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This study investigated the effects of students' prior science knowledge and online learning approaches (social and individual) on their learning with regard to three topics: science concepts, inquiry, and argumentation. Two science teachers and 118 students from 4 eighth-grade science classes were invited to participate in this research. Students in each class were divided into three groups according to their level of prior science knowledge; they then took either our social- or individual-based online science learning program. The results show that students in the social online argumentation group performed better in argumentation and online argumentation learning. Qualitative analysis indicated that the students' social interactions benefited the co-construction of sound arguments and the accurate understanding of science concepts. In constructing arguments, students in the individual online argumentation group were limited to knowledge recall and self-reflection. High prior-knowledge students significantly outperformed low prior-knowledge students in all three aspects of science learning. However, the difference in inquiry and argumentation performance between low and high prior-knowledge students decreased with the progression of online learning topics.

Keywords: *Social and individual online argumentation; Inquiry; Prior-knowledge*

Introduction

Science inquiry and argumentation, two essential abilities for achieving science literacy, have become important issues in recent educational research. Research

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has predominantly focused on collective argumentation discourses among groups of students. Previous studies pointed out that argument has both an individual and a social meaning (Billig, 1987; Jiménez-Aleixandre and Erduran, 2008; Kuhn, 1993). The individual meaning refers to an internal discourse; as an author articulates a point of view in his/her book, we can say the author is developing arguments (Billig, 1987). Jiménez-Aleixandre and Erduran (2008) clarified the meaning of social argumentation: 'Social meaning is that of a dispute or debate between people opposing each other with contrasting sides to an issue' (p. 12). These indications imply that there are two forms of argumentation. In other words, an argument can be either an inner chain of reasoning in one's mind, or differences in viewpoints between people. Both studies have raised but not examined the potential role of individual argumentation in cognitive development. This study attempts to examine the effects of social- and individual-based online learning approaches on the knowledge construction, science inquiry, and argumentation abilities of students.

Academic achievement and prior knowledge are important factors for predicting knowledge construction and comprehension (Cook, Carter, & Wiebe, 2008; Feltham & Downs; 2002). High-achieving students gain higher scores on various thinking skills than their low-achieving peers (Zohar & Dori, 2003). Low-achieving students usually focus more on the surface features of learning materials: 'They did not have the background knowledge to make the connections between the salient features they viewed and underlying content principles' (Cook *et al.* 2008, p. 257). Nevertheless, low-achieving students can perform as well as high-achieving students regardless of the levels of their problem-solving assessment skills when appropriate instruction is provided (Ben-David & Zohar, 2009; Cuevas, Lee, Hart, & Deaktor, 2005; Grimberg & Hand, 2009; Yerrick, 2000). It is interesting to know whether students with different levels of prior knowledge will benefit differently from social- and individual-based online learning approaches. The purpose of our study was to investigate the effects of students' prior science knowledge and online learning approaches (social and individual based) on their science learning, including science concepts, inquiry, and argumentation. Specifically, the following three questions are posed:

(1) What is the effect of different levels of prior science knowledge (high, median, and low) and different online learning approaches (social and individual) on science concept learning, inquiry, and argumentation?
(2) What is the effect of different levels of prior science knowledge and different online learning approaches on the inquiry ability of students in the online science learning environment?
(3) What is the effect of different levels of prior science knowledge and different online learning approaches on the argumentation ability of students in the online science learning environment?

Literature Review

Scientific Inquiry on the Internet

In the last decade, many advances have been made in the area of online learning. Internet-based learning has been adapted to improve students' personal understanding of complex science concepts (Kwon & Cifuentes, 2009; Trundle & Bell, 2010; Rutten, Joolingen, & Veen, 2012) and even integrated with community-centered design to improve students' learning process synchronously or asynchronously (Clark, Stegmann, Weinberger, Menekse, & Erkens, 2008; Huang, 2012; Yeh & She, 2010). Internet-based science learning benefits students' science learning, understanding, and construction of science concepts (Kwon & Cifuentes, 2009; Rutten et al., 2012; She & Liao, 2010; Trundle & Bell, 2010), and improves their science inquiry ability (Beal, Arroyo, Cohen, & Woolf, 2010; Maloy, Edwards, & Anderson, 2010).

However, in the Internet-based scientific inquiry environment, students tend to simplify inquiry tasks and seek 'correct' answers rather than deeply investigate (Wallace, Kupperman, Krajcik, & Soloway, 2000). This negative learning outcome can be avoided through the effective design of online learning programs. First, learning programs must advocate an inquiry cycle with several components: (1) defining research questions, (2) formulating research hypotheses, (3) experimenting, (4) observing outcomes and collecting data, (5) analyzing data, (6) summarizing and communicating, and (7) revising questions or hypotheses and beginning the cycle again (Ben-David & Zohar, 2009; Collins & Stevens, 1993; Tabak, Smith, Sandoval, & Reiser, 1996). Second, learning programs must promote scientific reasoning in the process of scientific inquiry (Lawson, 2010). The core scientific reasoning activities are (1) raising causal questions, (2) knowing which variables to select and which to omit, (3) generating hypotheses, and (4) proposing causal explanations. These four activities were considered in the design of an online science inquiry learning activity in the present study. We expected students to investigate given learning topics thoroughly following a series of inquiry steps, and not simply to seek for 'correct' answers.

Scientific Argumentation on the Internet

An Internet-based science learning environment allows students to practice their argumentation abilities/skills through scaffolding (Noroozi, Weinberger, Biemans, Mulder, & Chizari, 2012; Weinberger, Stegmann & Fischer, 2010; Yeh & She, 2010). Various scaffolding approaches (e.g. shared workspaces, game-based learning, awareness features, knowledge representations, and collaboration scripts) have been applied in the Internet-based science learning environment to improve students' argumentation abilities. However, these scaffolding approaches are complicated for students to generate quality arguments (Jonassen & Kim, 2010). The complex and not linear nature of argumentation (Noroozi et al., 2012, p. 82) increases the unwillingness of students to make arguments (Coffin & O'Halloran, 2009; Jiménez-Aleixandre, Rodríguez, & Duschl, 2000) and leads them to repeat points already constructed by others (Koschmann, 2003; Nussbaum, 2002). Students present naive arguments because of inexperience in the formulation of arguments and lack of knowledge concerning the learning topic (Kortland, 1996). To achieve deeper understanding and promote the construction of quality arguments in the online learning environment, Noroozi et al. (2012) designed an argumentation-based computer-supported collaborative learning program. They observed significant improvement in students and suggested that learning programs should be designed systematically and in consideration of diverse specific learning conditions. Chen and She (2012) introduced Toulmin's argumentation pattern (Toulmin, 1958) and provided an instructional framework for students to construct different kinds of quality arguments (i.e. data, claim, warrant, backing, and rebuttal). Their instructional framework proved helpful to students in scientific argumentation.

Researches in science education usually investigate the effects of peers' collaboration on their learning of argumentation (Asterhan & Schwarz, 2007; Chin & Osborne, 2010; Duschl, 2007; Duschl & Osborne, 2002; Evagorou & Osborne, 2013; Ryu & Sandoval, 2008; Sampson & Clark, 2009). In those studies, two approaches, namely monological and dialogical argumentation, were usually applied and compared (Asterhan & Schwarz, 2007; Ryu & Sandoval, 2008; Sampson & Clark, 2009). Monological argumentation concerns how a single person constructs an argument (Goldman, 1999). The characteristics of monological argumentation can be described as individual, deductive, and involving implicit dialogues (van Eemeren & Grootendorst, 1984). For example, Charles Darwin described his book *On the Origin of Species* as consisting of one long argument (see Jiménex-Aleixandre & Erduran, 2008, p. 3). He presented his claim and scientific discovery through converging lines of reasoning, theoretical idea, and empirical evidence. Piaget's theory (1954) of constructivism argues that people produce knowledge and form meaning based upon their individual experiences. Piaget's theory supports the explanation of how monological argumentation takes place in one's mind. The present study identified this kind of argumentation as consisting of an individual approach to argumentation. On the other hand, dialogical argumentation is another kind of argumentation in which two (or more) arguers elicit arguments for a point of view (van Eemeren, Grootendorst & Kruiger, 1987). Dialogical argumentation emphasizes the participants' co-construction of a knowledge claim through collaborative mediation of language (Asterhan & Schwarz, 2007; Duschl & Osborne, 2002). Some scholars used the term 'dialectical argumentation' to emphasize the knowledge interaction and co-evaluation in argumentation process (van Eemeren et al., 1987; Nielsen, 2013). Based on previous literature, there is little difference between 'dialogical' argumentation and 'dialectical' argumentation. Goldman (1999) indicated that 'dialogical argumentation is a stretch of argumentation in which two or more speakers discourse with one another' (p. 131). Clark and Sampson (2007) noted that 'dialogic argumentation stresses collaboration over competition' (p. 296). On the other hand, the term 'dialectical argumentation' refers to a form of public arguing in which two (or more) arguers elicit arguments for and against a point of view. Nielsen (2013) defined that 'the dialectical features of students' dialogic argumentation refer to the features that are operative when students collaboratively manage (potential) disagreement by providing arguments and engaging critically with the arguments provided by others' (p. 372). Participants in dialectical argumentation are expected to expose each other to a multiplicity of ideas and importantly, are encouraged to critique the validity of each other's ideas (Asterhan & Schwarz, 2007). Thus, the goal of dialectic argumentation is to focus more on the process of merging a point and counterpoint for a thesis. The goal of dialogical argumentation emphasizes the process of participants' language interactions.

Upon studying students' dialectical argumentation, Nielsen (2013) stated that there are two kinds of products that can be distinguished: the argument sequences and the argument cores. Argument sequences consist of an ordered series of speech acts and talk turns that were exchanged among the discussants. Argument cores typically involve at least a conclusion, claim, and premises. The argument cores can be extrapolated from the argumentation sequence (Nielsen, 2013). Fulkerson (1996) suggested that taking both argument sequences and argument cores into consideration can reveal the static and dynamic layout of the dialectical argumentation. Driver, Newton, and Osborne (2000) further specified two levels of dialectical argumentation in the science development process. The first level of dialectical argumentation takes place between individuals (e.g. persuasion in research groups), and the other level takes place between two or more social communities at large. The emphasis of dialogical argumentation in science teaching and learning is due to the theory of social constructivism, which states that 'little or no attention is given to how features of the social environment might influence the mental functioning of individuals' (Leach & Scotta, 2003, p. 93). The communication and negotiation that occur in a social environment can aid the construction of more detailed disciplinary knowledge, changing world views, and the development of more appropriate ways of reasoning (Orsolini & Pontecorvo, 1992; Pontecorvo & Girardet, 1993; Pontecorvo & Pirchio, 2000).

Online Inquiry and Argumentation

Various studies have developed online learning environments to enhance students' science argumentation and inquiry abilities (Demirbag & Gunel, 2014; Llewellyn, 2002; Sampson, Grooms & Walker, 2011; Walker, Sampson, Grooms, Anderson, & Zimmerman, 2012). Online inquiry and online argumentation facilitate the active learning process beyond what can be achieved in traditional learning environments. Online learning provides excellent opportunities for students to propose, support, evaluate, critique, and refine ideas productively (Hand, Norton-Meier, Staker, & Bintz, 2009; Wenning, 2005; White & Frederiksen, 1998). In the development of an appropriate online learning program, Clark and Sampson (2007) suggested it is needed for both the instructor and learning program to support students in understanding the scientific practices of argumentation as part of learning about scientific inquiry. For this purpose, they created a learning program that allows students to build principles and to describe the data they collect during inquiry activity. These principles become seed comments for further discussion. The learning program developed by Clark and Sampson benefitted from sorting students into different groups according to their seed comments. Thus, students can represent multiple perspectives and evaluate each other's arguments through interactions between groups.

To identify the relationship between scientific argumentation and inquiry and to provide guidance for the development of online science learning program, Sampson, Grooms and Walker (2011) constructed an argument-driven inquiry instructional model. Their model was developed based on two types of principles: authentic (i.e. engages students in scientific practices such as argumentation) and educative (i.e. leads to better understanding and improved abilities). Four stages are identified in their instruction to guide students to inquire and argue: identifying the task, investigating related data, producing a tentative argument, and evaluating claims or arguments. In Demirbag and Gunel's (2014) studies, they developed an instructional approach called argument-based science inquiry, and investigated its effect on students' science concept learning, argumentation, and writing skills. Students who participated in the study were asked to participate in the following learning stages: identifying research questions, designing an observation procedure, collecting related data and evidence, forming a claim in relation to the research question, reflecting the investigation procedure. The learning stages identified in the earlier-mentioned studies explain how inquiry and argumentation are connected. These studies provided us with ideas to develop our online learning environment.

A well-designed online argumentation and inquiry activity has also been found to benefit students' science learning regardless of their socioeconomic status (SES) and prior knowledge (Gunel, Kabataş-Memiş, & Buyukkasap, 2010; Hand & Choi, 2010; Hasancebi-Yesildag & Gunel, 2013). A template, script, or other form of guidance can be integrated into an online learning environment to facilitate their science learning. For example, Weinberger et al. (2010) investigated the effects of online scripted conditions (where students were scaffolded to argue scientifically) on students' science argumentation. They indicated that computer-supported scripts can specify, sequence, and assign roles to learners that support both students' collaboration and argumentation. Yeh and She (2010) developed an online scientific argumentation program with a scaffolding structure to improve the argumentation performance of students. The scaffolding learning program was proved to be appropriate for students to understand the target-scientific concept and to generate quality arguments. An online learning environment with scaffolding to facilitate inquiry and argumentation can provide opportunities for students to practice critical thinking, scientific reasoning, argumentation, writing, and other higher order cognitive skills.

Improvement in High- and Low-achieving Students.

Scholars hold different views on the science learning of students with high and low prior science knowledge. Grimberg and Hand (2009) used three types of inquiry activities (i.e. decision-making, description/speculation, and application) to analyze the reasoning pathways of high and low achievers (HAs and LAs). They concluded that although the reasoning pathways of both HAs and LAs display the same range of cognitive operations, HAs can move into higher order cognitive operations sooner than LAs can.

Studies have repeatedly highlighted the importance of prior knowledge in science learning, leading science teachers to believe that high-order thinking courses should be offered mainly to students with high prior knowledge (Warburton & Torff, 2005; Zohar, Vaaknin, & Degani, 2001). To challenge this belief, Zohar and Dori (2003) compared the learning outcomes of HA and LA. They found that HAs scored higher on various measures of thinking compared with LAs, but LAs exhibited a significantly higher net gain in one of the four teaching programs. This finding constitutes a powerful attack on conventional beliefs regarding LAs. Moreover, Yerrick (2000) investigated argumentation learning in students and found obvious improvement mainly in LAs. Cuevas et al. (2005) developed an inquiry-based instructional intervention, which can enhance the inquiry ability of students regardless of grade, achievement, gender, ethnicity, SES, home language, and other factors. With the intervention, low-achieving, low-SES, and non-English-speaking students can make impressive gains. Adesoji (2008) introduced a problem-solving strategy for three academic ability levels in chemistry and found no significant differences in problem-solving performance. Yu, She, and Lee (2010) further indicated that 'students' problem-solving ability was not affected by their initial level of academic achievement in biology' (p. 196). Although LAs do not have adequate domain knowledge, they still have the potential to perform at par with HAs (with high prior knowledge). In this study, we hope to know whether students with different levels of prior science knowledge perform differently in social and individual online argumentation.

Method

Participants and Procedures

Online Synchronous Scientific Inquiry and Argumentation Learning (OSSIAL) was offered to 118 students from 4 eighth-grade classes. Two classes ($N = 60$) were selected randomly for social online argumentation; the other two classes ($N = 58$) were selected for individual online argumentation. Social argumentation groups were made heterogeneous with four to five members.

To examine the effect of prior science knowledge, all students were divided into three groups (high, median, and low prior knowledge) according to their science academic assessment in the immediately preceding semester. Before participating in the online learning program, all students were introduced to the four components of argumentation (claim, warrant, backing, and rebuttal) and their relationships (Toulmin, 1958). The one-hour introduction enabled students to know what counted as high- or low-quality arguments. All students took the Scientific Concept Test (SCT), Scientific Inquiry Test (SIT), and Scientific Argumentation Test (SAT) before and after instruction on each topic in the online learning program. Independent sample t-test showed no significant differences between the social and individual argumentation groups in three pretests (SCT, $p = .421$; SIT, $p = .493$; SAT, $p = .782$).

Development of the OSSIAL Environment

The OSSIAL environment was developed based on the two types of principles: authentic and educative (Clark & Sampson, 2007; Demirbag & Gunel, 2014; Sampson, Grooms & Walker, 2011). Three aspects of science learning, namely science concepts, inquiry, and argumentation, are integrated in each topic. Six topics for the OSSIAL environment were selected from the current mandatory science contents and standards for junior high school. Those topics were: (1) the classification of substances, (2) fire prevention, (3) thermal convection, (4) chemical reaction rates, (5) sound waves, and (6) mass conservation. All students joined the OSSIAL during their science class time. They needed two hours to complete one topic of science learning online, and a total of 12 study hours were completed over two months. Each topic is organized around a scientific inquiry scenario. The first part of the OSSIAL includes information related to the topic, such as a brief introduction to target science concepts, graphics, and figures, to engage students in problem scenarios. The second part of the OSSIAL provides students with a series of well-designed multimedia learning activities. For example, a short film on the topic of 'fire prevention' demonstrates to students via an experiment how to put out fires with different kinds of fire extinguishers. The possible result of the experiment was also shown in this film (Figure 1).

Three types of open-ended questions reflecting the three aspects of science learning appeared in the OSSIAL after the multimedia activities (Figure 2). The first type of question focused on science knowledge. Students had to understand science concepts related to the topic and then provide responses. The second type of question aimed to evaluate each student's science inquiry abilities. The following four categories of inquiry ability were included in the OSSIAL: (1) identify scientific questions, (2) formulate hypotheses, (3) identify variables, and (4) make explanations. The third type of questions focused on argumentation ability. For example, in the topic 'classification of substances', students were asked to determine unknown substances through

Figure 1. Short introductory video in the OSSIAL

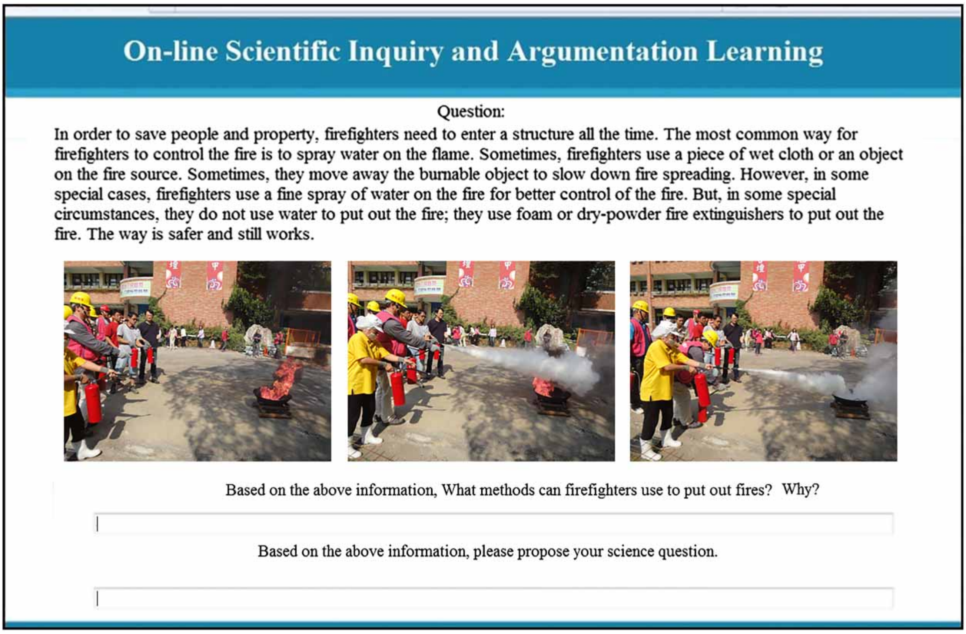

Figure 2. Scenario and questions in the OSSIAL

argumentation. Students could use the data and information in the OSSIAL or information from the Internet to make assertions and generate arguments (including claims, warrants, backings, and rebuttals) for defending their assertion against critiques.

The OSSIAL environment includes tools specifically designed for students to use while participating in argumentation. The right panel of the OSSIAL interface is for entering four different arguments, and the left panel is for showing all arguments generated by a group or by individuals across time. Figure 3 shows a sample online argumentation design under the topic 'fire prevention'. To help students generate arguments, two layers of templates are provided in the OSSIAL interface. The first layer provides definitions and choices relative to five argumentation components (data, claim, warrant, backing, and rebuttal), whereas the second layer provides three to four scripts/templates for each argumentation component. These scripts/templates were provided as scaffolding to facilitate students' argumentation. Different OSSIAL versions were developed for social and individual argumentation. In the social argumentation version, students in groups could share opinions, make arguments, and discuss ideas in the discussion block. Meanwhile, in the individual argumentation version, individual students could only write down or review their arguments and reflections in their own blocks.

Instruments

Scientific Concept Test. SCT is a two-tier multiple-choice diagnostic instrument developed to measure the degree of students' conceptual understanding in science

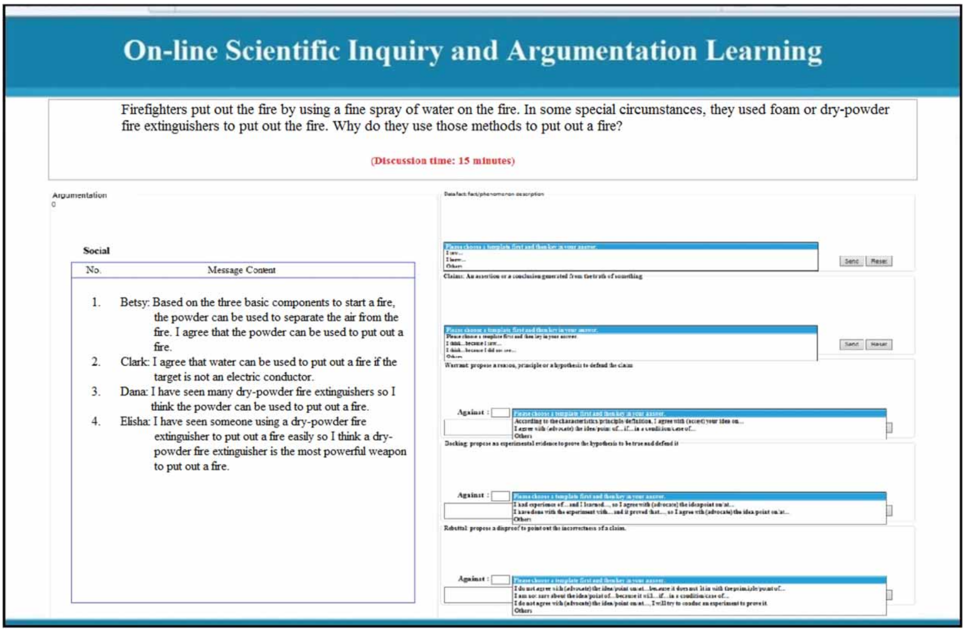

Figure 3. Discussion block for argumentation in the OSSIAL

(Cronbach's $\alpha = 0.81$; Appendix 1). Content validity was established with a panel of three evaluators (one professor and two science teachers), ensuring that the items were properly constructed and relevant to the six OSSIAL topics. Each topic includes five items/questions, with each question having two tiers. Students must answer both tiers for each question correctly to receive one point; so the highest possible score is 30.

Scientific Inquiry Test. SIT is a multiple-choice diagnostic instrument, which includes six scenarios related to the six OSSIAL topics (Cronbach's $\alpha = 0.91$; Appendix 2). Each scenario includes a contextual background for answering nine questions. Eight questions are distributed equally for measuring the four components of inquiry ability. Students must answer one question correctly to receive one point, and the highest possible score is 54.

Scientific Argumentation Test. The scenario-based SAT measures the degree of students' scientific argumentation ability (Cronbach's $\alpha = 0.93$; Appendix 3). Each scenario includes four open-ended questions for evaluating the four components of argumentation ability. One question, for example, asks students to generate arguments for predicting and explaining an unknown substance; possible answers for defining the substance are 'metal', 'metalloid', and 'nonmetal'. Each argument (i.e. claim) generated by a student is classified into two different quality levels (cross-coder reliability = 0.85). Level 1 and Level 2 arguments are given 1 and 2 points, respectively. The rating criterion is the same as that used in qualitative analysis for online scientific argumentation.

Data Analysis

Quantitative analysis of SCT, SIT, and SAT. Two-way ANCOVA was used to analyze the effect of two factors (level of prior science knowledge and online learning approaches) on the SCT, SIT, and SAT performance of students.

Qualitative analysis of online science inquiry learning. Online science inquiry learning was analyzed using a two-point scale reflecting the correctness of answers (0 point for an incorrect answer, 1 point for a partially correct answer, and 2 points for a correct answer). The corresponding reliability of raters was computed during the online inquiry learning activity process (mean inter-rater reliability = 0.85).

Qualitative analysis of online scientific argumentation learning. Individual online argumentation and statements from both groups (individual and social) were analyzed using a method based on the coding framework developed by Osborne, Erduran, and Simon (2004) and Erduran, Simon, and Osborne (2004). Based on the coding framework, each statement was classified into one of two levels of arguments for each component: claim, warrant, backing, and rebuttal. A claim without any supporting data or facts was treated as a Level 1 claim; a claim with supporting data or facts was treated as a Level 2 claim. A warrant without (with) any supporting theory was treated as a Level 1 (Level 2) warrant. A backing without (with) any connection to claim and warrant was interpreted as a Level 1 (Level 2) backing. A weak or unclear counterclaim was considered a Level 1 rebuttal, whereas a counterclaim with a clearly identifiable explanation was considered a Level 2 rebuttal. Level 1 and 2 arguments were given 1 and 2 points, respectively. Inter-rater reliability was 0.85.

Analysis of students' dialogue argumentation. The dialogue argumentation of students in the online learning environment was also analyzed to determine learning differences between the two learning groups (social and individual) and three prior-knowledge groups.

Results

Scientific Concept Test

Table 1 presents a summary of descriptive measures on SCT. The social online argumentation group obtained higher mean scores than the individual online argumentation group in the pretest (17.05 vs. 16.60) and posttest (19.02 vs. 18.87), whereas the social online argumentation group had smaller standard deviations than the individual online argumentation group in the pretest (5.74 vs. 6.38) and posttest (5.87 vs. 6.86). Students with high, median, and low levels of prior science knowledge obtained mean SCT scores of 11.98, 17.20, and 21.17 in the pretest, respectively. The scores increased to 13.85, 20.47, and 22.41 in the posttest, respectively.

Table 1 further shows the two-way ANCOVA analysis and post-hoc test (Sidak test) results. Online learning approaches showed no significant effect on students' SCT ($F = 0.92$, $p = .756$), whereas the level of prior science knowledge showed a significant effect ($F = 30.26$, $p < .001$). Additionally, high (MD = 5.20, $p < .001$) and median

Table 1. Two-way ANCOVA analysis in the SCT

Source	Mean		SD		df	F	Post-hoc test
	Pretest	Posttest	Pretest	Posttest			
Approach					1	0.092	
Social group	17.05	19.02	5.74	5.87			
Individual group	16.60	18.87	6.38	6.86			
Level of prior science knowledge					2	30.26***	(M) > (L)***
Low-level group	11.98	13.85	5.71	6.82			(H) > (L)***
Median-level group	17.20	20.47	4.82	2.90			
High-level group	21.17	22.41	3.55	5.24			
Approach × Level					2	0.99	

Note: (L), low prior-knowledge group; (M), median prior-knowledge group; and (H), high prior-knowledge group.

***$p < .001$.

(MD = 6.05, $p < .001$) prior-knowledge students significantly scored better in the test than low prior-knowledge students.

Scientific Inquiry Test

Table 2 presents a summary of descriptive statistics on SIT results. The social online argumentation group scored higher than the individual online argumentation group in both pretest (28.81 vs. 28.24) and posttest (36.93 vs. 34.90). Low, median, and high prior-knowledge students obtained mean pretest scores of 20.30, 28.62, and 36.44, respectively. In the posttest, these mean SIT scores were increased to 29.25, 37.87, and 40.44, respectively.

Table 2 further presents the ANCOVA analysis and post-hoc test (Sidak test) results. Online learning approaches showed no significant effect on students' SIT ($F = 0.62$, $p = 0.43$), whereas prior science knowledge showed a significant effect ($F = 11.19$, $p < .001$). In addition, high (MD = 7.43, $p < .05$) and median (MD = 6.59, $p < .05$) prior-knowledge students significantly scored higher than low prior-knowledge students.

Scientific Argumentation Test

Table 3 shows a summary of descriptive statistics on SAT results. The social online argumentation group scored higher than the individual online argumentation group in both pretest (20.22 vs. 18.42) and posttest (36.63 vs. 29.92). High, median, and low prior-knowledge students obtained mean SAT scores of 8.20, 18.75, and 30.66

Table 2. Two-way ANCOVA analysis in the SIT

	Mean		SD				
Source	Pretest	Posttest	Pretest	Posttest	df	F	Post-hoc test
Approach					1	0.62	
Social group	28.81	36.93	11.23	10.34			
Individual group	28.24	34.9	12.41	12.48			
Level of prior science knowledge					2	11.19***	(M) > (L)*
Low-level group	20.30	29.25	10.28	13.81			(H) > (L)*
Median-level group	28.62	37.87	10.10	7.65			
High-level group	36.44	40.44	9.16	9.14			
Approach × Level					2	1.27	

Note: (L), low prior-knowledge group; (M), median prior-knowledge group; and (H), high prior-knowledge group.

*$p < .05$.

***$p < .001$.

Table 3. Two-way ANCOVA analysis in the SAT

	Mean		SD				
Source	Pretest	Posttest	Pretest	Posttest	df	F	Post-hoc test
Approach					1	6.98**	(S) > (I)**
Social group	20.22	36.63	14.44	17.93			
Individual group	18.42	29.92	16.00	18.97			
Level of prior science knowledge					2	5.62**	(M) > (L)*
Low-level group	8.20	20.05	7.19	12.07			(H) > (L)**
Median-level group	18.75	31.73	11.27	12.21			
High-level group	30.66	47.44	16.30	19.47			
Approach × Level					2	0.079	

Note: (S), social group; (I), individual group; (L), low prior-knowledge group; (M), median prior-knowledge group; and (H), high prior-knowledge group.

*$p < .05$.

**$p < .01$.

in the pretest, respectively. In the posttest, these mean scores were increased to 20.05, 31.73, and 47.44, respectively.

Table 3 further presents the two-way ANCOVA analysis and Sidak test results. Both online learning approaches ($F = 6.98$, $p < .01$) and prior science knowledge ($F = 5.62$, $p < .01$) showed significant effects on SAT performance. In addition, students in the social online argumentation group performed better than students in the individual approach group. High prior-knowledge students significantly scored better than median (MD = 7.60, $p < .05$) and low (MD = 10.39, $p < .01$) prior-knowledge students. In all SCT, SIT, and SAT results, the interaction between learning approach and prior-knowledge was found insignificant ($p > .05$).

Online Science Inquiry Learning

Figure 4 presents a clustered bar chart generated from descriptive statistics and t-test data for comparing the online scientific inquiry performance of students with high, low, and median levels of prior science knowledge. High prior-knowledge students performed significantly better than low prior-knowledge students in Topic 1 (MD = 1.19, $p < .01$), Topic 2 (MD = 1.20, $p < .01$), Topic 3 (MD = 1.68, $p < .01$), and Topic 6 (MD = 1.80, $p < .01$).

Two-way repeated measure ANOVA was employed to analyze the effect of prior science knowledge and online learning approaches on the online science inquiry learning performance of students (Table 4). Online learning approaches showed no significant effect on online science inquiry performance ($F = 0.02$, $p > .05$), whereas prior science knowledge showed a significant effect ($F = 29.939$, $p < .001$). The progression of online science inquiry learning was found significant from the earlier to the later topics for within-subject effects ($F = 20.5$, $p < .001$).

Online Scientific Argumentation Learning

Figure 5 presents a clustered bar chart generated from descriptive statistics and t-test data for comparing the online argumentation performance of students with high, low, and median levels of prior science knowledge. High prior-knowledge students

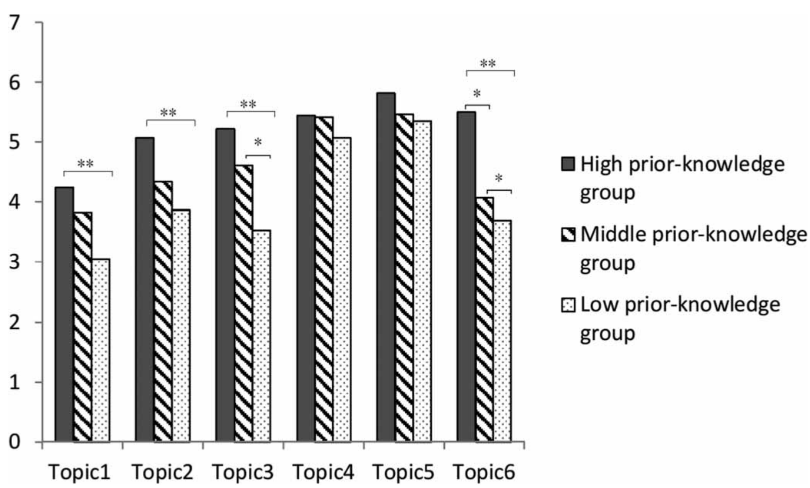

Figure 4. Distribution of online science inquiry learning mean scores across six topics in low, middle, and high prior-knowledge groups

Table 4. Two-way repeated measure ANOVA analysis across six topics in online science inquiry learning

Source	SS	df	MS	*F*	Post-hoc test		
Approach	0.014	1	0.014	0.002			
Level of prior science knowledge	373.9	2	186.9	29.39***	(M) > (L)*** (H) > (L)***		
Approach × Level	0.414	2	0.207	0.010			
Topic	253.5	5	50.7	20.5***	2 > 1***	4 > 2**	5 > 2***
					3 > 1**	4 > 3**	5 > 3***
					4 > 1***	5 > 1***	5 > 6***
							6 > 1**

Note: (L), low; (M), median; and (H), high prior-knowledge groups.

**$p < .01$.

***$p < .001$.

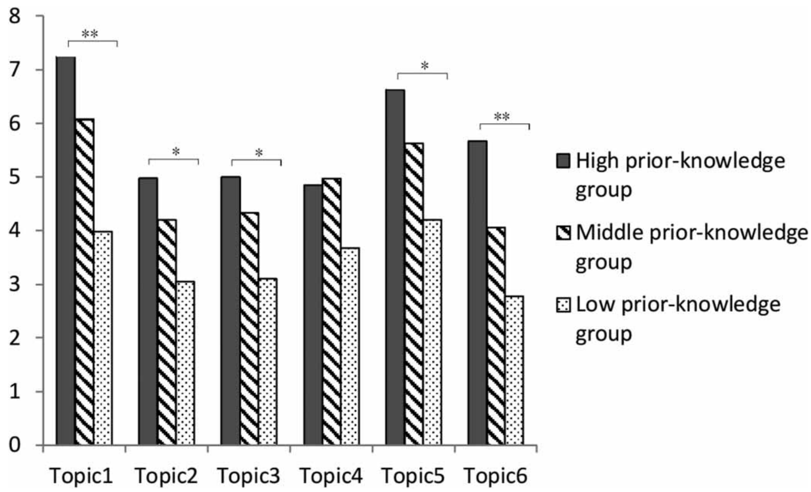

Figure 5. Distribution of online scientific argumentation learning mean scores across six topics in low, middle, and high prior-knowledge groups

performed better than low prior-knowledge students in Topic 1 (MD = 3.31, $p < .01$), Topic 2 (MD = 1.97, $p < .05$), Topic 3 (MD = 1.83, $p < .05$), Topic 5 (MD = 2.49, $p < .05$), and Topic 6 (MD = 3.02, $p < .01$).

Figure 6 presents descriptive statistics and *t*-test results for comparing the online argumentation performance of students in the social and individual argumentation groups. Students in the social online argumentation group scored significantly higher than those in the individual online argumentation group in four of six topics:

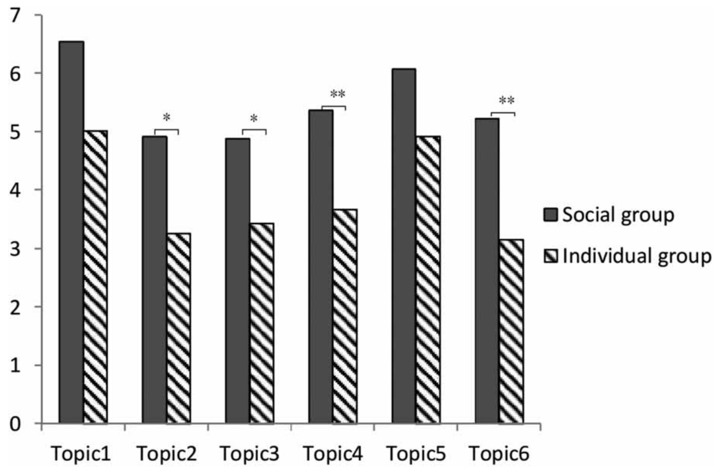

Figure 6. Distribution of online scientific argumentation learning mean scores across six topics in social and individual approach groups

Topic 2 ($F = 6.18$, $p < .05$), Topic 3 ($F = 5.34$, $p < .05$), Topic 4 ($F = 8.31$, $p < .01$), and Topic 6 ($F = 8.62$, $p < .01$).

Two-way repeated measure ANOVA results indicate that there were statistically significant effects for both online learning approaches ($F = 14.48$, $p < .001$) and for prior knowledge ($F = 10.54$, $p < .001$) on students' online argumentation performance (Table 5). Based on post-hoc results, students in the social online argumentation group performed significantly better than those in the individual argumentation group. Moreover, high prior-knowledge students outperformed their low prior-knowledge peers. Students made significant progress in online argumentation from the earlier to the later topics for within-subject effects ($F = 5.59$, $p < .001$).

Table 5. Two-way repeated measure ANOVA analysis across six topics in online scientific argumentation learning

Source	SS	df	MS	*F*	Post-hoc test
Approach	422.11	1	422.11	14.48^{***}	$(S) > (I)^{***}$
Level of prior science knowledge	614.59	2	307.29	10.54^{***}	$(H) > (L)^{***}$
Approach × Level	30.493	2	15.247	0.523	
Topic	326.2	5	71.61	5.59	$1 > 2^{**}$ $1 > 3^{*}$ $1 > 6^{*}$

Note: (S), social group; (I), individual group; (L), low prior-knowledge group; (M), median prior-knowledge group; and (H), high prior-knowledge group.

$^{*}p < .05$.

$^{**}p < .01$.

$^{***}p < .001$.

Dialogue Argumentation in Social and Individual Online Argumentation Groups

To further investigate the differences in argumentation performance, we analyzed the dialogue argumentation of students in the social and individual online argumentation groups. We focused on the groups and individual students whose performance scores were near the mean.

Question for argumentation in Topic 6:

Acid liquid reacts with marble and it produces gas. Does mass change after the chemical reaction?

Sample argumentation discourses from the social online argumentation group:

(1) Herman: I think the total mass will be the same if there is no gas produced in this reaction. (Level 1 claim)
(2) Cliff: I think the total mass will change because I saw this experiment before. (Level 1 claim)
(3) Herman: I saw the liquid became turbid (giving a precipitate) after the chemical reaction, so I think the total mass will be the same. (Level 2 backing)
(4) Cliff: I'm not sure Herman's idea is right. If the condition of the chemical reaction changes, the total mass will change. (Level 1 rebuttal)
(5) Cliff: I have conducted this experiment before, and I think a chemical reaction changes matter. (Level 1 backing)
(6) Ann: I saw the experiment that hydrochloric acid reacts with calcium chloride, and it produces carbon dioxide gas. I think the total mass changes in this chemical reaction because the CO_2 is lost in the air. (Level 2 backing)
(7) Cliff: The mass will change even if no gas was produced. (Level 1 warrant)
(8) Ann: I saw this experiment produces bubbles, the mass is decreased … (Level 1 backing)
(9) Dolly: I have conducted this experiment before. When hydrochloric acid reacts with marble, it will produce carbon dioxide gas and it proves the total mass will change in an open system. (Level 2 backing)
(10) Dolly: If the experiment was conducted in a closed system, the total mass of those materials would not change. (Level 2 rebuttal)
(11) Herman: I think the total mass will never change. (Level 1 warrant)
(12) Cliff: I'm not sure Herman's idea is correct because the mass of the reactant will change. (Level 2 rebuttal)
(13) Herman: I'm not sure Cliff's opinion is right because the total mass of those materials does not change in a closed system. (Level 2 rebuttal)
(14) Dolly: I saw sodium carbonate solution reacts with calcium chloride. It will produce precipitate and then the total mass will be the same. (Level 2 backing)

Students in the social online argumentation group reflected on contrary opinions and thereby showed better understanding of science concepts. As seen in the above example, two opposing opinions were proposed by students. Both Cliff and Ann thought that the total mass would change after the chemical reaction based on their experience of conducting the science experiment (Statements 2 and 6). In contrast, Herman believed that the total mass would not change because the mass of the produced precipitate would be equal to the mass lost by the reactant (Statement 3). Herman's arguments and explanations were unpersuasive and unclear, so he was rebutted by his peer, Cliff, who held an opposing point of view (Statement 4).

Students in the social online argumentation group were able to enhance the quality of their arguments through social interaction and critical thinking activities. For instance, Ann reminded Herman that the reaction of hydrochloric acid (HCl) with calcium chloride ($CaCl_2$) would produce CO_2 and the total mass would change because of CO_2 loss in the air (Statement 6). Although Ann's argument was based on an inaccurate understanding of science concepts, her explanation was quite clear. Dolly integrated Ann's and Herman's viewpoints and explained that the mass of the products would be equal to the mass of reactants in a chemical reaction (Statements 9, 10, and 14). Through the process of critical thinking and the sharing of ideas, students in the social online argumentation group co-constructed quality arguments and explained science concepts accurately.

Monological argumentation samples from the individual online argumentation group:

(1) Bruce: It produces CO_2 when the acid liquid reacts with calcium carbonate, CO_2 will be lost in the air and the total mass will be lower in the open system. (Level 2 claim)
(2) Bruce: But … we have to make sure it is an open system. (Level 1 rebuttal)

Bruce is a student in the low prior-knowledge group. In this example, he first claimed that the mass would be decreased because the experiment was held in an open system (Statement 1). Bruce made a high-level claim by recalling related knowledge on the given chemical reaction to support his assertion. He was also learning to make rebuttals (Statement 2). The self-reflection process in the case of Bruce illustrates how students can improve their argumentation skills. Simply stated, students in the individual online argumentation group could generate high-quality arguments only through knowledge recall and reflection. Students in the social online argumentation group were then at an advantage in terms of learning how to argue. They co-constructed high-quality arguments through both self-reflection and peer interaction. Meanwhile, students in the individual online argumentation group could only reflect on what they had learned to support their arguments; they had limited opportunity to improve their argumentation skills.

Discussion and Conclusion

The qualitative results of this study demonstrate that learning approaches (individual or social) have a significant effect on students' learning of argumentation. Students in the social online argumentation group significantly outperformed their peers in the individual online argumentation group in terms of both SAT and online argumentation. Our findings are consistent with the growing emphasis on social and cooperative argumentation learning and the strong relationship between the argumentation ability and communication/critique skills of students (Clark & Sampson, 2008; De Vries, Lund, & Baker, 2002; Newton, Driver, & Osborne, 1999; Yeh & She, 2010). Compared with individual argumentation, social argumentation resulted in richer discussion in this study. The students constructed quality arguments by elaborating the learning material and reviewing arguments. They made significant progress in online argumentation from the earlier to the later topics.

Our study supports earlier findings that dialogue interaction in collaboration plays a large role in both knowledge evaluation and co-construction (Albe, 2008; Berland & Hammer, 2012). In the analysis of dialogue argumentation, we found that clearer explanation and the accurate understanding of science concepts are required for students to support their arguments and enhance their persuasiveness. In addition, if students reflect a misunderstanding of science concepts in their opinions, they will be criticized easily by other students with different assertions. Social interaction therefore benefits knowledge evaluation and the construction of high-quality arguments. In individual argumentation, students can evaluate their knowledge and construct arguments only through the self-reflection learning process, which is related to prior knowledge (Hmelo, Nagarajan, & Day, 2000). This explains the relationship between the level of student's prior science knowledge and argumentation learning; insufficient prior science knowledge limits the construction of quality arguments. In the present study, high prior-knowledge students significantly outperformed low prior-knowledge students in Topics 1, 2, 3, 5, and 6.

The difference in argumentation performance between these two groups was larger for Topics 2, 4, and 6. The larger difference in performance suggests that the online learning program developed in this study can more greatly benefit students in the social online argumentation group, regardless of their level of prior knowledge. Previous studies have similarly suggested that low-achieving students engaged in collaborative learning can show better improvement than their high-achieving peers in argumentation and other tasks that require higher order thinking skills (Yerrick, 2000; Zohar & Dori, 2003). Quantitative analysis shows that only prior knowledge has a significant effect on inquiry performance. High prior-knowledge students outperformed low prior-knowledge students in Topics 1, 2, 3, and 6. However, the difference in inquiry performance between these two groups was insignificant for Topics 5 and 6, implying that the low prior-knowledge students progressed in their inquiry ability under the online science learning program. Thus, low prior-knowledge students have the potential to perform similar with or better than high prior-knowledge students in scientific inquiry tasks (Adesoji, 2008; Cuevas et al., 2005; Yu et al., 2010).

It is particularly worth mentioning that participation in the OSSIAL program is anonymous, and such anonymous online discussion may reduce peer pressure and enable low and median prior-knowledge students to break out of their normal reticence and speak freely (Chan & Chan, 2008; Russell & Aydeniz, 2013). This reason might explain why low and median prior-knowledge students make progress in argumentation and inquiry learning. However, the influence of peer pressure on student science argumentation is an issue that needs to be further explored (Asterhan & Schwarz, 2009). Future studies should analyze the causes of peer pressure and how peer pressure affects students' performance of argumentation.

Our findings on low prior-knowledge students' performance provide evidence which might encourage science teachers to provide students with online argumentation and inquiry in their science instruction. In addition, this instruction can facilitate all students' learning of science, not just the learning of high prior-knowledge students. Similar suggestions can also be found in previous studies of science teaching on argumentation and inquiry (Adesoji, 2008; Cuevas et al., 2005; Yerrick, 2000; Yu et al., 2010; Zohar & Dori, 2003). The other suggestion we would like to address is that the collaborative learning strategies may enhance students' argumentation and inquiry ability. Argumentation is a form of collaborative and idea-sharing activity in which both parties are working together to elaborate an issue (Andriessen, 2006; Crawford, 2000; Mcneill, 2009). As part of participation in collaborative argumentation, students have more opportunities to co-construct their ideas, and this helps them better understand what science is and how it works (Bell, 2004; Bricker & Bell, 2008). Our qualitative data demonstrate that students in social online environments engage in more communication of ideas, more co-constructions of arguments, and more explanations of knowledge, resulting in better performance compared with individual online learning. This implies that if science teachers create more collaborative learning environments, it could promote students' reflections and the interactions among peers. However, Herrenkohl, Palincsar, DeWater, & Kawasaki (1999) point out that such environments may be very different from traditional ones and require explicit social supports. It is very important if a science teacher can encourage students to share their ideas about an issue, explain their personal reflection processes, and evaluate arguments different from their own in the classroom. In addition, our results show that even low prior-knowledge students can generate at least a claim or a rebuttal in an argumentation activity. This sheds light on the effectiveness of facilitating students' argument formation efforts with the support of template and scripts. We would highly encourage science teachers to provide students with a small handout of these templates and scripts which would help students to learn how to generate high-quality arguments. We believe such supports would benefit students' internal and external dialogue interactions and improve their inquiry and argumentation ability and science learning.

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Appendix 1. Sample questions from the Science Concept Test

( ) 1-1. There are marble chips in a bottle. A balloon is mounted on top of the bottle immediately after pouring 50 ml hydrochloric acid (HCl) into the bottle. Please refer to the picture and describe the reaction.

(A) Nothing will happen to the balloon.
(B) The balloon will be deflated.
(C) The balloon will be inflated.
(D) The balloon will be inflated and deflated alternately.

( ) 1-2. What is your explanation to this phenomenon?

(A) The chemical reaction turns the water into steam.
(B) The chemical reaction changes the balloon's property and inflates the balloon.
(C) The chemical reaction heats up the air and inflates the balloon, and then the balloon is deflated after the air cools down.
(D) The chemical reaction generates gas, increasing pressure in the bottle.

Appendix 2. Sample question from the SIT

Table A.1. Properties of six substances

	Appearance	Fragility	Electrical conductivity	Density (g/cm^3)	Melting point (°C)	Flammability	Hardness
Substance A: Unknown	Dark silver, lustrous	Hard but Fragile	Increases with temperature	2.33	1414	Difficult to burn	6.5
Substance B: Sulfur	Yellow, lackluster	Fragile	N/A	1.96	115.2	Burns after melting	2
Substance C: Iodine	Dark purple, lustrous	Fragile	N/A	4.94	113.7	Sublimation	0
Substance D: Germanium	Grey, lustrous	Hard but fragile	Increases with temperature	5.32	938	No change	6
Substance E: Aluminum	Silver, lustrous	Flat and thin	Decreases with temperature	2.7	660.3	Difficult to burn	2.75
Substance F: Nickel	Silver, lustrous	Flat and thin	Decreases with temperature	8.9	1455	No change	4.0

Based on the table (Table A.1) above, a student grouped these substances into two types. The first type contains substances A, B, C, and D. The other type contains substances D and E. Which question fits the student's grouping?

A. Is ‘fragility’ appropriate for grouping all substances into just two types?
B. Is ‘electrical conductivity’ appropriate for grouping all substances into just two types?
C. Is ‘hardness’ appropriate for grouping all substances into just two types?
D. Is ‘flammability’ appropriate for grouping all substances into just two types?

Appendix 3. Sample question from the SAT

Based on Table A.1, please generate arguments to guess the unknown substance (Substance A). Is it ‘metal’, ‘metalloid’, or ‘nonmetal’?

Explain how you came up with your answer.