literacy is viewed as the central purpose of science education (Bybee, 2008; Lin, Hong, & Huang, 2012; Nentwig et al., 2009). Researchers need to provide more experimental data in terms of PISA scientific competencies in order to contribute to educational policies. Therefore, the main objective of this study was to propose a learning strategy for improving such literacy.

Some researchers (Lee, 2009) have recommended the improvement of argumentation skills in light of the relationship between PISA scientific competencies and argumentation, reasoning that students who improve their argumentation skills might simultaneously cultivate their scientific competencies. In addition, the Internet is an effective tool for conducting argumentation instruction and activities (Bell & Linn, 2000; Clark & Sampson, 2008), and the current generation of students is quite familiar with the use of social networking services such as Facebook. The present study therefore considered the use of Internet tools and argumentation as a medium to explore the improvement of students' PISA scientific competencies.

Research Question

In light of the background discussed above, this research used an online argumentation system to complement argumentation instruction and activities regarding PISA issues. This study investigated the improvement of PISA scientific competencies throughout these online argumentation processes. The research question was as follows: Were there any differences in scientific competencies between students who participated in online argumentation instruction and activities and those who did not?

PISA Scientific Competencies and Taiwanese Students' Performance on the PISA Assessment

The OECD (2009) has illustrated the definition of scientific literacy and its framework for the PISA science assessment. In this framework, the term scientific literacy denotes an overarching competency comprising a set of specific scientific competencies. Such competencies include the abilities to mobilize cognitive and non-cognitive resources in any given context. These competencies are regulated by an individual's appreciation, interest, values, and actions relative to scientific matters, and are characterized as crossing through three interrelated aspects, including context, knowledge, and attitudes (as shown in Figure 1).

Scientific competencies comprise a set of three specific constructs (OECD, 2009):

(1) Identifying scientific issues: This construct includes recognizing issues that are open to scientific investigation; identifying keywords to use in searching for scientific information; and recognizing the key features of a scientific investigation.
(2) Explaining phenomena scientifically: This construct includes the application of scientific knowledge in a given situation; describing or interpreting phenomena scientifically and predicting changes; and identifying appropriate descriptions, explanations, and predictions.

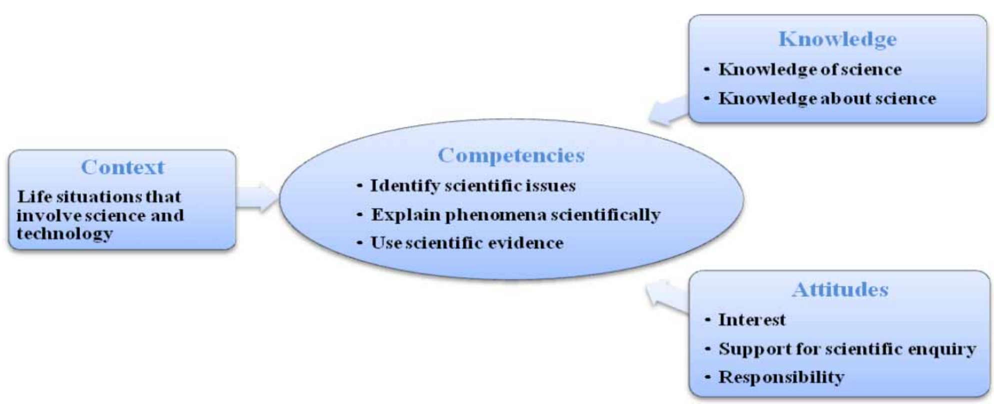

Figure 1. Framework for the PISA science assessment (OECD, 2009)

(3) Using scientific evidence: This construct includes interpreting scientific evidence and making and communicating conclusions; identifying the assumptions, evidence, and reasoning behind conclusions; and reflecting on the societal implications of scientific and technological developments.

In the dimension of 'context' shown in Figure 1, the assessment is built around life situations involving five topics: health, natural resources, the environment, hazards, and the frontiers of science and technology. In addition, each context spans personal, social, and global scales. The dimension of 'knowledge' includes 'knowledge of science' and 'knowledge about science'. The former refers to knowledge of the natural world, while the latter entails knowledge of scientific inquiry. The dimension of 'attitudes' includes interest in science, support for scientific inquiry, and motivation to act responsibly toward, for example, natural resources and environments.

The PISA focuses on students' competencies in applying their acquired knowledge in daily scenarios (Bybee, 2008). The students are asked to read short stories, journal reports, statistical diagrams, and other various forms of information before answering related questions. PISA science assessment is not constrained by declarative knowledge and instead requires procedural knowledge for the application of processing skills. These competencies are important skills in the development of contextualized science concepts and thinking skills about contextually embedded issues with science education (Bybee & McCrae, 2011; Sadler & Zeidler, 2009).

The PISA scientific competencies emphasize various aspects of scientific literacy in the context of daily life, including knowledge and attitudes (OECD, 2009). Taiwan's nine-year integrated curriculum for the science and technology domain (Ministry of Education, 2008) is similar to the principles of the PISA in terms of cultivating the required competencies in students. However, the global rankings of Taiwanese students in scientific literacy fell from 4th place in 2006 (total score of 534) to 12th in 2009 (total score of 520) (TWPISA National Center, 2012a). In particular, the gaps between the scores for the competence 'identifying scientific issues' and those of two others have been suggested as a cause for concern (Lin, 2008). Such performances are related to complex factors such as students' self-concepts (Areepattamannil & Kaur, 2013; Lin, Lawrenz, Lin, & Hong, 2013), interest (Areepattamannil & Kaur, 2013; Lin et al., 2013; Renninger, Ewen, & Lasher, 2002), and family values (Ho, 2010; Huntsinger, Jose, Larson, Krieg, & Shaligram, 2000). Statements to the effect that international evaluation results such as those of the PISA are due to education performances are controversial (Wang & Lin, 2005). However, improving PISA scientific competencies currently in the curriculum would also improve those scientific competences of students that are emphasized by science education. It is still feasible to implement relevant teaching strategies in the classroom for promoting such performance. The enhancement of PISA scientific competencies has become an important issue in efforts being undertaken by Taiwan's science educators to reform school curricula.

Argumentation and Online Argumentation

Argumentation in scientific learning can be defined as a process of connecting claims and data through justification or through the evaluation of knowledge claims in light of empirical or theoretical evidence (Clark & Sampson, 2009; Jimenex-Aleixandre & Erduran, 2008; Osborne, Erduran, & Simon, 2004; Yeh & She, 2010). Arguments are the artifacts of argumentation and consist of either assertions or conclusions, including their justifications, reasons, or supporting factors (Zohar & Nemet, 2002). Toulmin's Argument Pattern (TAP) (1958) has been seen as an effect pattern in argumentation instruction (Tsai, Jack, Huang, & Yang, 2012). The main components of TAP are claims (conclusions), data (the information used to support a claim), warrants (the statements regarding the relationship between the data and a claim), backing (the theories that support the warrants), and rebuttals (the exceptions to the warrants). In science education, argumentation is seen as entailing three overlapping goals: making sense of the phenomenon under study (i.e. constructing claims and explanations), articulating those understandings (presenting arguments), and persuading others to adopt one's ideas (critiquing and evaluating opposing ideas while defending one's own) (Berland & Reiser, 2009, 2011).

Discourse is an essential component of argumentation, and social structures in the classroom are important factors for designing activities that foster argumentation (Osborne et al., 2004). Such social interaction forms an environment for discussion which allows individual thinking to move from implicit to explicit, and this can result in group reflection to reach a common coordination (Clark & Sampson, 2007; Kuhn, 2005; Osborne et al., 2004). However, students are often not able to propose evidence or reasons supporting their arguments (Kuhn, 1991; Nussbaum, 2002). Argumentation should be imparted to students through suitable instruction, task structuring, and modeling (Kuhn, 1991; Osborne et al., 2004; Zohar & Nemet, 2002). Such teaching objectives would be more easily achieved by complementing them with scaffolding (Bell & Linn, 2000; Nussbaum, 2002; Osborne et al., 2004).

Argumentation activities require specific steps and thinking processes which information technology can assist students in completing (Bell & Linn, 2000; Lin, Hong, & Lawrenz, 2012; Yeh & She, 2010). Studies have shown several advantages of asynchronous computer-mediated communication as a cultivation tool of argumentation activities (Bell & Linn, 2000; Clark & Sampson, 2008; Lin, Hong, & Lawrenz, 2012; Tsai et al., 2012; Yeh & She, 2010). For example, it allows time delays for deliberation (Brem, Russell, & Weems, 2001; Clark & Sampson, 2007; Joiner & Jones, 2003; Lin, Hong, & Lawrenz, 2012); it provides more opportunities for students to participate (Clark & Sampson, 2007; Joiner & Jones, 2003); and it provides tools that enable scaffolds (Bell & Linn, 2000; Clark & Sampson, 2007; Tsai et al., 2012; Yeh & She, 2010). Asynchronous online discussion can function as an extension of answering time for students (Joiner & Jones, 2003). High-level questions can stimulate more accurate and definite answers from students when the students are given more time to respond (Lin, Hong, & Lawrenz, 2012). In addition, online discussion is free from the traditional classroom constraints whereby the discussion is led by a few dominant students, and low-achieving students can express their own opinions asynchronously. Moreover, computer-mediated communication can provide scaffolding prompts directing students' attention toward information that was not clear or pertinent to the constructed argument and helping them to develop logical and critical ways of thinking (Tsai et al., 2012). Therefore, this study hoped to complement argumentation instruction and activities with the advantages of an online environment and to observe how this process might improve students' PISA scientific competencies.

Argumentation and Fostering of PISA Scientific Competencies

Argumentation consists of the coordination of evidence and theory to support or refute an explanatory conclusion, model, or prediction (Clark & Sampson, 2007, 2009; Osborne et al., 2004). Such a process requires PISA scientific competencies in using scientific evidence and explaining phenomena scientifically. Competency in using scientific evidence involves accessing scientific information and producing arguments and conclusions based on scientific evidence, while competency in explaining phenomena scientifically includes describing, interpreting phenomena, and predicting changes, and may involve recognizing or identifying appropriate descriptions, explanations, and predictions (OECD, 2009). The competency of identifying scientific issues includes recognizing questions that it would be possible to investigate scientifically in a given situation (OECD, 2009). Recognizing a science problem is not straightforward and often leads to argumentation. The above comparison shows the potential relationship between argumentation and the PISA scientific competencies. Therefore, conducting argumentation instruction and activities may improve students' PISA scientific competencies.

When using argumentation to improve students' PISA scientific competencies, it is recommended that the sequence of instructions should be considered. Zohar and Nemet (2002) suggested that argumentation instructions should be addressed in two ways: first, they should be addressed in a lesson that is entirely devoted to explicit instructions about argumentation. Arguments are defined, and their structure is explained. These principles are then practiced through several concrete examples. Second, argumentation skills should be addressed for each dilemma for which students are asked to formulate and justify arguments and then formulate alternative arguments and rebuttals and justify those as well. In order to develop students' argumentation skills, Tsai et al. (2012) incorporated the cognitive apprenticeship theory as a method for arranging the argumentation instruction. Tsai et al. (2012) arranged argumentation activities from simple to complex, with a focus on the use of TAP. The use of cognitive apprenticeship was revealed as a viable teaching strategy in helping students learn the argumentation skills in the science classroom. The underlying concept of cognitive apprenticeship emphasizes a process of moving from simplicity to complexity and from singularity to diversity (Collins, Brown, & Newman, 1989). Along with this increase in complexity and diversity, the learners' familiarity with the TAP and the logical thinking necessary to use it might be increased.

The improvement of PISA scientific competencies also requires students to go through the scientific learning process in the scientific context. Previous science learning studies have viewed individual learning as a form of conceptual change (Posner, Strike, Hewson, & Gertzog, 1982), and relevant researchers (Dole & Sinatra, 1998; Nussbaum & Sinatra, 2003; Yeh & She, 2010) believe that argumentation can effectively promote students' conceptual change. The process of argumentation allows students to compare and contrast arguments through in-depth thinking (Dole & Sinatra, 1998), essentially triggering a cognitive conflict in an individual by giving him/her new information that varies from his/her prior knowledge. This is the first condition proposed by Posner et al. (1982) for conceptual change: the learner has to feel dissatisfaction with a current concept. A cognitive conflict triggered by in-depth thinking can then lead to learning and conceptual change (Nussbaum & Sinatra, 2003; Yeh & She, 2010).

Argumentation training has specific features to help strengthen students' scientific competencies and foster conceptual change. At the top of the PISA proficiency scale, items may involve more than a scientific explanation, require carefully constructed arguments (Bybee, 2008), and require that students engage in argumentation (Sadler & Zeidler, 2009). The construction of evidence-based arguments and communications requires critical thinking and abstract reasoning (Bybee, 2008). The argumentation process trains students to propose evidence when constructing arguments and allows them to think about the differences between their prior concepts and other variations (Nussbaum & Sinatra, 2003). The process also helps to train their critical thinking ability (Sanders, Wiseman & Gass, 1994), allowing students to engage in cognitive accommodation in the context of conceptual conflict. Therefore, scientific argumentation instruction and activities have the potential to help improve students' scientific competencies and provide opportunities for their conceptual change.

Methodology

Experimental Design

The study adopted a quasi-experimental design. The PISA science assessment was conducted on both groups before the experiment. The students in the experimental group then went through argumentation instruction and activity using an online argumentation system for a total of four hours. After the experiment, both groups completed the same PISA science assessment.

Participants

This study selected eighth grade students from two high schools situated on the edge of the Kaohsiung city in southern Taiwan. Four classes were randomly selected among 14 classes in two schools, with 2 classes in the experimental group and 2 classes in the control group. In the beginning, 150 students participated. Six students in each group applied for leave during the experimental process, leaving a total of 138 students who participated fully in the research, with 69 of them in the experimental group and 69 in the control group. To ensure that there were no significant differences in scientific competencies between these two groups, the independent samples *t*-test was performed on the pretest completed by the students at the beginning of this study. The results of this analysis showed that there were no significant differences between these two groups ($t = 0.26$, $p > .05$), which meant that the students in these two groups had roughly the same levels of scientific competencies.

The PISA Science Assessment

The PISA science assessment test items that have been made public can be downloaded from the TWPISA National Center (2012b). These sample items were constructed or translated by experts and researchers from various fields in the past when Taiwan participated in the PISA. The majority of the items are the same as the OECD released items, which can be downloaded from the official PISA website (http://www.oecd.org/pisa/testquestions-pisa2006.htm). The American Psychological Association, American Educational Research Association, and National Council on Measurement in Education (1985) have pointed out that content validity and construct validity should be used to ensure testing validity, which is defined as 'the degree to which evidence and theory support the interpretations of test scores'. Five teachers in the research team from the biological, life sciences, earth sciences, physics, and chemistry fields were tasked with selecting the appropriate items to determine the content validity. The inclusive criteria of these items were that they had to (1) be distributed over each of the five contexts, (2) be distributed over three competencies, and (3) provide questions leading students to the use of logical arguments. These items belonging to three competencies were then reviewed and verified by two science educators. A two-way specification table was formulated (as shown in Table 1). To achieve construct validity, the Rasch model (1960) was applied for analysis and the infit mean square (MNSQ) error values of the items were calculated to be between 0.95 and 1.18, which is between the suggested cutoffs of 0.6 and 1.4 (Linacre & Wright, 1994). In terms of reliability, the item separation reliability of the whole test was 0.95, which was above the suggested cutoff of 0.9 (Waugh & Addison, 1998). The validity and reliability were both within acceptable range. Proficiency levels represent the difficulty of items and were calculated to be between level 2 and level 6. The answering formats of the assessment items included multiple choice questions, true or false questions, and short answer questions. There were a total of 15 items, with each item having a full score of 10, a partial score of 5, and a score of zero for a wrong answer. The full score for the entire assessment was thus 150.

The Online Argumentation System

The argumentation system used (Tsai et al., 2012) is shown in Figure 2. The upper portion shows the argumentation topic, for which the instructor can set up two

Table 1. The two-way specification table of PISA science assessment in this study

Scientific competencies	Item	Context	Knowledge	MNSQ	Full score
Identifying scientific issues	S485Q5	A	KAS	0.97	30
	S529Q4	W	KOS	1.07	
	S08Q3	S	KAS	1.05	
Explaining phenomena scientifically	S114Q5	G	KAS	0.99	50
	S485Q2	A	KOS	0.99	
	S529Q2	W	KAS	0.95	
	S529Q3	W	KOS	1.01	
	S08Q2	S	KAS	1.08	
Using scientific evidence	S114Q3	G	KAS	1.12	70
	S114Q4	G	KAS	1.13	
	S126Q3	B	KAS	1.00	
	S126Q4	B	KAS	1.18	
	S485Q3	A	KAS	1.06	
	S529Q1	W	KAS	0.98	
	S08Q1	S	KOS	0.99	

Note: G = greenhouse (hazard); B = biodiversity (environment); A = acid rain (health); W = wind farms (natural resources); S = solar power (frontiers of science and technology) (items were developed in Taiwan); KOS = knowledge of science; KAS = knowledge about science.

opposing viewpoints. The lower left portion is the column for the tree directory of the students' argument titles. This directory provides a way for both the instructor and students to view the arguments of all the students in the class by means of hyperlinking to their saved location in a database. In addition, this column provides records reflecting the thought processes of all the students, helping individuals to reflect on their own

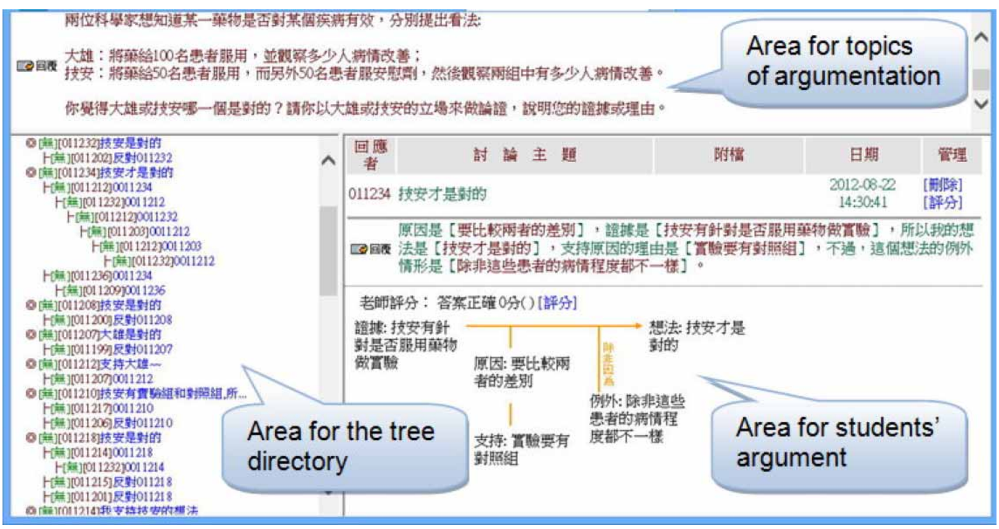

Figure 2. The system overview

thoughts. The lower right portion shows the argument of an individual student. Students are able to understand the perspectives of other students and achieve the objective of mutual interaction.

As shown in Figure 3, the system that provided the students a scaffold with which to construct their arguments was designed based on the TAP. When constructing each component of the TAP, students are given guiding statements (such as 'my idea is . . . ') with textboxes next to them in which they can type information to complete the TAP structure. Therefore, the format of the argument written by students could be something along the lines of the following:

> my reason is that all three sisters of Ming have red hair (warrant); my data is that Hua is the fourth sister of Ming (data); so my idea is that Hua might have red hair as well (claim); the supporting reason is that their family members have red hair genetically (backing); the exception is that Hua's hair turns white as she ages (rebuttal).

There are buttons next to the textboxes, which prompt the students about the explanation for each component of the TAP (Bell & Linn, 2000; Osborne et al., 2004). When each student finished the argument, the instructor marked corrections on each component of the argument, which is itself saved in the argumentation system. If a student's information did not adequately complete the statement, the button remains visible and indicates that the TAP was not adequately completed by the previous response. Should the preceding argument encompass all five components, then the buttons would disappear in order to indicate to the student that his or her argument has successfully incorporated all five components.

The Argumentation Instruction and Activities

Students in the experimental group went through online argumentation instruction and activities using the argumentation system for four classes (four hours) (Table 2). Argumentation instruction focused on how to use the argumentation

Figure 3. The scaffold for argumentation

Table 2. The learning goals, instructional examples, and scientific thinking of the argumentation instruction

Class	Learning goals	Instructional examples	Scientific thinking
1	Understanding the three components of TAP (claim–data–warrant)	*All men are mortal (warrant). Ming is a man (data), so Ming is mortal (claim)*	Deduction
2	Understanding the four components of TAP (claim–data–warrant–backing)	*All men have hands (warrant). Ming is a man (data), so Ming has hands (claim). The exception is that Ming has lost his hands in an accident (rebuttal)*	Deduction and rebuttal
3	Understanding the five components of TAP (claim–data–warrant–backing–rebuttal)	*All three sisters of Ming have red hair (warrant). Hua is the fourth sister of Ming (data), so she might have red hair as well (claim). The supporting reason is that their family members have red hair genetically (backing). The exception is that Hua's hair turns white as she ages (rebuttal)*	Deduction, rebuttal, and backing
4	Being able to conduct argumentation by using TAP	*Two scientists wanted to know if a particular medicine is effective for a particular disease, and raised their opinions: Nobita—Give the medicine to 100 patients and observe how many of them see an improvement in their condition; Goda—Give the medicine to 50 patients while giving the other 50 patients a placebo. Observe how many patients in each group see an improvement to their condition. Which of the two techniques above do you think is correct?. Why?*	Argumentation

system, and the key components of the TAP were explained to all the participants by the instructor. During the instruction sequences which were suggested by Zohar and Nemet (2002), the instructor explained the structure of TAP and tried to allow individual students to construct the arguments that best suited their logical thinking by following the instructor's argument example for 25 minutes during each class. Students were then asked to evaluate others' arguments for another 25 minutes to experience argumentation with others. Each student was then asked to make two or more arguments in each class.

The teaching strategy enabled students' learning to progress from simplicity to complexity and from singularity to diversity (Collins et al., 1989) in terms of argument construction. The three lessons of argumentation instruction were conducted, in order, using a three-component argumentation pattern, a four-component argumentation pattern, and a five-component argumentation pattern. The templates used for student practice in argumentation instruction were based on examples in Toulmin's book (1958). These examples include deductive reasoning and inductive reasoning (Table 2). The instructor explained the difference between these two forms of reasoning in the argumentation instruction. During the instruction, the instructor was the facilitator who coached, mediated, and prompted students to develop and assess their argumentation learning.

The students experienced the most difficulties in responding to PISA items about 'identifying scientific issues', especially when they were required to describe specifically the treatment and dependent variable of a contextual investigation (Lin, Hong, & Huang, 2012). The score for the competence 'identifying scientific issues' was obviously lower in Taiwan (Lin, 2008). The final lesson for the current study thus included argumentation activities based on two topics relevant to the scientific process: control variables and experimental designs. Both topics were related to 'identifying scientific issues' in order to compensate for the lack of argumentation instruction in this area for the related PISA competencies. One of the topics about experimental design was extracted from another scientific literacy report—the Science and Engineering Indicators (National Science Board, 2010) (Table 2).

Data Processing and Analyses

As some of the PISA science assessment items are short answer questions, manual evaluation was needed to decide whether a score of 0, 5, or 10 was awarded. In terms of inter-rater reliability, one researcher in the research team evaluated all the answers given by the students. To ensure internal consistency during the evaluation process, raw data for half of the students already evaluated were randomly selected for evaluation by another researcher. The inter-rater reliability between the two evaluators was found to be 0.89, and any inconsistencies were resolved after discussion.

In order to evaluate the effects of online argumentation instruction on the students' scientific competencies, this study used an analysis of covariance (ANCOVA) to conduct comparisons. The scientific competency scores achieved before the instruction were used as the covariate to investigate whether or not online argumentation instruction led to variation between the two groups of students in terms of their scientific competencies. Before the ANCOVA, tests for the homogeneity of regression slopes assumption were conducted. ANCOVA was then used to investigate the difference in performance between the two groups of students in terms of 'identifying scientific issues', 'explaining phenomena scientifically', 'using scientific evidence', and 'overall score'.

Results

The tests of homogeneity conducted before ANCOVA obtained the following results for 'identifying scientific issues', 'explaining phenomena scientifically', 'using scientific evidence', and 'overall score', respectively: $F(1, 134) = 0.33$ ($p > .05$), $F(1, 134)$

$= 3.58$ ($p > .05$), $F(1, 134) = 2.09$ ($p > .05$), and $F(1, 134) = 0.10$ ($p > .05$). These results, in which all the tests did not reach significance, matched the basic assumption of regression analyses. Therefore, the ANCOVA was conducted as illustrated below.

The ANCOVA results for the various scientific competencies are shown in Table 3. Under the construct of 'identifying scientific issues', the post-test difference between the two groups achieved significance ($F(1, 135) = 8.35, p < .01$) with an effect size of 0.25. According to the definition of Cohen's *f* (1988), the small, medium, and large effect sizes were 0.10, 0.25, and 0.40, respectively. This shows that the experimental treatment had a medium effect on the competency of 'identifying scientific issues'. The comparison in Table 3 shows an adjusted mean post-test score of 18.79 for the experimental group, higher than the 15.84 obtained for the control group.

Under the construct of 'explaining phenomena scientifically', the post-test difference between the two groups did not achieve significance ($F(1, 135) = 1.30$, $p >$ .05) with a small effect size of 0.10. The adjusted mean post-test score of the experimental group was 35.53, compared to 33.66 for the control group.

Under the construct of 'using scientific evidence', the post-test difference between the two groups achieved significance ($F(1, 135) = 4.61, p < .05$) with an effect size of 0.19. This shows that the experimental treatment had a small to medium effect on the competency of 'using scientific evidence'. The comparison in Table 3 shows the

Table 3. The ANCOVA of scientific competencies

Competencies	Group	Pre-test mean (SD)	Post-test mean (SD)	Post-test mean' (SE)	*F*	η^2	Cohen's *f*
Identifying scientific issues	Experimental	15.14 (7.01)	18.55 (6.24)	18.79 (0.71)	8.35**	0.058	0.25
	Control	16.52 (6.08)	16.09 (6.46)	15.84 (0.71)			
Explaining phenomena scientifically	Experimental	32.97 (10.78)	35.36 (9.63)	35.53 (1.16)	1.30	0.010	0.10
	Control	33.77 (10.41)	33.84 (11.63)	33.66 (1.16)			
Using scientific evidence	Experimental	51.74 (9.22)	54.71 (7.56)	54.38 (1.00)	4.61*	0.033	0.19
	Control	50.36 (9.71)	51.01 (10.93)	51.33 (1.00)			
Overall score	Experimental	99.71 (19.53)	108.55 (16.60)	108.77 (1.98)	8.21**	0.057	0.25
	Control	100.58 (19.75)	100.94 (21.54)	100.72 (1.98)			

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

*$p < .05$.

**$p < .01$.

adjusted mean post-test score of 54.38 for the experimental group, which is higher than the 51.33 obtained for the control group.

Finally under 'overall score', the post-test difference between the two groups achieved significance ($F(1, 135) = 8.21$, $p < .01$) with an effect size of 0.25. This showed that the experimental treatment had a medium effect on the scientific competencies overall. The comparison in Table 3 shows an adjusted mean post-test score of 108.77 for the experimental group, which is higher than the 100.72 obtained for the control group.

Discussions

The results of this study show that conducting online argumentation instruction has positive effects on scientific competencies. The experimental group students went through a logical training process in which they used TAP to construct their arguments and evaluate those of others. The TAP itself has a logical structure, and using TAP to construct arguments or evaluate those of others may engage students in logical thinking. Argumentation leads to social interaction processes through conflicts of opinion, possible solutions, and eventually consensus (Voss & Van Dyke, 2001). Such a process engages students in a rational direction and reasonable path to solve issues. During argumentation instruction in the current study, the instructor also introduced deductive and inductive reasoning. The PISA scientific competencies include inductive/deductive reasoning and critical thinking (Bybee, 2008). The argumentation instruction and activities may help in improving students' logical reasoning abilities and thereby improve their scientific competencies.

This study used a scaffolding design with prompt functions to help students to fill in the blanks for the five components of TAP (Figure 3). This scaffold provided students with a clear idea of the components required to construct an argument. Such a strategy dissects the complex work procedures, making it easier for students to think about how to construct an argument. The results of the scaffold effectiveness were in line with the studies of Bell and Linn (2000) and Tsai et al. (2012). The online adaptable assistance may help to reduce the cognitive load of students (Sweller, 1988), enabling them to carry out logical reasoning in order to complement them in the use of evidence and the construction of complete arguments (Tsai et al., 2012). Completion of the PISA science assessment requires a logical scientific writing format be followed. A study by Chin, Yang, and Tuan (2010) found that guided argumentation can help to preserve working memory capacity during the writing process and thereby allow greater use of it in the automaticity of sophisticated processes (Schneider & Chein, 2003). Such guided scaffolding would in turn improve the scientific reading and writing skills of students. The argumentation instruction used in the current study may also have improved skills needed for the PISA science assessment through these processes.

The results found that online argumentation activities could provide opportunities for students to achieve conceptual development, a finding which was in line with the studies by Bell and Linn (2000) and Zohar and Nemet (2002). Bell and Linn (2000) and Zohar and Nemet (2002) conducted relevant concept teaching in these experiments. The current study merely conducted argumentation activities, which also had an impact on the students' concepts in terms of 'identifying scientific issues'. The improvement in argumentation skills of the experimental group students through the online argumentation may also have helped them to learn the scientific concepts through cognitive conflict situations. In addition, the experimental group students were able to interact with their peers online when identifying scientific issues, and in the process of doing so may have obtained more arguments and evidence to adjust their original concepts. These advantages may have helped them to outperform their counterparts in terms of mean scientific competencies.

In the post-test, the mean overall scientific competency score of the experimental group was higher than that of the control group, as was the case for the individual competencies of 'using scientific evidence' and 'identifying scientific issues'. However, the experimental group students did not outperform their counterparts in terms of competency in 'explaining phenomena scientifically'. The nature of argumentation tends to produce scientific evidence to support conclusions. The argumentation instruction in the current study fostered students' skills regarding the use of data to support various claims, such as using the data about that someone is a man and thus reasoning that he has hands. The process of argumentation instruction appeared to improve the abilities of students to raise scientific evidence, such as answering items S114Q3 and S485Q3 based on data given in a diagram or data provided in a table. This improvement might be the reason why the experimental group students could outperform their counterparts in the competency of 'using scientific evidence'. The argumentation topics in the current study were based upon identifying scientific issues, and the argumentation process appeared to improve the students' abilities to identify scientific topics, such as understanding control variables and experimental designs. For example, students had to justify an experimental design used to test the effectiveness of medicine in argumentation with their classmates during the argumentation activities. This trained skill could later be applied in answering item S485Q5 in the PISA assessment. This might be the reason, then, why the experimental group students could outperform their counterparts in the competency of 'identifying scientific issues'. Nevertheless, more items of the 'explaining phenomena scientifically' competency in the PISA assessment (e.g. S485Q02 and S529Q03 in Table 1) require more specific knowledge of science than do those of the other two competencies. The instruction in the current study did not involve the teaching of specific scientific knowledge, and the lack of such knowledge may have affected students' application of the competency of 'explaining phenomena scientifically'. These selected items may not reflect the skills trained in the current experimental design. It may thus, in turn, be the reason why the experimental group students did not outperform their counterparts in that competency.

One limitation in the current study was the unbalanced choice of the testing items, which consisted of three items for 'identifying scientific issues', five items for 'explaining phenomena scientifically', and seven items for 'using scientific evidence'. This imbalance in the number of items for different competencies might be another reason why the experimental group students outperformed their counterparts in certain scientific competencies but not others. If different numbers of items had been selected for the various competencies, the results might have been different. Future research could seek to replicate the results of the current study using different selections of items or other contexts with differing characteristics.

Simultaneously reducing the share of low performers and increasing the share of top performers from previous PISA assessments to the most current ones is a reasonable target for both countries and economies (OECD, 2013). This study reports the development of a form of online argumentation instruction based on the TAP theories to promote students' PISA scientific competencies. The study takes a major step beyond previous online argumentation learning by incorporating PISA scientific competencies into the online argumentation learning program. In addition, online argumentation scaffolds were developed to provide students with assistance in building effective arguments to foster their scientific competencies. Moreover, this study also included the ideas of computer-mediated communication, which provided students with opportunities to debate with their classmates and develop their abilities with regard to life contexts.

Conclusions

This study proposed online argumentation, which comprised argumentation instruction and activities, as teaching contexts and found a possible improvement in the PISA scientific competencies of experimental group students. The argumentation process may help to train students to practice deductive/inductive reasoning and to justify the relationships between evidence and claims. The trained ability acquired through such a process is not constrained to application to any particular subject, enabling students to apply prior knowledge in any life context. Therefore, argumentation instruction can be seen as a means for improving PISA scientific competencies which focus on preparedness for life in modern society (OECD, 2013).

Use of the Internet as an argumentation tool may improve the PISA scientific competencies of students. A website interface can be specially designed with appropriate scaffolds to efficiently guide students in constructing arguments (Yeh & She, 2010). The aid of scaffolding allows students to easily write out individual arguments and evaluate others (Tsai et al., 2012). Well-designed argumentation scaffolds provided through the Internet may help students to develop their reasoning skills and scientific writing performances. Through this process, the scaffolds may in turn help to improve students' PISA scientific competencies.

Embedding related topics into argumentation instruction is likely to help students to improve their PISA scientific competencies. The questioning strategies of teachers at appropriate times can help students give more enriching answers (McNeill & Pimentel, 2010), and clear instruction guides students to draw conclusions and make interpretations (Lavonen & Laaksonen, 2009). Guided online argumentation allows learners to express their opinions and stimulate their own thinking through external ideas from others. Such social construction allows learners to share their knowledge, go through the process of obtaining knowledge from others, and groom their individual competencies. As science education is designed to meet the objectives of future civic life contexts (Fensham, 2009), teaching contents in the classroom need to be adjusted as well, and topic discussions should be based on diversified life contexts to empower individuals to participate in determining public policy where issues of science and technology affect their lives (OECD, 2013). This may help students to improve their scientific competencies under simulated life contexts in the classroom.

In summary, argumentation instruction comprising a specific process, online scaffolding assistance, and argumentation conflict scenarios may help to improve students' PISA scientific competencies. Therefore, using an online environment to complement argumentation instruction and organizing argumentation activities focused on related topics may be a potential direction to consider for improving students' PISA scientific competencies in the future.

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