A Spiral Model of Collaborative Knowledge Improvement to Support Collaborative Argumentation for Science Learning: Technological and Pedagogical Design

Wenli Chen, Si Zhang, Yun Wen, Chee-Kit Looi, and Jennifer Yeo
wenli.chen@nie.edu.sg, si.zhang@nie.edu.sg, yun.wen@nie.edu.sg, cheekit.looi@nie.edu.sg,
jennifer.yeo@nie.edu.sg
Nanyang Technological University, Singapore

Abstract: Innovations in teaching and learning are not merely about merely the design of technologies but the integration of technologies and pedagogical practices in supporting meaningful learning. This paper presents the design, implementation and evaluation of a web-based system to support secondary school students' collaborative argumentation (CA) in science learning in Singapore. A pedagogical model named the Spiral Model of Collaborative Knowledge Improvement (SMCKI) is proposed in this study to inform the system and learning activity design. Starting with a stage of individual brainstorming, the pedagogical model scaffolds students to go through five stages of intra-group and inter-group knowledge improvement and refinement, to support the advancement of their collective and individual knowledge. The results showed that the students significantly improved on their scientific content knowledge through the staged collaboration argumentation activities in the web based learning environment.

Introduction

In recent years there is a shift in science education from focusing on exploration and experiment to the construction of argument and explanation (Duschl & Osborne, 2002). Argumentation refers to the process of discussion and negotiation among peoples of different point of view (Osborne, Erduran, & Simon, 2004; Sampson & Clark, 2009). Argumentation is part of the practice of science for evaluating, refining and establishing new theories (Duschl & Osborne, 2002). It has been widely recognized as an effective approach for science learning (Osborne & Patterson, 2011) as it helps students improve their conceptual understanding (Bouyias & Demetriadis, 2012), understand the nature of science, promotes deeper learning of content (Nussbaum, 2008), enhance knowledge creation (Erduran, Simon, & Osborne, 2004), and develop metacognitive skill (Böttcher & Meisert, 2011).

Many effective argumentation happens among students (Scheuer, Loll, Pinkwart, & McLaren, 2010) who engage in proposing, critiquing, coordinating evidence with claims to construct arguments and explanations, reflecting, and evaluating each other's' ideas. Educational researchers have developed some pedagogical approaches and tools to support students' collaborative argumentation (Scheuer et al., 2010). However, students were often found as working ineffectively and inefficiently when doing the argumentation. Students are still not substantively engaged in the process of discussion and negotiation (Yun & Kim, 2015). One of the critical issues is that students' discussions do not lead to significant improvement of idea improvement due to the lack of interdependence among group members. More carefully designed collaborative argumentation activities which can support idea imporvement is needed.

This paper presents a web-based platform to support students' collaborative argumentation in science learning. Developed by National Institute of Education, Nanyang Technological University Singapore, this system is designed for supporting generalized coordination of collaborative argumentation among students and the teacher in the following three aspects: 1) argumentation: developing graph-based argumentation to represent argument elements, and relationships between them, 2) collaboration: scaffolding student's continuous knowledge improvement through a staged Spiral Model for Collaborative Knowledge improvement, 3) peer assessment and critique: supporting intra-group peer assessment and critique by quantitative rating and qualitative feedbacks.

Literature review

Argumentation and learning

Argumentation is viewed as a vital type of knowledge construction activity that can lead to knowledge advancement (Weinberger & Fischer, 2006). Science teachers have designed various learning activities to support students' argumentation (Emig, McDonald, Zembal-Saul, & Strauss, 2014), and students are encouraged to participate in scientific practice activities, reflective dialogue, and actively use evidence to support their own

claims (Bulgren et al.,2014; Duschl et al., 2002). Argumentation is as an effective learning process and educational outcome for science education (Osborne & Patterson, 2011).

Many argumentative frameworks have been proposed to support students' argumentation in science education. Toulmin Argument Pattern (TAP) is the most commonly used framework (Toulmin, 1958). TAP consists of six elements: claim, qualifier, data, warrant, backing, and rebuttal. A *claim* is an assertion, or statement, about a belief or idea. *Grounds* are statements or reasons that support the *claim*. *Warrants* are an elaboration on the reasoning behind why the person believes their *claim* to be true. A *qualifier* provides strength and clarification to the *grounds* and *warrant*. With a *qualifier*, the claim is valid only during a specific circumstance. A *rebuttal* is a particular condition in which the *warrant* becomes void and the *claim* is not valid. While a *qualifier* can provide strength and clarification, the *backing* provides support to the *warrant* by stating why the *warrant* is acceptable.

Another argumentation framework is Walton's argumentation scheme (Walton & Reed, 2005). Walton breaks down argumentation into six different types of dialogue: persuasion dialogue, the inquiry, negotiation, information-seeking dialogue, deliberation, and eristic dialogue. Persuasion dialogue is when one person is trying to persuade another person that some particular suggestion is true through the use of arguments that show or prove that it is true. Inquiry dialogue involves a group of people investigating the reasons for some event or phenomenon. Negotiation dialogue involves bargaining, while information-seeking dialogue is when one person has, or appears to have, information that another person wants. Deliberation dialogue is making a decision to solve a problem and lastly, eristic dialogue is a quarrel between two people. The argumentative patterns are widely used to evaluate students' argumentation ability and its development (Garcia-Mila, Gilabert, Erduran, & Felton, 2013).

In addition to providing argumentative frameworks to help students develop their ability to argue, many studies have found that graph-based computer application tools can help students develop argumentation skills and scientific knowledge (Dwyer, Hogan, & Stewart, 2012; Hsu, Dyke, Smith, & Looi, 2018). Compared with these previous studies, this study especially emphasizes the integration of technology and pedagogy. While technical tools support scientific argumentation, pedagogical design better supports students' collaborative learning.

Collaborative argumentation

As reflected in literature, students encounter a lot of difficulties in collaborative argumentation. Except for unequal participation and low level engagement as often observed in collaborative learning activities (Choo, Eshaq, Samsudin, & Guru, 2009), students might also not use appropriate and/or enough evidence to warrant their claims, or justify their choice of evidence in the arguments they produce (Erduran, Simon, & Osborne, 2004; Weinberger, Stegmann, & Fischer, 2010). The self-explanations made during argumentation were only sporadically generated by even good students (Larusson & Alterman, 2009). Students did not evaluate the validity or acceptability of an explanation for a given phenomenon in a satisfying way as well (Bouyias & Demetriadis, 2012). There was also evidence that students had problem producing "a good argumentation sequence" (Larusson, &Alterman, 2009). When required to engage in scientific argumentation, a critical type of discourse epistemic practice in doing and communicating science (Lazarou, Sutherland, &Erduran, 2016), students were confronted with more challenges. Existing research has indicated that students often lacked ability to determine the acceptance, rejection, or modification of ideas (Hogan & Maglienti, 2001). Their acts of distorting, trivializing, and ignoring certain evidence frequently resulted in misconceptions (Sampson & Clark, 2008). In the realm of CSCL research, collaborative argumentation is regarded as a key type of knowledge construction process that should be mastered by students to enable knowledge advancement. Yet in the argumentation processes, students without necessary training were often noted as working ineffectively and inefficiently. They did not ask each other questions, not explain or clarify their own opinions, not articulate the reasoning behind, not elaborate and reflect on knowledge (Kollar, Fischer, & Hesse, 2006; Martin & Hand, 2009). They also hardly take alternative perspectives into consideration (Sampson, Grooms, & Walker, 2011).

In science education, engaging in collaborative argumentation is challenging for most students (Gould & Parekh, 2018). During the process of collaborative argumentation, it is difficult for students to construct scientific explanations, and students adopt the wrong ways of arguing and only a few students can complete the argumentation task (Ryu & Sandoval, 2012). The main reason for this phenomenon is that students lack the basic skills of collaborative argumentation. Students don't know how to create a logical point of view and present evidences for support it. To improve students' performance of collaborative argumentation, one kind of method is to provide students with a structured argumentation scaffold (Suthers, 2003).

Web-based system design

The web-based system development is based on the J2EE platform, and adopts the SSH (Spring, Struts, and Hibernate) technology. The system includes three modules: graph-based argumentation, collaborative knowledge

improvement, and peer assessment and critique. Figure 1 shows the screenshots of the system. The central area of the screen is students' graph-based argument workspace, where students use evidence to support or oppose the claim. The activity description (such as activity topic, activity introduction, role assignment, experimental data and evaluation rules, etc) and chat window are shown on the top right of the page.

Graph-based argumentation design

The system is a graph-based argumentation application that uses different shapes to represent the argument elements. The oval node represents the claim, the cloud node represents the idea (not sure if it is claim or evidence), and the rectangle node represents the evidence. The explanation of shapes of the argument elements in the system are shown in figure 1. The arrows represent the relationships among the nodes. Green arrows represent "evidence for" whereas red arrows represent "evidence against".
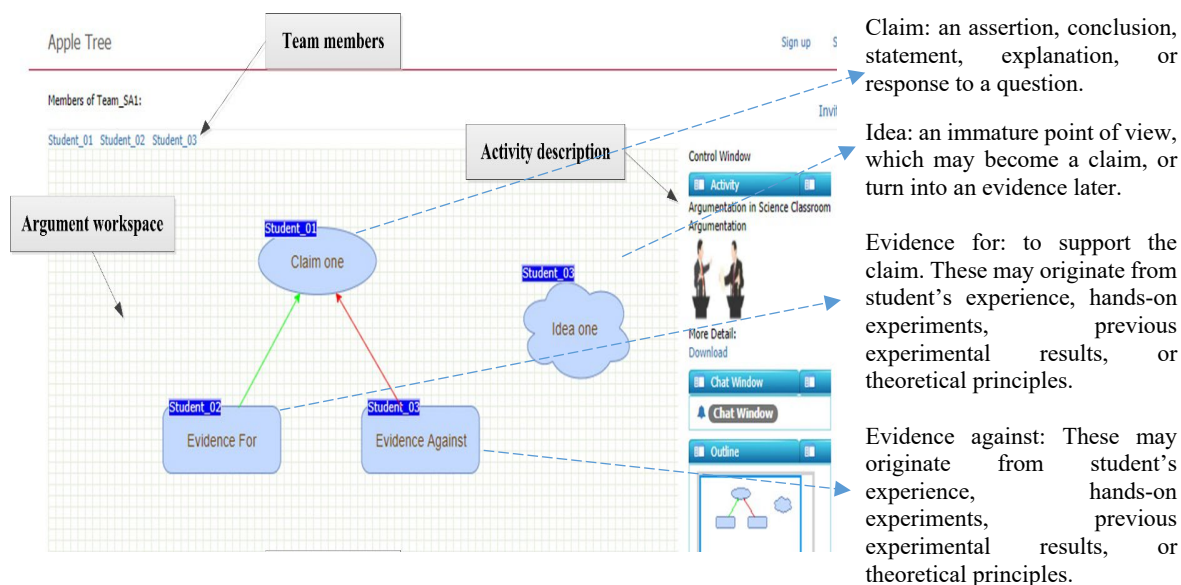

Figure 1. The Screenshot and explanation of augment elements of the System.

The system supports uploading and downloading attachments (including pictures and documents) with the nodes. In addition, the system supports the transitions between different shapes, for example, the idea can be changed to the claim, or changed to the evidence if it was connected with the claim. Because the team members are engaged in collaborative argumentation, members from the same group can modify or delete the nodes/relationships created by other members of the group.

Collaboration design: Spiral Model of Collaborative Knowledge Improvement (SMCKI)

Instead of collaboration scripts that generally provide a detailed set of guidelines, rules and structured tools for describing how the group members should interact, we propose a pedagogical model to guide the interaction processes so that Collaborative Knowledge Improvement can happen more effectively in classrooms. The 5-stage Spiral Model of Collaborative Knowledge Improvement (SMCKI) provides a tangible structure for one operational collaborative activity design beginning with brainstorming and a structured process of constant knowledge improvement. The model focuses on democratic knowledge sharing as well as cycles of individual, group and class knowledge enhancement (see Figure 2).

This model is based on the authors' previous work on Funnel Model for rapid collaborative knowledge improvement (Wen, Looi, & Chen, 2011), which consists of three stages of collaborative learning process. By respecting and encouraging cognitive diversity, the first stage encourages the creation of diverse ideas. The subsequent stages tap on this diversity to seek synergy of ideas, and a stage of convergence and consensus seeking leading to knowledge convergence and advancement of the individuals, groups and class. The CMCKI model entails 5 stages (Figure 2). The teacher used verbal instructions and system buttons to regulate the 5 stages of scientific argumentation activity.

I: Individual brainstorming: Students individually construct argument with claims and evidences of the scientific phenomena. The argument represents the best knowledge of the individuals.

II: Intra-group synergizing: Students discuss, synergize and consolidate group members' work by deleting, adding, modifying nodes/relationships. A group graph-based argumentation diagram is created which represents the best knowledge of the group.

III: Inter-group peer assessment and critique: Students go to other groups to provide quantitative ratings and qualitative comments by identifying the strengths and areas for improvements.

IV: Intra-group refinement: Students go back to their own groups and refine the group work based on other groups' ratings and feedbacks. After further verbal negotiation, they were required to seek consensus and finalize their group idea.

V: Individual idea perfection: Individually, students write an argumentative essay or reflection report to explain the scientific phenomena.
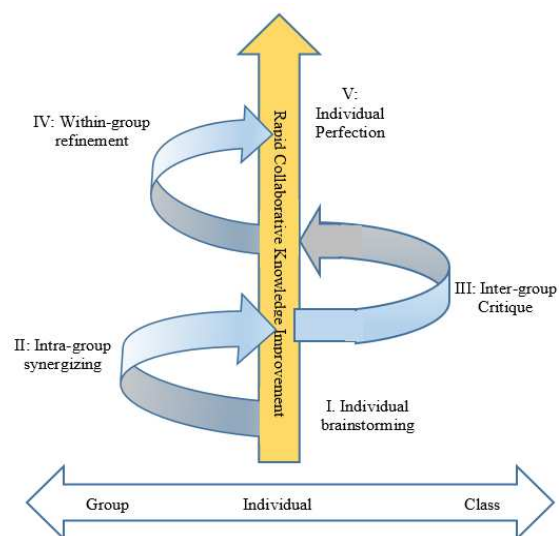

Figure 2. Spiral Model of Collaborative Knowledge Improvement.

Peer assessment and critique

In stage III of SMCKI, students go to other groups to provide quantitative rating and qualitative feedbacks on the content and structure of the argument. Students can rate both the nodes and the relationships in the argument diagram. When students double-click the node or relationship, an assessment window will pop up (see Figure 3). All the students' qualitative feedbacks will be displayed in a table format. In order to encourage thoughtful critique and rating, each element of the argument diagram can only be rated once. Students name will not be shown in this stage.

To make the ratings more intuitive for students, the color of the lines of those nodes and relations which received positive ratings will be highlighted whereas the color of the lines of those nodes and relations which received negative ratings will be lighter. This feature will help channel teacher and students' attention when they do stage 3 and 4 argumentation activities. On top of assessing the individual elements of the argument diagram, students can assess the whole diagram based on the rubrics given by the teacher.
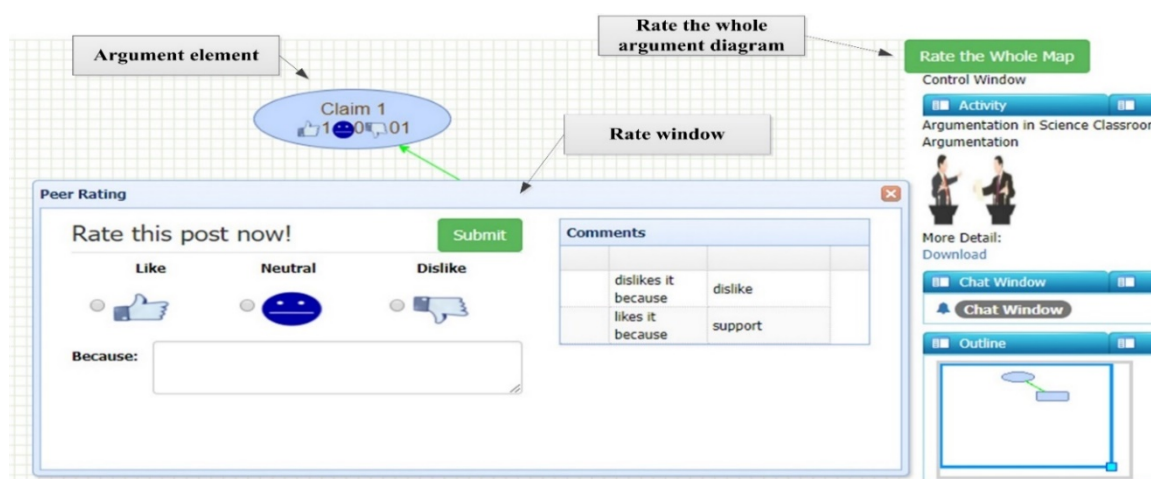

Figure 3. The screen shot of the peer assessment and critique (Stage III of SMCKI).

Research questions

In this study, we focus on investigating whether and how was the use of web-based system informed by the SMCKI helpful for improving students' conceptual knowledge learning?

The enactment of SMCKI in science classroom

Participants

A secondary grade 4 (16 years old on average) class with a total of 33 students in Singapore participated in the project. They studied physics phenomenon though SMCKI approach using the system. All the students in this school are equipped with a personal iPad 24/7, and they are proficient in using iPad as a learning tool. The teacher has rich experiences in science teaching and he is tech-savvy. Before the project started, researchers conducted training for the teacher with the aim to improve teacher's understandings of the technological and pedagogical design of the system. All the students were heterogeneously grouped by the teacher according to their ability. There were nine groups of 3-4 students in the class.

The collaborative argumentation activities were co-designed by the teachers and researchers. Three lessons were implemented (50 minutes per lesson) from July to August in 2018. The data analyzed in this paper were from the third lesson on the electromagnetic induction phenomenon. Following the SMCKI approach, students went through 5 staged of collaborative argumentation. The time allocation for each stage is: Individual brainstorming (7 minutes), within-group synergizing (10 minutes), inter-group assessment and critique (8 minutes), intra-group refinement (10 minutes), and individual perfection (after class). The paper examines the students' conceptual development in the process for 5-staged collaborative argumentation activities.

Methods and instruments

During the collaborative argumentation activities, students were asked to provide explanation about the phenomena that they observed from an iPad which showed the induced current flowed in a solenoid over time when a magnet fell through it. Students presented their explanations based on an explanation framework which consisted three elements: claim, evidence, and reasoning (McNeill, Lizotte, Krajcik, & Marx, 2006). A total of 48 explanations generated in students' collaborative argumentation activities. Content analysis was employed to analyze the nature of peer comments in Stage 3. The unit of content analysis is one comment.

Pre-test and post-test design. Pretest and posttest were used to measure students' conceptual knowledge before and after the collaborative learning activity and used the same text paper, which contained 4 questions, one point for each question. The test questions were closely related to the knowledge points in this lesson.

Coding scheme of peer feedbacks. A coding scheme adapted from Clark & Sampson (2007) was used to code students' qualitative feedbacks in stage 3. The coding scheme consists of five codes: rebuttal, support, query, emotive appeal, and off-task comments. The second and third authors independently coded all the 79 comments, with an inter-rater reliability of 0.864 (Cohen's Kappa).

Students' interview design. Students were required to reflect on their experiences of collaborative learning based on one guiding questions in the post-intervention interview: What did you do at each stage of collaborative learning activity?

Data analyses and results

Comparison of students' conceptual understanding between Stage I and Stage V.

In Stage I and V, individual students are required to construct argument and explanation of the scientific phenomenon individually. A comparison was made to measure students' conceptual knowledge between stage I and V. Descriptive statistics were used to analyze the mean and standard deviation of conceptual understanding, see Table 1. As the data do not conform to normal distribution, the Wilcoxon signed Ranks test was used to detect differences on conceptual knowledge between 2 stages. The results in table 1 showed that students' conceptual understanding in Stage V was significantly higher than the stage I ($z=-4.647^{**}$, $p<0.001$).

Table 1: Wilcoxon signed Ranks test results

	N	Minimum	Maximum	Mean	Std.Dev	Z
Stage I	33	0	4	2.58	0.830	-4.647***
Stage V	33	2	4	3.70	0.529	

Note. *** $p<0.001$.

Students' conceptual development throughout staged activities: Group 3 as the case study

We provide a qualitative account of group 3's process of doing the staged collaborative argumentation. In order to clearly show the process of students' revision of their explanations, we used bold font and underlining in the text to show the position of students' revision.

Stage I individual posting. All 4 students (Jenny, Hellen, Nichole, and Sabrina, all pseudo names) managed to post their explanation of the scientific phenomena based on their pre-existing knowledge.

Stage II intra-group synergizing. After seeing each other's posting, students compared each other's explanations and tried to synergize their work through negotiation and discussion. In this stage, Helen added a scientific knowledge element to her previous explanation in stage 1.

*"When the magnet first enters the solenoid, there is a momentary increase in rate of cutting of magnetic field lines by the coil, hence by Faraday's Law, an e.m.f. is induced in the coil and there is a current. In the moment that the magnet is completely in the solenoid, there is no rate of cutting of magnetic field lines by the coil, so there is no e.m.f. induced in that moment and the current is 0. When the magnet falls out of the solenoid, there is a momentary decrease in rate of cutting of magnetic field lines by the coil, hence by Faraday's Law, an e.m.f. is induced in the coil. Since the motion of the magnet is in the opposite direction as compared to when it enters the solenoid, the induced e.m.f. is in the opposite direction and the current is also in the opposite direction, **by Lenz's Law**." (14:02, posted by Helen)*

In this stage, Sabrina repeatedly revised the statements that represent her explanation. In the process of revision, the representation of Sabrina's explanation moved closer to the expert scientific concept knowledge.

*"When the magnet is dropped into the solenoid, **there is a momentary rate of cutting of magnetic** field lines and thus an e.m.f is induced and a current in the solenoid is recorded. According to Lenz's law of motion, as the magnet changes direction to move out of the magnet, the current recorded would be of **similar magnitude** and amplitude but in a different direction." (14:06, posted by Sabrina)*

In stage II, students not only revised their own explanations, but also added new explanations. Sabrina added a new claim and evidence to improve own explanation. Jenny put forward a backing to Helen's explanation. During the post-activity interviews, the 4 students explained to researcher how they synergized their group argumentation diagram in Stage 2. Students discussed with her group mates first and then modified her explanation (from the interview transcript with Sabrina). If student's concept is wrong, she would modify her explanation (from the interview transcript with Sabrina). If students thought their partners' explanations make more sense, they will add others' idea to her explanation (from the interview transcript with Helen).

Stage III Intra-group assessment and critique. Group 4 students went to group 3 to provide ratings and feedbacks. To examine the role of stage 3 peer critique for students knowledge improvement in argumentation, content analyses was done to understand the nature of peer comment given. Group 4 gave a total of 7 comments in this stage, including 1 support, 3 rebuttals, and 3 emotive appeals. Table 2 shows an example of comments given by group 4.

Table 2: An example of comments given by group 4 to group 3

1.Explanation	Group 3 (Student *Jenny*) "When the magnet is drops into the coil, there is a momentary rate of cutting of the magnetic field lines from the magnet by the coil. By faraday's law, an emf is induced in the coil, which drives an induced current, hence a sudden increase in magnitude of current was recorded. This repeated in the opposite direction when the magnet fell into the solenoid, hence by lenz's Law, the direction of the current is opposite to that at first, so a current of similar magnitude but in opposite direction was recorded."
1.1 Rebuttal	Group 4 (comments to group 3) "why does the direction change? "
1.2 Rebuttal	Group 4 (comments to group 3) "What does "direction of current is opposite to that at first" a bit confusing."
1.3 Emotive appeal	Group 4 (comments to group 3) "True"

During the post-activity interviews, students explained their experiences in this stage. In this stage, students of group 4 gave comments to group 3 based on the following criteria: (1) key words, (2) explanation was clear or not, (3) the number of evidence supported one claim, (4) students' understanding of the conceptual knowledge, and (5) the concept was correct or accurate. If students thought that the other group's explanations were better, they would bring other groups' ideas to their own group.

Stage IV Intragroup refinement. Based on the explanations and comments from other group, students in group 3 further revised their explanations. Students added scientific conceptual knowledge in their explanations or had their doubts about some conceptual knowledge cleared.

Discussion and conclusion

This study proposes web-based platform to support students' collaborative argumentation in science education by scaffolding students' graph based argumentation informed by a spiral model of collaborative knowledge improvement. An empirical study was conducted to investigate how student construct argumentation for science learning throughout the stage-collaborative argumentation activity. The paper provides a descriptive account of the interactions of a group as the students engaged in spiral cycles of knowledge improvement. The case study demonstrates that students' conceptual understanding improved continuously through the 5 stages of SMCKI. This study also showed that revision, deletion and synthesis of explanation were sophisticated skills, and the web-based system needed to provide scaffoldings for the development of students' these skills. In addition, teachers' feedback was also very important. In the second and fourth stages, students would perform better if teachers could provide some feedback on scientific knowledge and collaboration process.

Informed by SMCKI, our web-based system has 3 characteristics: "low floor", "wide walls", and "high ceiling". "Low floor" means all students can easily participate and contribute to the group and class's knowledge improvement; "Wide walls" means the networked online system enables everyone to connected through individual-group-class-group-individual interaction pattern. There are many opportunities for students be exposed to diversified ideas and perspectives. "High ceiling" means that students can tap on each other's ideas to improve the knowledge throughout the staged spiral model. Our empirical study shows that the quality of ideas of the one stage is always higher than the preceding stage. Students work on increasingly complicated ideas by communication, negotiating and critique, all of which require higher order thinking.

The SMCKI is also meant to scaffold teachers to enact and orchestrate the collaborative learning activities in the classroom as well as to build capacity to be able to design such learning activities themselves. It has the potential for teachers to embark on collaborative learning activities in the classroom and to manage the risks of the activities breaking down or not reaching any kind of fruitful collaboration. SMCKI is not specific to collaborative argumentation or science learning. It can be applied in any collaborative learning activity. Further study is needed to investigate the application of SMCKI in other contexts of collaborative learning.

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