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Enhancing skill in constructing scientific explanations using a structured argumentation scaffold in scientific inquiry

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ABSTRACT

Constructing scientific explanations is necessary for students to engage in scientific inquiry. The purpose of this study is to investigate the influence of using a structured argumentation scaffold to enhance skill in constructing scientific explanations in the process of scientific inquiry. The proposed approach is designed to scaffold the following aspects of argumentation: the argumentation process, the explanation structuring, explanation construction, and explanation evaluation. A quasi-experiment was conducted to examine the effectiveness of the structured argumentation scaffold in developing skill in constructing scientific explanations and engaging in electronic dialogues. A web-based collaborative synchronous inquiry system, ASIS (Argumentative Scientific Inquiry System), was utilized to support students as they worked in groups to carry out inquiry tasks. Two intact sixth grade classes ($n = 50$) participated in the study. The data show that the ASIS with the structured argumentation scaffold helped students significantly improve their skills in constructing scientific explanations, make more dialogue moves for explanation and query, and use more of all four argument components. In addition, the use of warrants, one of the components of an argument, was found to be a critical variable in predicting students' competence with regard to constructing scientific explanations. The results provide references for further research and system development with regard to facilitating students' construction of scientific argumentation and explanations.

1. Introduction

Explanation is not only a central artifact of science (McNeill & Krajcik, 2011) but a central issue in science education (Pallrand, 1996; Yang & Wang, 2014). Moreover, construction of scientific explanations may help students obtain a deeper comprehension of content knowledge (McNeill & Krajcik, 2008; Zohar & Nemet, 2002). Furthermore, many studies indicate that constructing scientific explanations is necessary for students to engage in scientific inquiry (Kuhn & Reiser, 2005; Sandoval, 2003). An explanation can be seen as a statement of causation about how or why something occurred, and science education researchers have further defined the term by specifying that a causal statement must be linked to evidence (Berland & Reiser, 2009; Kuhn & Reiser, 2005; Sandoval & Reiser, 2004). Because scientific inquiry is seen as central to science education as a whole (American Association for the Advancement of Science, 1993; C. B. Hall & Sampson, 2009; Kuhn & Reiser, 2005; National Research Council,

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1996), students' abilities to construct explanations based on evidence, which are essential to engaging in scientific inquiry, is now considered critical (Huang et al., 2011; Kuhn & Reiser, 2005; Lemke, 1990; National Research Council, 1996; Schauble, Glaser, Duschl, Schulze, & John, 1995). This issue is made more urgent by the fact that many studies indicate that constructing scientific explanations is difficult for students (Kuhn & Reiser, 2005; McNeill & Krajcik, 2011; Sandoval & Millwood, 2005). Therefore, greater effort must be made to help learners both understand and construct explanations.

Many researchers have attempted to identify the difficulties that students encounter when constructing and communicating explanations and have sought to design supports to address these difficulties (Kuhn & Reiser, 2005), using Toulmin's Argument Pattern (Toulmin, 1958), which is often used as a scaffold in this context (P. Bell, 2000; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Kuhn & Reiser, 2005; McNeill & Krajcik, 2008; McNeill, Lizotte, Krajcik, & Marx, 2006). The construction and evaluation of explanations are closely related to the core scientific practice of argumentation (McNeill & Krajcik, 2011) because, in developing an argument, students must explain their reasoning and link evidence to it (Kollar, Fischer, & Slotta, 2007). Similarly, Berland and Reiser (2009) observed that explanations can be developed through argumentation in scientific communities. The present study thus seeks to develop a structured argumentation scaffold that not only applies Toulmin's Argument Pattern but also integrates several other strategies that promote argumentation and explanation to help students understand and construct scientific explanations as part of the process of scientific inquiry. With regard to the use of educational technology to extend the scope of classroom discourse beyond school walls (Scardamalia & Bereiter, 1994) and the convenience and effectiveness of technology in facilitating learning (Hsu, Van Dyke, Chen, & Smith, 2015; Tsai, 2015; Wang, 2014), several promising learning technologies, with particular interface designs, have been developed to support collaborative inquiry-based learning (Chang, Sung, & Lee, 2003; Gomez, Gordin, & Carlson, 1995; Guzdial, Turns, Rappin, & Carlson, 1995; Lund, Molinari, Séjourné, & Baker, 2007; Scardamalia & Bereiter, 1991; Suthers, Weiner, Connelly, & Paolucci, 1995) and argumentation (P. Bell, 2000; Golanics & Nussbaum, 2008; Hong, Brudvik, & Chee, 2006; Hsu et al., 2015; McAlister, Ravenscroft, & Scanlon, 2004; Tsai, 2015; Wang, 2014). Similarly, this study seeks to use this structured argumentation scaffold in a computer-supported scientific inquiry environment.

1.1. Background

1.1.1. Scientific explanation in scientific inquiry

Recent research on science education has stressed that scientific learning involves more than memorization but rather is a way of knowing and thinking (Hsu et al., 2015; McNeill & Krajcik, 2006). This means that scientific learning should help students learn how to think and act like scientists (McNeill & Krajcik, 2006). More specifically, science curriculums should help students learn more about the processes that scientists engage in when they validate scientific knowledge through the method of scientific inquiry (Sandoval & Reiser, 2004). Like scientists, students should learn to ask questions, generate evidence, propose explanations based on evidence and reasoning, and form conclusions in the process of their inquiries (T. Bell, Urhahne, Schanze, & Ploetzner, 2009; National Research Council, 1996). To propose explanations, students must offer evidence to support their claims and use scientific language and ideas to illustrate their reasoning (Duschl, Schweingruber, & Shouse, 2007). In other words, constructing scientific explanations is indispensable for students in engaging in scientific inquiry (Kuhn & Reiser, 2005; Sandoval, 2003). Moreover, many studies have found that engaging students in scientific inquiry enhances their ability to construct explanations and arguments (McNeill & Krajcik, 2006; McNeill et al., 2006). H. K. Wu and Hsieh (2006) observed that participating in inquiry-based learning activities can significantly improve students' abilities to construct explanations. In brief, the practices of scientific inquiry not only provide opportunities for students to construct scientific explanations but improve their abilities to do so.

Broadly, an explanation is a statement of causation about how or why something occurred (Berland & Reiser, 2009; Kuhn & Reiser, 2005). However, science education researchers have further defined this term by specifying that a causal statement must be linked to evidence (Berland & Reiser, 2009; Kuhn & Reiser, 2005). Similarly, scientific standards emphasize the importance of reasoning according to evidence and logic when developing explanations (Kuhn & Reiser, 2005). Rutherford and Ahlgren (1990) noted that explanations should include or correspond with appropriate scientific principles. The National Research Council (1996) proposed that students should be able to construct explanations that provide "causes for effects and establishing relationships based on evidence and logical argument" (p. 145). McNeill and Krajcik (2006) defined scientific explanation as proposed explanations of phenomena, using relevant evidence and reasoning to support such explanations. This definition is adopted in the current study.

Many studies have reported that students face difficulties in constructing scientific explanations (Kuhn & Reiser, 2005; McNeill & Krajcik, 2011; Sandoval & Millwood, 2005; H. K. Wu & Hsieh, 2006). Kuhn and Reiser (2005) found that constructing scientific explanations is difficult for students because it requires incorporating many different elements, including amassing evidence to appraise and revise claims, reasoning about how to support claims, connecting evidence to scientific principles, and communicating what has been understood. However, students often do not clearly interpret their inferences or clearly articulate relationships between evidence and claims in their explanations. Sandoval and Millwood (2005) found that students often fail to cite sufficient and appropriate evidence for their claims and articulate how a certain piece of evidence relates to a particular claim. H. K. Wu and Hsieh (2006) found that students tend to generate incoherent explanations from personal thoughts and fail to make logical connections between evidence and claims in their explanations. McNeill and Krajcik (2011) observed that students are often unclear about what it means to construct a scientific explanation and about what to include in their explanations. It is thus important to help students understand the importance of constructing a scientific explanation and guide them in the process of doing so. In summary, the common difficulties that students face in constructing scientific explanations include failing to cite sufficient and appropriate evidence for their claims, failing to connect evidence to appropriate scientific principles, and not clearly interpreting their inferences and articulating relationships between evidence and claims.

Many studies have reported that practice in making arguments can help students in constructing explanations. Sandoval and Millwood (2005) noted that explanations are a core production of science, and constructing and evaluating explanations require the central scientific activity of argumentation. McNeill and Krajcik (2006) observed that the construction of explanations is developed via evaluation and debate over different explanations within scientific communities. Berland and Reiser (2009) also stated that explanations are developed through argumentation in which explanations are queried, debated, evaluated, and revised within a community of scientists. Argument is a social interaction aimed at persuading or defending an opinion (Van Eemeren et al., 1996). In terms of argumentation, students can use their epistemological understandings to not only logically construct scientific explanations but also critically evaluate one another's scientific explanations (Kenyon & Reiser, 2006). However, a lack of opportunities for students to practice argument and a lack of teaching techniques that teachers can employ in organizing argumentative discourse are significant obstructions to progress in science education (Driver, Newton, & Osborne, 2000). This study thus supports the view that providing opportunities for argumentation and the mechanisms needed to organize argumentative discourse in scientific inquiry can help students construct better scientific explanations.

1.1.2. Argumentation and argument construction

Viewing science as a form of knowledge building emphasizes the role of scientific communities in the growth of scientific knowledge (Kuhn & Reiser, 2005; Scardamalia & Bereiter, 2006). Scardamalia (2002) stressed that the construction of knowledge is supported by engaging students in continuous dialogue and discourse to improve ideas within a community. In this context, learners should engage in sustained discussion to support their claims and in dialogues to argue like scientists. In science, argumentation is not a competition involving justification and debate to determine winners and losers but rather a form of logical discourse used to extract relationships between claims and evidence (Duschl & Osborne, 2002). Golanics and Nussbaum (2008) observed that collaborative argumentation is important in an educational context because it helps students extract relationships between ideas, alter their conceptions, and deliberate on the meaning of evidence for claims. Not only does practicing argumentation help in constructing explanations, but science educators also believe it is a core scientific practice that students should learn (Sandoval & Millwood, 2005).

Promoting the practice of argumentation requires the development of appropriate pedagogical approaches (Hong et al., 2006), and Maloney and Simon (2006) noted that a science program must incorporate pedagogical approaches and appropriate activities that offer exercises that enable students to effectively practice argument. Thus, many studies have developed pedagogical approaches to foster argumentation skills. For example, Ge and Land (2004) presented a framework using question prompts to direct students' attention to key points of a problem, help students to construct arguments grounded in evidence, and guide the peer problem-solving process. Hong et al. (2006) scaffolded the learning process by modeling the argumentation steps and providing sentence openers that help students compose their arguments. Maloney and Simon (2006) found that the practice of discussing evidence and adopting roles that strive to use argumentation skills can enhance students' scientific reasoning skills and comprehension of scientific concepts. Golanics and Nussbaum (2008) adopted an intervention in which question prompts are used to remind students of various arguments and counter-arguments. This form of question prompts balanced argumentation for all students, especially for those with relatively low levels of knowledge.

To encourage learners to argue in a dialogue, teachers can arrange different types of interaction or scaffold argumentation to support such efforts. Chin and Osborne (2010) suggested that students can be aided in engaging in productive discussion by encouraging them to question, illustrating the criteria of a good argument, and providing a structure that facilitates organization and verbalization of arguments. Dansereau et al. (1979) developed a strategy of using a basic four-step script to scaffold peer cooperation. Many studies report that the strategy of scripted peer cooperative learning not only assists in initial cooperative learning but also results in positive transfer in subsequent individual learning (R. H. Hall et al., 1988; McDonald, Larson, Dansereau, & Spurlin, 1985; O'Donnell, Dansereau, Hall, & Rocklin, 1987).

A number of studies apply Toulmin's Argument Pattern (Toulmin, 1958) to analyze arguments (McNeill et al., 2006; Osborne, Erduran, & Simon, 2004; Simon, 2008). According the framework of Toulmin's Argument Pattern (TAP), an argument includes six components: a claim, data supporting the claim, qualifiers that indicate the strength of the claim, warrants for connecting the claim and the data, backing that strengthens the warrants, and rebuttals that indicate exceptions or limitations to the claim (Simon, 2008; Toulmin, 1958). Although the use of TAP as an analytical tool for argument has been subjected to various criticisms (Voss & Van Dyke, 2001), it remains an effective way to structure an argument or design an argument scaffold. Lin, Chiu, Hsu, and Wang (2015) noted that TAP offers a complete structure to construct a high-quality argument by fully and accurately connecting various components to the issue discussed. This structure is flexible and field-invariant and thus may be applied to different fields (e.g., law, science, politics, etc.) (Jimenez-Aleixandre et al., 2000; Lin et al., 2015). Moreover, Gott and Duggan (2007) suggested that TAP can be used as a structure to help students think about how to create an argument by depicting the relationship between argument components. To this end, numerous other researchers have used TAP to design argument scaffolds to help students construct arguments or explanations (Chambliss & Murphy, 2002; McNeill & Krajcik, 2006; McNeill et al., 2006; Osborne et al., 2004; Stegmann, Weinberger, & Fischer, 2007; Yeh & She, 2010).

Based on a review of the literature, as summarized above, engaging in argumentation appears to be an effective way to help students address the difficulties of constructing scientific explanations. The present study seeks to integrate several appropriate pedagogical strategies into a structured argumentation scaffold to help students construct scientific explanations and engage in argumentation during processes of scientific inquiry.

1.2. Purpose and questions

This study seeks to develop a structured argumentation scaffold that integrates several appropriate pedagogical strategies to help students construct scientific explanations during the process of scientific inquiry. More specifically, the purpose of this study is to investigate the influence of using the structured argumentation scaffold to develop elementary students' skills in constructing scientific explanations in a computer-supported scientific inquiry environment. Two types of interface were developed to support students engaged in scientific enquiry: a discussion interface, which enables users to engage freely in discussion without the use of argumentation scaffolds, and a structured argumentation interface, which integrates a systematic argumentation scaffold.

The specific research questions addressed in this study are as follows:

- Are there differences between students that use the free discussion interface without any scaffolding and those that use the structured argumentation interface with scaffolding with regard to the dialogue attributes related to scientific inquiry?
- Are there differences between students that use the discussion interface and those that use the structured argumentation interface with regard to skill in constructing scientific explanations in scientific inquiry?
- Is skill in constructing scientific explanations influenced by the dialogue attributes of scientific inquiry?

2. The structured argumentation scaffold

The structured argumentation scaffold is designed to scaffold certain aspects of argumentation. These include the argumentation process, the explanation structure, explanation construction, and explanation evaluation.

2.1. Scripting the argumentation process

The present study applies the Think-Pair-Share approach (Lyman, 1981), a collaborative learning strategy, to script argumentation processes during scientific inquiry. Under this strategy, after a teacher poses a question, students are allowed to think about the question individually, discuss it in pairs, and then share their ideas with the class (Butler, Phillmann, & Smart, 2001). Think-Pair-Share not only involves learners in the discussion (Butler et al., 2001); it engages them in higher-order thinking (Cooper & Robinson, 2000). The Think-Pair-Share script used at each step of the inquiry process (Eick, Meadows, & Balkcom, 2005) is shown in Table 1.

Rotating the scripted roles could facilitate learning by helping students focus on task performance (Noroozi, Weinberger, Biemans, Mulder, & Chizari, 2012). Our previous study also found that playing a balanced role and searching for both supporting and opposing evidence can significantly improve related skills (Lin et al., 2015). For example, rotating the roles of speaker and questioner during a period of cross-questioning can be helpful when formulating an explanation. The script for this is as follows: member A acts as a speaker and proposes an explanation; member B acts as a questioner and asks about the explanation; finally, member A defends his or her proposal. The roles are then reversed, and it is member B's turn to propose an explanation, while member A must question it.

2.2. Structuring scientific explanations

Supporting structures or scaffolds can help learners engage in advanced thinking (Bransford, Brown, & Cocking, 2000). McNeill et al. (2006) found that written curricular scaffolds can help students improve their abilities to support their claims in

Table 1
The Think-Pair-Share script used at each step of the inquiry process.

Scientific inquiry process	Inquiry task requirements		
	Think	Pair	Share
Clarifying the question	Identifying the key concept in a question and getting a feel for the scale, nature, and possibility of various answers	Sharing ideas with one's partner	NA
Collecting evidence	Collecting evidence individually	Sharing evidence collected individually with one's partner	Sharing evidence collected by one's group with the class
Formulating explanations	Analyzing evidence and formulating one's own explanation of it	Proposing an explanation to one's partner and working together to form an agreed explanation	NA
Communicating the explanation	Writing the explanation for the common inquiry group report	Working with one's partner to review and revise the explanation for the group report	Reviewing reports produced by other groups

written explanations with the use of appropriate evidence and reasoning. A simplified version of Toulmin's Argument Pattern (Toulmin, 1958) - which includes the components of claim, data, warrant, and rebuttal - has also been used in the design of argument scaffolds for students, as the original pattern is quite complex (Chambliss & Murphy, 2002; McNeill & Krajcik, 2006; McNeill et al., 2006; Osborne et al., 2004; Stegmann et al., 2007; Yeh & She, 2010). The present study uses this simplified version of Toulmin's Argument Pattern as a model for structuring scientific explanations. The model offers students support in constructing explanations and expressing opinions. Additionally, it helps them learn the meaning of constructing a scientific explanation and what to include in it.

2.3. Guiding the construction of explanations

McNeill and Krajcik (2011) noted that guidance should be provided to enable learners to construct good explanations based on the components derived from Toulmin's Argument Pattern. Furthermore, Noroozi et al. (2012) observed that the use of prompts can raise the level of critical discussion that students engage in and that the use of carefully developed sentence openers can also be effective in the construction of arguments. Yang and Wang (2014) noted that providing students with examples can help them understand what scientific explanation is. Similarly, P. Bell and Davis (2000), in an online investigation, reported that scaffolds with prompts and hints can help students construct causal scientific explanations. Therefore, a user interface with prompts and sentence openers based on the key components of a good argument is used in the current work.

2.4. Evaluating evidence and explanations

Many researchers have emphasized the importance of evaluating evidence and explanations in enhancing the quality of argumentation (Iordanou & Constantinou, 2015; Kenyon & Reiser, 2006; Maloney & Simon, 2006; Osborne et al., 2004; Sampson, Grooms, & Walker, 2011). For example, Kenyon and Reiser (2006) observed that offering students the criteria needed to evaluate evidence and explanations can help them produce better work. Thus, in the present study, students were asked to use scoring rubrics as criteria in evaluating the quality of their evidence and explanations as they were developing and sharing them. In this way, learners are encouraged to determine whether the evidence they are using is appropriate for the claims they are making and whether the relationships between their evidence and inferences are clear and logical.

3. Method

A quasi-experiment was designed with pretests, posttests and a control group. The independent variable was whether students were asked to use the structured systematic argumentation scaffold to support the process of scientific inquiry. The experimental group (argumentation group) used the structured argumentation interface that integrates the systematic argumentation scaffold in the inquiry process, while the control group (discussion group) used the free–discussion interface to engage freely in discussion in the inquiry process. The dependent variables included students' skill with regard to constructing scientific explanations and the electronic dialogues used in the inquiry process. The electronic dialogues refer to messages that were written and posted by students in a chat room throughout the experimental period, with each message regarded as a dialogue move to be counted. Four online scientific inquiry activities, supported by a collaborative scientific inquiry system, ASIS (Argumentative Scientific Inquiry System), were arranged. Details of the communication and task implementation during the experimental period were tracked and collected, and these were used in the subsequent data analyses.

3.1. Participants

Two sixth grade elementary classes (N = 50, aged 11–12) were used to form the argumentation (26, 13 boys and 13 girls) and discussion (24, 12 boys and 12 girls) groups. The two classes were chosen to participate in the experiment because each student in these classes had been given a tablet computer that could be conveniently used to participate in experimental inquiry activities. The classes were both conducted at the same school, located in Kaohsiung, a city in southern Taiwan. The homeroom teachers of the two classes were different, but the homeroom teachers did not intervene in the inquiry activities. The two classes consisted of students of similar socio-economic backgrounds ranging from low-class to middle-class. The academic performances of participants were about average compared with other students of the same ages. The students had taken computer courses in computer basics and applications for three years. Thus, they could use a word processor, type in Chinese, and use an Internet browser. Additionally, they had studied a natural sciences curriculum for three years. However, they had no experience engaging in scientific inquiry using computers. This study randomly selected one class to join the argumentation group and the other to join the discussion group.

3.2. Instrumentation and measurement

3.2.1. Argumentative scientific inquiry system

A web-based collaborative synchronous inquiry system, ASIS (Argumentative Scientific Inquiry System), was utilized to help students carry out the inquiry tasks. ASIS guided students in completing scientific inquiry tasks step by step, according to a four-step scientific inquiry strategy proposed by Eick et al. (2005). These four steps of the scientific inquiry process, as noted in Table 1, are as follows: clarifying questions, collecting evidence, formulating explanations, and communicating explanations. Based on the requirement of helping students complete inquiry tasks, ASIS supported students in obtaining inquiry tasks, discussing and co-editing inquiry reports with the paired partner, and sharing inquiry reports with the class. The student interface in ASIS was divided into two main areas: the chat room and the workspace. Students in both groups could use these two areas, although, as noted above, the argumentation group had access to the structured argumentation scaffold, while the discussion group could engage in free discussion without such support. Fig. 1 shows a screenshot of the students' interface.

1. Chat room

The chat room was a synchronous text-based communication tool for each pair, and thus, each pair was free of interference from other students while working. The chat room not only enabled communication but also provided guidance with regard to completing the inquiry tasks. An automatic tutor for each pair played the role of teacher, interacting with students and posting messages to help them carry out inquiry tasks. The members of each pair could enter text into the system to communicate with the other member of the pair. Thus, they could discuss and support their explanations in generating a shared inquiry report. In addition to text, the input field in the chat room could be changed to show a check-list for the various components of an argument or a confirm button based on the learning task requirement in each step.

2. Workspace

The workspace was used to present the group report editor and examples of arguments and reports. Each pair's scientific inquiry report was completed in the form of a written report. The group report editor enabled students to work online and co-edit the shared inquiry reports. Although each partner could read and write the content of a shared report at the paragraph level, they could only modify and delete the paragraphs that they had written. If a student had a comment on a paragraph that he or she had not written, the student could discuss this with the author using the text-based chat room. The writer could then decide whether to modify the text. Any changes in the group reports would then be relayed back to the other member. After a group report was completed, and all members of the group had confirmed their support for the final product, the report was shared with the other group. In addition to the group report editor, examples of explanations and completed group reports, written by the teacher, were provided for students' reference in the workspace.

3.2.2. Structured argumentation interface and generic discussion interface

Two different interfaces, a structured argumentation interface and a generic discussion interface, were provided to the argumentation and discussion groups, respectively, to help them complete the scientific inquiry tasks. With regard to the argumentation group, sets of argumentative sentence openers were provided to help students articulate their ideas and then ask questions and respond to each other. A check-list was provided to help students evaluate the evidence that they found online as well as the group reports that were completed using the group report editor. Prompts were embedded in sentence

Fig. 1. The students' interface in ASIS with the structured argumentation scaffold.

openers to remind students of the definitions of each of the argument components. ASIS also asked the students to take turns as proposer and questioner, using sentence openers to help familiarize them with the process of argumentative scientific inquiry. In contrast to the argumentation group, the discussion group used a generic discussion interface (non-structured). These students could discuss their ideas freely, using the chat box feature.

3.2.3. Coding electronic dialogues to compare scientific explanations in the inquiry process

Each message written and posted by students in the chat room was regarded as a dialogue move. The dialogue moves within each group were analyzed using a coding system that was a modification of the coding system proposed by Chiu and Hsiao (2010). Each dialogue move that was categorized as an explanation was analyzed using Toulmin's Argument Pattern to determine whether it included the components of an argument. In summary, the dialogue analysis examined four move categories and four argument components, using the coding system shown in Table 2.

3.2.4. Evaluating the skill of constructing scientific explanations

The pretest and posttest developed by C.-L. Wu (2006), which consist of 2 multiple choice questions and 16 short-answer essay questions (Cronbach's $\alpha = 0.769$), were used to measure skill employed in constructing scientific explanations. Answers to the multiple choice questions were worth 1 point each, and each of the short-answer essay questions were worth 2 or 3 points. The total test was worth 39 points. To prevent the scientific concepts obtained from experimental inquiry activities from affecting the measure of skill in constructing scientific explanations, the topic of the test, classical mechanics in physics (e.g., force measurement, pulley, and lever), was unrelated to the topics of the experimental inquiry activities. The test measured four aspects of skill in constructing scientific explanations: describing relationships between variables, using evidence to support claims, incorporating scientific principles into explanations, and demonstrating the reasoning behind the constructions of explanations. Two content experts, including a professor and a senior science teacher, reviewed and revised the test questions to vouch for the content validity of the test.

3.3. Procedure

The quasi-experiments were conducted for a period of six weeks, including five weeks for the inquiry activities and one week for the training, pretest and posttest. Four inquiry activities lasted five weeks, with a one-week interval between the first (rusty bicycle) and second (browned apple) topics. The participants were free to engage in scientific inquiry using a tablet computer (tablet, hereafter) in the classroom. The homeroom teachers maintained classroom order and offered technical support when necessary. The following steps were carried out:

1. Grouping

Harasim (1993) reported that groups with 2–4 people are effective for group work in online courses and preferred by students for task-oriented activities. Because the intricate script of the cross-examination processes in a multi-person argument would force participants to wait a long time for their partners to respond, creating confusion about what task they should perform in each step, this study used pairs to simplify the process. Within-class random group assignment was used to create 25 pairs.

2. Training

Both argumentation and discussion groups were introduced to the ASIS, and they learned how to use it on the tablets. In addition, both groups watched a 20-min video introducing the various components of a scientific explanation.

3. Pretest

Students took a pretest to establish their ability to construct scientific explanations before the treatment.

Table 2
The coding system for the electronic dialogues.

Category of dialogue	Description
Explanation	Dialogue moves used to express one's views or provide sources of evidence or explain the causes, context, and consequences of something that has happened. Each explanation was also checked as to whether it included a claim, data, a warrant or a rebuttal.
Query	Dialogue moves used to express doubts about one's partner's explanations or ask them to check an explanation's validity or accuracy.
Task	Dialogue moves used to accomplish group tasks, including asking for and providing help, checking for agreement, and requesting refinement.
Social	Dialogue moves unrelated to task completion, including name calling, bickering, gibberish, and other social actions.

Modified from Chiu and Hsiao (2010).

4. Treatment

Each student used a tablet to accomplish the inquiry activities with one's partner. The students were required to use the chat function within ASIS to engage in online discussions and were asked to avoid oral communication. Students used the first class to complete inquiry tasks in classrooms on each weekday. Additionally, students sometimes used lunch breaks or recesses between classes. Both argumentation and discussion groups followed the same inquiry process in every inquiry activity. The major difference between the groups was that the argumentation group had the support of the structured argumentation scaffold when using ASIS, while the discussion group engaged in free discussion during the activities.

The collaborative tasks included a series of four inquiry activities related to two topics, a rusty bicycle and a browned apple. The collaborative tasks focused on inquiry-based units in which scientific ideas were contextualized in inquiry activities that the students investigated throughout the unit. The inquiry activities were used to encourage students to engage in longer-term investigations, with one activity corresponding to one week's unit. In these investigations, the students were asked to understand and apply scientific concepts in analyzing and examining the data they obtained.

5. Posttest

After the four inquiry activities were completed, the students retook the test on constructing scientific explanations they had taken in the pretest and completed ASIS feedback questionnaires.

3.4. Analyses

A multivariate analysis of variance (MANOVA) was performed to determine whether there were significant differences between the argumentation and discussion groups in the electronic dialogues. The independent variable was whether the structured systematic argumentation scaffold helped students conduct scientific inquiry. The dependent variables were the number of various types of dialogue moves and the number of components of an argument included in the explanations. An analysis of covariance (ANCOVA), with pretest scores for skill in constructing scientific explanations as the covariate, was performed to determine whether there was a significant difference between the argumentation and discussion groups in this regard. The independent variable was whether the structured argumentation scaffold was used in inquiry-based learning activities, and the dependent variable was the student's posttest score for skill in constructing scientific explanations. Furthermore, in the regression model, electronic dialogues acted as predictors of skill in constructing scientific explanations. The independent variables were the number of different types of dialogue moves and the number of components of an argument included in the explanations. The dependent variable was students' scores with regard to skill in constructing scientific explanations. A stepwise regression analysis was conducted to identify which combination of the independent variables predicted the results of the dependent variable.

4. Results

4.1. Comparison of the electronic dialogues

A summary of the MANOVA results for the electronic dialogues is found in Table 3.

Table 3
Summary of the MANOVA results for electronic dialogues.

	Group	*M*	*SD*	*F*	*p*
Claim	Discussion	1.63	1.813	34.801	.000***
	Argumentation	7.50	4.554		
Data	Discussion	1.67	3.435	5.535	.023*
	Argumentation	4.83	4.596		
Warrant	Discussion	.21	.415	29.490	.000***
	Argumentation	2.85	2.344		
Rebuttal	Discussion	.00	.000	20.924	.000***
	Argumentation	2.04	2.181		
Explanation	Discussion	3.21	3.611	83.167	.000***
	Argumentation	19.35	7.939		
Query	Discussion	.71	1.160	25.772	.000***
	Argumentation	3.42	2.369		
Task	Discussion	2.62	3.876	9.319	.004**
	Argumentation	.27	.667		
Social	Discussion	5.17	5.961	2.251	.140
	Argumentation	2.96	4.368		

*$p < .05$ level; **$p < .01$ level; ***$p < .001$ level.

The results of the MANOVA indicate significant differences between the discussion and argumentation groups in all dialogue moves other than social dialogue moves. The explanation dialogue moves, the query dialogue moves and all of the argument components regarded as beneficial to skill in constructing scientific explanations were all significantly more common in the argumentation group than in the discussion group (see Fig. 2). On the other hand, task dialogue moves used to accomplish group tasks and regarded as irrelevant to skill in constructing scientific explanations in the argumentation group were significantly less important in the argumentation group than in the discussion group. This shows that the argumentation group had more dialogues that aided the construction of scientific explanations than the discussion group.

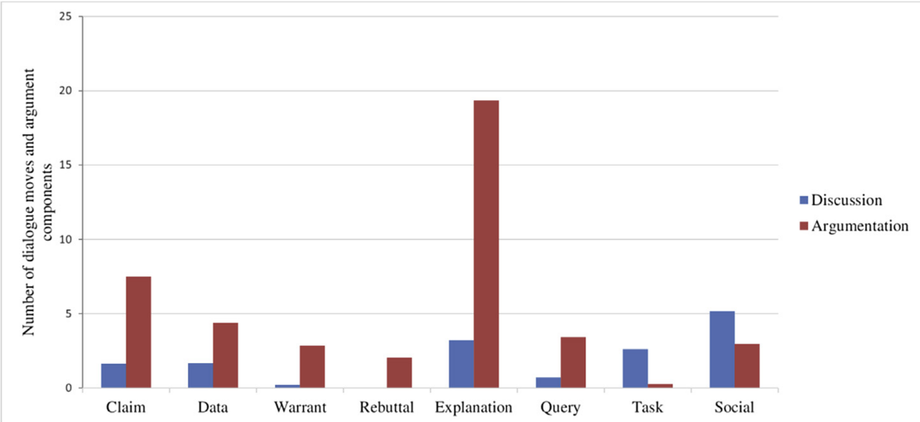

Fig. 2. Comparison of the number of dialogue moves and argument components.

The argumentation group also differs from the discussion group in the distribution of both dialogue move categories and argument components. With respect to the proportion of argument components (as shown in Fig. 3), while most of these in both the argumentation and discussion groups were claims and data, warrants were seldom used by the discussion group, which also used no rebuttals.

In terms of the proportion of dialogue move categories (as Fig. 4), most of dialogue moves of the argumentation group were explanations, with very few task dialogues. In contrast, most of dialogue moves of the discussion group were social and explanation dialogues, with query dialogues being the least common.

4.2. Skill in constructing scientific explanations

The means and standard deviations of the posttest scores for the discussion and argumentation groups are reported in Table 4.

Tests of the homogeneity of the regression coefficient revealed that the interaction $F = 0.001$ between the independent variables and covariance is 0.973 ($p > 0.05$). This confirms the hypothesis of homogeneity of the regression coefficient, as indicated by the results of the ANCOVA (Table 5).

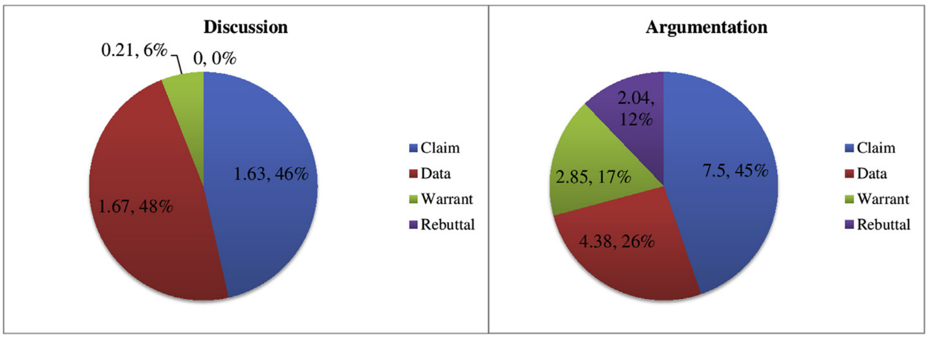

Fig. 3. Comparison of the distributions of argument components.

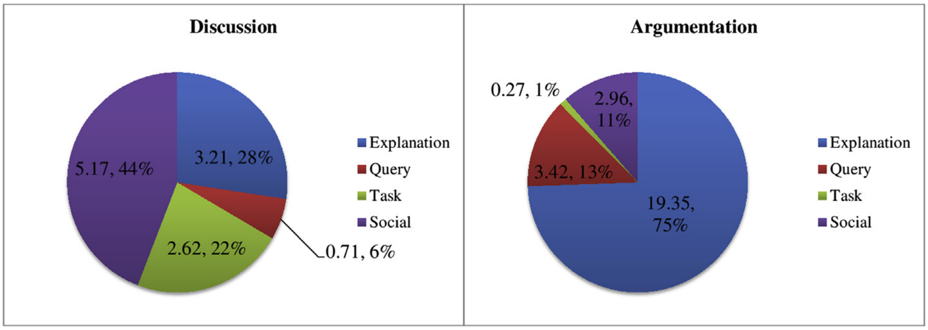

Fig. 4. Comparison of the distributions of dialogue move categories.

The results of the ANCOVA, as shown in Table 5, indicate a significant difference between the discussion and argumentation groups in the posttest, with scores significantly higher in the latter [$F = 21.241$; $p = 0.000$ ($p < 0.001$)]. This shows that the argumentation group was more effective than the discussion group in constructing scientific explanations.

4.3. Relationship between electronic discussions and skill in constructing scientific explanations

Table 6 presents the results of the stepwise regression analysis. Skill in constructing scientific explanations was predicted by the warrant dialogue moves ($F = 23.275$; $R^2 = 0.327$; adjusted $R^2 = .313$; $p = .000$). Although this prediction does not establish a cause and effect relationship, it does indicate that in the online scientific inquiry activities carried out in the current study, warrants were positively associated with higher scores in skill in constructing scientific explanations.

5. Discussion

The results of the ANCOVA show that the argumentation group is superior to the discussion group with respect to skill in constructing scientific explanations. To determine the difference between scientific inquiry by students with and without the structured argumentation scaffold, electronic dialogues are analyzed and compared. The results of the MANOVA show that the argumentation group engaged in more dialogues benefiting the construction of scientific explanations (i.e., explanation, query, claim, data, warrant, and rebuttal) than the discussion group. On the other hand, the argumentation group engaged in fewer task dialogues than the discussion group. The effects of the structured argumentation scaffold on the dialogues were seen not only in the number of dialogue move categories and argument components used but in the distributions. To further illustrate the differences in dialogues between the discussion group and argumentation group, two representative segments of dialogues belonging to the two groups are shown as Tables 7 and 8. In terms of dialogue move categories, the structured

Table 4
Summary of means (*M*) and standard deviations (*SD*) for the posttest.

	n	*M*	*SD*
Discussion group	24	8.13	5.591
Argumentation group	26	12.73	7.175
Total	50	10.52	6.949

n, the number of participants.

Table 5
Summary of analysis of covariance (ANCOVA) between groups on the posttest with the pretest as the covariate.

	SS	*df*	*MS*	*F*	*p*
Contrast	487.681	1	487.681	21.241	.000***
Error	1056.143	46	22.960		

***$p < .001$ level; *df*, degrees of freedom; *SS*, sum of squares; *MS*, mean squares.

Table 6
Results of stepwise regression analysis ($n = 50$).

Variable	β	*T*	*p*
Warrant	.571	4.824	.000***

$R^2 = .327$; ***$p < .001$.

Table 7
A segment of a dialogue of one pair in the discussion group.

No.	Student	Dialogue move	Category	Components
1	A	Hurry up.:-(:-(:-(:-(:-(:-(:-(:-(:-(:-(	Task	
2	B	Do you have any ideas?	Task	
3	B	I am bored.	Social	
4	B	>.<....?!	Social	
5	A	Have you found any data?	Task	
6	A	Acid seems to remove rust.	Explanation	Claim
7	A	A web page said that rust is usually formed … (web page content).	Explanation	Data
8	A	I have waited for you for quite a while.	Task	
9	B	Tomato juice seems to remove rust.	Explanation	Claim
10	B	*_*	Social	

Table 8
A segment of a dialogue of one pair in the argumentation group.

No.	Student	Dialogue move	Category	Components
Script: Tutor guided student C to explain.				
1	C	I think that spreading the acid solution on bikes can't prevent rust. I found a web page saying that iron in contact with acid will rust. Because acid will make it rusty, spreading the acid solution will speed up rust rather than prevent it.	Explanation	Claim, Data, Warrant
2	C	A web page said that methods of rust prevention include … (web page content)	Explanation	Data
Script: Tutor guided student D to query.				
3	D	Are there other uses for acid?	Question	
Script: Tutor guided student C to defend.				
4	C	Acid will corrode things. It can't prevent rust unless it doesn't corrode the bike.	Explanation	Claim, Rebuttal
Script: Tutor guided student D to explain.				
5	D	A web page said that acid can remove rust. Because acid can corrode rust, it will remove the rust from the bike if rust forms.	Explanation	Data, Warrant
6	D	I think spreading the acid solution on the bike can prevent rust.	Explanation	Claim
Script: Tutor guided student C to query.				
7	C	Are there other things that can remove rust?	Question	
Script: Tutor guided student D to defend.				
8	D	Rust remover can remove rust.	Explanation	Claim

argumentation interface meant that the argumentation group needed to explain and query according the structured argumentation scaffold script during the activity. The dialogue moves of explanations and queries were thus the two main dialogue move categories for the argumentation group. Moreover, the use of the structured argument interface meant that the task each group member needed to carry out in each step was clear, preventing confusion in this regard. There were thus very few task dialogue moves in the argumentation group. Although the dialogues in the argumentation group, as shown in Table 8, reveal that the reasoning employed was fallible and that the phrases in explanations were inexact, students nevertheless focused on the discussion and tried to reason and link data to their claims. In contrast, the discussion group only received some guidance about the scientific inquiry process and could freely discuss the activity using the text-based chat room. Thus, the dialogues in the discussion group reveal, as shown in Table 7, that students tend to discuss at will. As Choi, Hand, and Norton-Meier (2014) noted, discussion of inquiry activities does not mean that students can automatically engage in scientific reasoning and argumentation. While the proportions of explanations, tasks, and social dialogues were similar across the discussion groups, there were many fewer query dialogues in the absence of support of the structured argumentation scaffold. This finding is similar to the finding of Hu and Chiou (2012) that Taiwanese students rarely ask questions in the classroom. These result shows that the structured argumentation scaffold used in this work can encourage student dialogues to focus on expressing, explaining, and arguing about the focal issues in the scientific inquiry process.

The most common argument components in students' explanations in the discussion group related to claims and data, and without the aid of the structured argumentation interface, few warrants and no rebuttals were used in the explanations. Many studies have claimed that generating warrants by connecting data to claims is especially difficult for students (McNeill et al., 2006) and that generating rebuttal arguments is even more difficult than generating claims, warrants, and backing arguments (Yeh & She, 2010) when no assistance is provided. In contrast, due to the support provided by the structured argumentation scaffold, the argumentation group formulated explanations that included all of the components of an argument. Moreover, not only did the argumentation group display an even distribution of argument components, it also made more use of argument components than the discussion group did. This reveals that the structured argumentation scaffold helped students construct better explanations.

The results of the regression analyses show that skill in constructing a scientific explanation was predicted by the use of warrants (with $R^2 = .327$). This may be because the main part of a scientific explanation is to coordinate causal claims with data to illustrate what the data mean and how the data support claims based on scientific principles (Sandoval & Reiser, 2004). Moreover, the process of reasoning is based on the logic of forming inferences from data and thinking about why specific data support particular claims (McNeill et al., 2006). Both reasoning and creating an explanation to include a warrant provide a context in which students can consider the relationships among a scientific principle, a specific claim based on this scientific principle, and the data that may support this claim. Although this prediction does not establish a cause and effect relationship, it does indicate that the use of more warrants is related to higher scores for skill in constructing scientific explanations.

Although the argumentation group constructed better explanations with the assistance of the structured argumentation scaffold, warrants and rebuttals in the explanations of the argumentation group were nevertheless insufficient. A few explanations constructed by the argumentation group included too few warrants or rebuttals. The objective of this study is to help students construct explanations that include all four components. It is evident that the structured argumentation scaffold can more effectively help students construct explanations by including not only claims and data but also warrants and rebuttals.

6. Conclusions

This study examines whether students' skills in constructing scientific explanations can improve over time through the use of ASIS with a structured argumentation interface to support scientific inquiry and argumentation. The results show that the argumentation group, which made use of the structured argumentation interface, was more effective than the discussion group in constructing scientific explanations. The results of comparing the electronic dialogues produced by both groups reveal that the argumentation group made more dialogue moves for explanations and queries than the discussion group, although the latter used more of the task-related dialogue moves. In addition, the argumentation group used more of all four argument components than the discussion group. This reveals that the use of ASIS with a structured argumentation interface positively impacted student performance on the learning task and in creating good arguments and explanations. Finally, the use of warrants was found to be a key predictor of skill in constructing scientific explanations. In conclusion, the results show that ASIS with the structured argumentation interface positively impacts skill in constructing scientific explanations and the argumentative dialogues that the students engaged in during the scientific inquiry process. Given that the use of warrants is a key predictor of skill in scientific argumentation, it is suggested for future research that the mechanism of the structured argumentation scaffold guiding students to use warrants be strengthened.

The results of this study provide references for further research and system development with regard to argumentation and construction of explanations. Additionally, the structured argumentation scaffold and ASIS developed in this study can be applied to the formal and informal science curriculum. The structured argumentation scaffold can be used as a reference in designing scientific inquiry strategies for teachers to script the process of scientific argumentation and help students in constructing scientific explanations. The implementation and working of ASIS can provide students with opportunities to participate in online scientific inquiry courses on argumentation and construction of explanations anytime, anywhere.

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References

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.
Bell, P. (2000). Scientific arguments as learning artifacts: designing for learning from the web with KIE. *International Journal of Science Education, 22*(8), 797–817. http://dx.doi.org/10.1080/095006900412284.
Bell, P., & Davis, E. A. (2000). Designing mildred: scaffolding students' reflection and argumentation using a cognitive software guide. In B. Fishman, & S. O'Connor-Divelbiss (Eds.), *Fourth International Conference of the learning sciences* (pp. 142–149). Mahwah, NJ: Erlbaum.
Bell, T., Urhahne, D., Schanze, S., & Ploetzner, R. (2009). Collaborative inquiry learning: models, tools, and challenges. *International Journal of Science Education, 32*(3), 349–377. http://dx.doi.org/10.1080/09500690802582241.
Berland, L. K., & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education, 93*(1), 26–55. http://dx.doi.org/10.1002/sce.20286.
Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn: Brain, mind, experience and school*. Washington D.C.: National Academy Press.
Butler, A., Phillmann, K.-B., & Smart, L. (2001). Active learning within a lecture: assessing the impact of short, in-class writing exercises. *Teaching of Psychology, 28*(4), 257–259. http://dx.doi.org/10.1207/S15328023TOP2804_04.
Chambliss, M. J., & Murphy, P. K. (2002). Fourth and fifth graders representing the argument structure in written texts. *Discourse Processes, 34*(1), 91–115. http://dx.doi.org/10.1207/S15326950DP3401_4.
Chang, K. E., Sung, Y. T., & Lee, C. L. (2003). Web-based collaborative inquiry learning. *Journal of Computer Assisted Learning, 19*(1), 56–69. http://dx.doi.org/10.1046/j.0266-4909.2003.00006.x.
Chin, C., & Osborne, J. (2010). Students' questions and discursive interaction: their impact on argumentation during collaborative group discussions in science. *Journal of Research in Science Teaching, 47*(7), 883–908. http://dx.doi.org/10.1002/tea.20385.
Chiu, C.-H., & Hsiao, H.-F. (2010). Group differences in computer supported collaborative learning: evidence from patterns of Taiwanese students' online communication. *Computers & Education, 54*(2), 427–435. http://dx.doi.org/10.1016/j.compedu.2009.08.026.
Choi, A., Hand, B., & Norton-Meier, L. (2014). Grade 5 students' online argumentation about their in-class inquiry investigations. *Research in Science Education, 44*(2), 267–287. http://dx.doi.org/10.1007/s11165-013-9384-8.
Cooper, J. L., & Robinson, P. (2000). Getting started: Informal small-group strategies in large classes. *New Directions for Teaching and Learning, 2000*(81), 17–24. http://dx.doi.org/10.1002/tl.8102.
Dansereau, D. F., McDonald, B. A., Collins, K. W., Garland, J. C., Holley, C. D., Diekhoff, G. M., et al. (1979). Evaluation of a learning strategy system. In J. H. F. O'neil, & C. D. Spielberger (Eds.), *Cognitive and affective learning strategies* (pp. 209–239). Hillsdale, NJ: Lawrence Erlbaum Association.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*(3), 287–312. http://dx.doi.org/10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A.

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education, 38*(1), 39–72. http://dx.doi.org/10.1080/03057260208560187.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (2007). *Taking science to school: Learning and teaching science in grades k-8*. Washington, DC: National Academies Press.

Eick, C., Meadows, L., & Balkcom, R. (2005). Breaking into inquiry: scaffolding supports beginning efforts to implement inquiry in the classroom. *Science Teacher, 72*(7), 49.

Ge, X., & Land, S. M. (2004). A conceptual framework for scaffolding III-structured problem-solving processes using question prompts and peer interactions. *Educational Technology Research and Development, 52*(2), 5–22. http://dx.doi.org/10.1007/BF02504836.

Golanics, J. D., & Nussbaum, E. M. (2008). Enhancing online collaborative argumentation through question elaboration and goal instructions. *Journal of Computer Assisted Learning, 24*(3), 167–180. http://dx.doi.org/10.1111/j.1365-2729.2007.00251.x.

Gomez, L. M., Gordin, D. N., & Carlson, P. (1995). A case study of open-ended scientific inquiry in a technology supported classroom. In I. Greer (Ed.), *Proceedings of AI-Ed '95, Seventh World Conference on Artificial Intelligence in education* (pp. 17–24). Charlottesville, VA: Association for the Advancement of Computing in Education.

Gott, R., & Duggan, S. (2007). A framework for practical work in science and scientific literacy through argumentation. *Research in Science & Technological Education, 25*(3), 271–291. http://dx.doi.org/10.1080/02635140701535000.

Guzdial, M., Turns, J., Rappin, N., & Carlson, D. (1995). Collaborative support for learning in complex domains. In J. L. Schnase, & E. L. Cunnius (Eds.), *Proceedings of CSCL 95: Computer Supportfor collaborative learning* (pp. 157–160). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Hall, R. H., Rocklin, T. R., Dansereau, D. F., Skaggs, L. P., O'Donnell, A. M., Lambiotte, J. G., et al. (1988). The role of individual differences in the cooperative learning of technical material. *Journal of Educational Psychology, 80*(2), 172–178. http://dx.doi.org/10.1037/0022-0663.80.2.172.

Hall, C. B., & Sampson, V. (2009). Inquiry, argumentation, and the phases of the moon: helping students learn important concepts and practices. *Science Scope, 32*(8), 16–21.

Harasim, L. (1993). Collaborating in cyberspace: using computer conferences as a group learning environment. *Interactive Learning Environments, 3*(2), 119–130.

Hong, K. S., Brudvik, O. C., & Chee, Y. S. (2006). The impact of structured discussion on students' attitudes and dispositions toward argumentation. In R. Mizoguchi, P. Dillenbourg, & Z. Zhu (Eds.), *Proceedings of 14th International Conference on computers in education* (pp. 133–140). Amsterdam: IOS Press.

Hsu, P. S., Van Dyke, M., Chen, Y., & Smith, T. J. (2015). The effect of a graph-oriented computer-assisted project-based learning environment on argumentation skills. *Journal of Computer Assisted Learning, 31*(1), 32–58.

Huang, C.-J., Wang, Y.-W., Huang, T.-H., Chen, Y.-C., Chen, H.-M., & Chang, S.-C. (2011). Performance evaluation of an online argumentation learning assistance agent. *Computers & Education, 57*(1), 1270–1280. http://dx.doi.org/10.1016/j.compedu.2011.01.013.

Hu, H.-W., & Chiou, G.-F. (2012). The types, frequency and quality of elementary pupils' questions in an online environment. *Turkish Online Journal of Educational Technology – TOJET, 11*(4), 325–335.

Iordanou, K., & Constantinou, C. P. (2015). Supporting use of evidence in argumentation through practice in argumentation and reflection in the context of SOCRATES learning environment. *Science Education, 99*(2), 282–311.

Jimenez-Aleixandre, M. P., Rodriguez, A. B., & Duschl, R. A. (2000). "Doing the lesson" or "doing science": argument in high school genetics. *Science Education, 84*(6), 757–792.

Kenyon, L., & Reiser, B. J. (2006). A functional approach to nature of science: using epistemological understandings to construct and evaluate explanations. In *Paper presented at the American educational research association, San Francisco, CA*.

Kollar, I., Fischer, F., & Slotta, J. D. (2007). Internal and external scripts in computer-supported collaborative inquiry learning. *Learning and Instruction, 17*(6), 708–721. http://dx.doi.org/10.1016/j.learninstruc.2007.09.021.

Kuhn, L., & Reiser, B. (2005). Students constructing and defending evidence-based scientific explanations. In *Paper presented at the national association for research in science teaching, Dallas, TX*.

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Norwood: Ablex Publishing Company.

Lin, C.-H., Chiu, C.-H., Hsu, C.-C., & Wang, T.-I. (2015). The influence of playing a for or against a controversial position on elementary students' ability to construct cogent arguments. *The Asia-Pacific Education Researcher, 24*(2), 409–418. http://dx.doi.org/10.1007/s40299-014-0193-2.

Lund, K., Molinari, G., Séjourné, A., & Baker, M. (2007). How do argumentation diagrams compare when student pairs use them as a means for debate or as a tool for representing debate? *International Journal of Computer-Supported Collaborative Learning, 2*(2–3), 273–295.

Lyman, F. T. (1981). The responsive classroom discussion: the inclusion of all students. In A. Anderson (Ed.), *Mainstreaming digest* (pp. 109–113). College Park: University of Maryland.

Maloney, J., & Simon, S. (2006). Mapping children's discussions of evidence in science to assess collaboration and argumentation. *International Journal of Science Education, 28*(15), 1817–1841. http://dx.doi.org/10.1080/09500690600855419.

McAlister, S., Ravenscroft, A., & Scanlon, E. (2004). Combining interaction and context design to support collaborative argumentation using a tool for synchronous CMC. *Journal of Computer Assisted Learning, 20*(3), 194–204.

McDonald, B. A., Larson, C. O., Dansereau, D. F., & Spurlin, J. E. (1985). Cooperative dyads: Impact on text learning and transfer. *Contemporary Educational Psychology, 10*(4), 369–377. http://dx.doi.org/10.1016/0361-476X(85)90033-5.

McNeill, K. L., & Krajcik, J. (2006). Supporting students' construction of scientific explanation through generic versus context-specific written scaffolds. In *Paper presented at the annual meeting of the American Educational Research Association, San Francisco*.

McNeill, K. L., & Krajcik, J. (2008). Scientific explanations: characterizing and evaluating the effects of teachers' instructional practices on student learning. *Journal of Research in Science Teaching, 45*(1), 53–78. http://dx.doi.org/10.1002/tea.20201.

McNeill, K. L., & Krajcik, J. S. (2011). *Supporting grade 5-8 students in constructing explanations in science: The claim, evidence, and reasoning framework for talk and writing*. New Jersey: Pearson.

McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *Journal of the Learning Sciences, 15*(2), 153–191. http://dx.doi.org/10.1207/s15327809jls1502_1.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academies Press.

Noroozi, O., Weinberger, A., Biemans, H. J. A., Mulder, M., & Chizari, M. (2012). Argumentation-based computer supported collaborative learning (ABCSCL): a synthesis of 15 years of research. *Educational Research Review, 7*(2), 79–106. http://dx.doi.org/10.1016/j.edurev.2011.11.006.

O'Donnell, A. M., Dansereau, D. F., Hall, R. H., & Rocklin, T. R. (1987). Cognitive, social/affective, and metacognitive outcomes of scripted cooperative learning. *Journal of Educational Psychology, 79*(4), 431–437. http://dx.doi.org/10.1037/0022-0663.79.4.431.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching, 41*(10), 994–1020. http://dx.doi.org/10.1002/tea.20035.

Pallrand, G. J. (1996). The relationship of assessment to knowledge development in science education. *Phi Delta Kappan, 78*(4), 315–318.

Rutherford, F. J., & Ahlgren, A. (1990). *Science for all Americans*. New York: Oxford University Press.

Sampson, V., Grooms, J., & Walker, J. P. (2011). Argument-Driven inquiry as a way to help students learn how to participate in scientific argumentation and craft written arguments: an exploratory study. *Science Education, 95*(2), 217–257. http://dx.doi.org/10.1002/sce.20421.

Sandoval, W. A. (2003). Conceptual and epistemic aspects of students' scientific explanations. *Journal of the Learning Sciences, 12*(1), 5–51. http://dx.doi.org/10.1207/S15327809JLS1201_2.

Sandoval, W. A., & Millwood, K. A. (2005). The quality of students' use of evidence in written scientific explanations. *Cognition and Instruction, 23*(1), 23–55. http://dx.doi.org/10.1207/s1532690xci2301_2.

Sandoval, W. A., & Reiser, B. J. (2004). Explanation-driven inquiry: integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education, 88*(3), 345–372. http://dx.doi.org/10.1002/sce.10130.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.), *Liberal education in a knowledge society* (pp. 67–98). Chicago: Open Court.

Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge building: a challenge for the design of new knowledge media. *The Journal of the Learning Sciences, 1*(1), 37–68. http://dx.doi.org/10.2307/1466656.

Scardamalia, M., & Bereiter, C. (1994). Computer support for knowledge-building communities. *The Journal of the Learning Sciences, 3*(3), 265–283. http://dx.doi.org/10.2307/1466822.

Scardamalia, M., & Bereiter, C. (2006). Knowledge building: theory, pedagogy, and technology. In K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 97–118). New York: Cambridge University Press.

Schauble, L., Glaser, R., Duschl, R. A., Schulze, S., & John, J. (1995). Students' understanding of the objectives and procedures of experimentation in the science classroom. *Journal of the Learning Sciences, 4*(2), 131–166. http://dx.doi.org/10.1207/s15327809jls0402_1.

Simon, S. (2008). Using Toulmin's argument pattern in the evaluation of argumentation in school science. *International Journal of Research & Method in Education, 31*(3), 277–289. http://dx.doi.org/10.1080/17437270802417176.

Stegmann, K., Weinberger, A., & Fischer, F. (2007). Facilitating argumentative knowledge construction with computer-supported collaboration scripts. *International Journal of Computer-Supported Collaborative Learning, 2*(4), 421–447. http://dx.doi.org/10.1007/s11412-007-9028-y.

Suthers, D. D., Weiner, A., Connelly, J., & Paolucci, M. (1995). Belvedere: engaging students in critical discussion of science and public policy issues. In J. Greer (Ed.), *Proceedings of Proceedings of the 7th World Conference on Artificial Intelligence in education (AI-ED 1995)* (pp. 266–273). Washington DC: Association for the Advancement of Computing in Education.

Toulmin, S. (1958). *The uses of argument*. Cambridge, England: Cambridge University Press.

Tsai, C.-Y. (2015). Improving students' PISA scientific competencies through online argumentation. *International Journal of Science Education, 37*(2), 321–339.

Van Eemeren, F. H., Grootendorst, R., Henkemans, F. S., Blair, J. A., Johnson, R. H., Krabbe, E. C. W., et al. (1996). *Fundamentals of argumentation theory: A handbook of historical backgrounds and contemporary developments*. Mahwah, NJ: Lawrence Erlbaum Associates.

Voss, J. F., & Van Dyke, J. A. (2001). Argumentation in psychology: background comments. *Discourse Processes, 32*(2–3), 89–111. http://dx.doi.org/10.1080/0163853X.2001.9651593.

Wang, T. H. (2014). Implementation of web-based argumentation in facilitating elementary school students to learn environmental issues. *Journal of Computer Assisted Learning, 30*(5), 479–496. http://dx.doi.org/10.1111/jcal.12061.

Wu, C.-L. (2006). *Exploring the development of fifth-grade students' explanation skills and their scientific epistemologies in inquiry-based activities* (Master's thesis). Taipei: National Taiwan Normal University. Retrieved from http://etds.lib.ntnu.edu.tw/cgi-bin/gs32/gsweb.cgi/ccd=tm6MQT/record?r1=1&h1=1.

Wu, H. K., & Hsieh, C. E. (2006). Developing sixth graders' inquiry skills to construct explanations in inquiry-based learning environments. *International Journal of Science Education, 28*(11), 1289–1313. http://dx.doi.org/10.1080/09500690600621035.

Yang, H.-T., & Wang, K.-H. (2014). A teaching model for scaffolding 4th grade students' scientific explanation writing. *Research in Science Education, 44*(4), 531–548.

Yeh, K.-H., & She, H.-C. (2010). On-line synchronous scientific argumentation learning: nurturing students' argumentation ability and conceptual change in science context. *Computers & Education, 55*(2), 586–602. http://dx.doi.org/10.1016/j.compedu.2010.02.020.

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39*(1), 35–62. http://dx.doi.org/10.1002/tea.10008.