Education Tech Research Dev (2019) 67:63–83
https://doi.org/10.1007/s11423-018-9606-x

RESEARCH ARTICLE

Elementary students enhancing their understanding of energy-saving through idea-centered collaborative knowledge-building scaffolds and activities

Huang-Yao Hong[1] · Pei-Yi Lin[2]

Published online: 4 June 2018

Abstract Effective energy education depends on continuing research designed to identify instructional strategies that will proof effective in particular learning contexts. The aim of this study was to help Taiwanese students learn about energy-saving related concepts through idea-centered, collaborative knowledge-building activities carried out in an online environment. The participants were 34 fifth-grade Taiwanese students. The data were taken mainly from students' online interaction logs and discourse content. We found that knowledge-building activities helped to transform students into more collaborative, autonomous and creative learners, capable of working innovatively with ideas to address the energy-related issues under discussion. The students also demonstrated deeper understanding of the energy-related topics they explored. This study suggests that knowledge-building, an innovative pedagogical approach, was conducive to collaborative learning even in young students.

Keywords Energy education · Collaborative learning · Knowledge-building scaffolds

Energy-saving is a very complex environmental issue that is relevant to the future survival of all human beings and our planet (Boyes and Stanisstreet 1993; Hansen 2010). Collaborative problem-solving will be required to address this difficult issue; it will not be possible to rely on an individual genius. This implies that we need to raise global awareness of the need to save energy through education. Young students can be taught the

✉ Pei-Yi Lin
hanapeiyi@gmail.com

[1] Department of Education, National Chengchi University, Taipei, Taiwan

[2] Ontario Institute for Studies in Education, University of Toronto, Toronto, Canada

collaborative science and problem-solving skills that will be needed to address emergent environmental problems. The aim of this study was to use collaborative learning to improve students' understanding of issues related to greenhouse effects and sustainable energy use. To this end, a knowledge-building approach that emphasizes "idea-centered collaboration" (Hong 2011) was implemented. This kind of collaborative approach is very different from group-based collaboration, which is commonly used in schools in Taiwan. The latter approach was designed to help students learn and master rich knowledge (e.g., textbook concepts) as efficiently as possible, through group-based division of labor or collaboration. In contrast, idea-centered collaboration is more concerned with students' ability to work creatively with ideas in tackling an inquiry problem. It is posited that carrying out well-designed collaborative learning activities will help students develop the necessary knowledge, skills and attitudes to learn about the science relevant to energy and environmental issues. In the following, we first discuss the importance of energy education, and outline our rationale for using an idea-centered collaborative approach. Then we present the method, research questions, study design, data and analytical approach used to address the research questions. Finally, we present and discuss our findings.

Literature review

Energy education

Boyes and Stanisstreet (1993) proposed that energy education should start from the early years of childhood. Hansen (2010) argued that if environmental issues (such as ozone depletion) are to be addressed it is important to include discussion of the related issues in both formal and informal science education. Hansen also noted that news media constitute a primary source of misconceptions and inaccurate information that are widely available to young children. One can conclude from this that energy education should start as early as possible. Zografakis et al. (2008) pointed out that people actually become more energy-savvy after receiving energy-saving education or information. Dias et al. (2004) noted that energy education is an effective way of promoting environmental awareness. Through effective energy education, a positive, instant, and permanent impact on the future citizens is more likely. However, identifying more effective pedagogical approaches to informing young children about energy-related environmental issues remains an educational challenge.

Most previous studies of energy education have been based on surveys of knowledge, attitude or behaviors in relation to energy issues (e.g., Boyes and Stanisstreet 1993; Hansen 2010; Kukkonen et al. 2014; Skamp et al. 2013; Zografakis et al. 2008). There have been fewer intervention studies (Solbes et al. 2009); however effective energy education depends on continuing research designed to identify instructional strategies that will proof effective in particular learning contexts and it is important to continue this strand of research. Better education about energy issues—better curricula and better pedagogical methods—is more likely to lead a more energy-conscious population.

To address the worldwide environmental and energy-related issues, education should not merely focus on passive reception of basic concepts from textbooks, but should promote active and interactive discussion of actionable ideas that would lead to in-depth understanding for solving real-world problems. This study represents an attempt to test an innovative pedagogical approach that relies on emergent, idea-centered collaborative knowledge building through discussion to achieve the above educative aim.

Collaborative learning

The concept of collaborative learning originated with Johnson and Johnson (1993), who were amongst the first to advocate this approach, setting up the Cooperative Learning Center in America during 1960s. They were also amongst the first to apply this learning theory in classroom settings. Since then, more and more studies have been conducted, and now collaborative learning is a widely accepted and practiced pedagogical approach. It is a learner-centered instructional strategy (Cuseo 1992), so students work together to discuss, clarify, and explore ways of solving specific problems (Johnson and Johnson 1993; Slavin 1995). The collaborative process requires students to deepen their interpersonal relationships and develop their social skills in order to make group learning more effective (Slavin 1995). In their collective endeavors students may choose to divide the labor or work in teams (Deutsch 1949). Collaborative learning has been shown to have positive effects on learning ability because it involves working together to achieve group goals (Lipponen 2000; Hewitt 2002; Stahl 2006). It also improves social skills (Kirschner 2001; So and Brush 2008; Stahl 2006), promotes cognitive, psychomotor, and affective skills, and promotes healthy personality development and good mental health (Huang and Lin 1996). More importantly, collaborative learning enhances knowledge outcomes and students' capacity for argument (Deutsch 1949).

Two types of collaborative learning

A review of collaborative learning by Dillenbourg et al. (1996) noted that an early definition of collaborative learning was that it involved "learning in group" or related to how individuals achieved personal knowledge goals within a group. The concept has been extended to encompass "learning by group" (Hong and Scardamalia 2014) or how the group as an epistemic agency performs collective learning tasks as a whole (e.g., see Stahl 2006). Often group-driven, collaborative learning depends on highly structured group activities and group-working techniques, such as division of labor and scripted role-play (Fischer et al. 2007, 2013), to ensure efficient collaboration. Group-based collaboration is not the only form of collaboration to attract interest. For example, another type of collaboration emphasizes emergent, random, and self-organized interactions (e.g., Biehl et al. 2008; Moreno et al. 2003). As noted by Moreno et al. (2003), the Internet has enabled users to work collaboratively from their personal computer terminals in a more random and opportunistic manner and outside of traditional small and fixed group structures. Internet collaborators gather together based on a shared interest and then work collaboratively without any pre-determined division of labor or any particular group format. Hong's (2011) study showed that young students were capable of working collaboratively outside formal group structures, by embracing more emergent approaches to collaborative learning. During the collaboration, community members may group and re-group based on similarity of inquiry problems and interests. Below, we discuss these two different types of collaborative learning in greater depth.

Group-based collaboration

Group-based collaborative work has a long history dating back to the industrial age (Johnson and Johnson 1993). Back then, division of labor played an essential role in teamwork and completion of tightly scheduled production tasks. Under this influence, school learning placed considerable emphasis on equipping students with the skills they would need to perform group-based tasks in their working lives. School work and projects often involved assigning students clearly-defined roles and asking each group member to do a part of a whole-group task. The Jigsaw method (Aronson and Patnoe 1997) is a well-known example of this collaborative instructional approach and has been shown to be a very successful collaborative strategy. It was based on the concept of division of labor. In the Jigsaw method each group member is assigned a part of the whole task—a puzzle piece—the task is completed when all the puzzle pieces are put into place (see also Brown and Campione 1990). All group members are expected to achieve a much more comprehensive understanding of the whole task through the help of other group members.

This kind of group-based, task-driven, or scripted collaborative learning is especially helpful as a way of enabling individual learners to work with specified, textbook-based knowledge and develop skills efficiently. For example, studies suggest that scripted group work facilitates better argumentation skills (e.g., Noroozi et al. 2013b; Vogel et al. 2016), promote more critical and elaborative discussion skills (e.g., Scheuer et al. 2014), and foster better knowledge acquisition skills (e.g., van Dijk et al. 2014) and knowledge transfer skills (e.g., Noroozi et al. 2013a). However, there are also concerns such as challenge in deciding how much to script for learners (Fischer et al. 2013), helping learners develop their own (Tchounikine 2016) or over-scripted group learning (Dillenbourg 2002) that require further research.

Idea-centered collaboration

This type of collaboration is an alternative approach that emphasizes flexible and emergent ways of collective working that go beyond fixed group formats. Such collaborations are usually opportunistic, less-scripted, and self-directed rather than pre-planned or highly-structured, and they are often driven by people with shared interests who want to work on the same problem (Tsai et al. 2017). Because of this, they choose less rigid, more flexible collaboration structures (Biehl et al. 2008; Moreno et al. 2003). One example of this kind of approach to collaboration is idea-centered collaboration. Idea-centered collaboration is possible because the collaborators have a common interest in certain ideas. People who collaborate in this way tend to see ideas as what Bereiter (2002) called conceptual artifacts. Idea-centered collaboration is commonly practiced in the scientific community. Ideas, as an immature form of scientific theory, are the key determinant of who is involved in a collaboration and where and how it develops, hence pre-determined, fixed-group based collaboration is less relevant in these contexts. Usually, the ideas that are created and developed through idea-centered collaboration will have their own social life and can be opportunistically improved by anyone in the community of interest. The ideas are thus subjected to continual refinement and advancement by the community. The rapid development of Web 2.0 technology has meant that such idea-centered collaboration has become quite common on the Internet and is also found in many technology, research, design and business communities. For example, many of today's state-of-the-art technologies are designed collaboratively by online, self-organizing technology communities (Rycroft 2003). For instance, Linux was developed and is continually improved by an informal community of volunteer programmers who constantly exchange open-source coding ideas without any clear division of labor or defined group structure (Evans and Wolf 2005).

Knowledge-building environment

Knowledge building is defined as a collaborative process that is focused on sustained production and improvement of ideas that are of value to a community (Scardamalia 2004). The opposite of knowledge building is knowledge telling, in which the emphasis is on individuals' acquisition, internalization and accumulation of existing knowledge and activities that validate and confirm such knowledge. In contrast, in knowledge building the emphasis is on students' engagement in the production, communication, diversification, and reflection, elaboration, improvement and creative use of ideas to advance knowledge.

In order to support sustained idea-centered collaboration, knowledge building emphasizes community-based work. It is possible to organize students into small groups that engage in group-based activities; however in a knowledge building environment the preferred approach is to encourage students to work as a larger community and to group and re-group based on the similarities and differences in the ideas they are dealing with at a given time. For example, a student may come up with the idea that walking (instead of driving) to work would reduce emission of carbon dioxide. The student would then search the forum for similar ideas and work on them, regardless of the element of group interaction. This kind of idea-centered collaborative process is inherently emergent and opportunistic. All the student members of a class community can become idea contributors and collaborators as long as the idea under consideration is of interest to them. Pre-defined grouping is not essential. New understanding and knowledge takes shape gradually, through collective reflection, communication, and refinement of ideas as the students' work progresses (Scardamalia 2002; Scardamalia and Bereiter 2003). In a knowledge-building environment students need to serve as knowledge workers, thinking and creating collaboratively, continually modifying and improving ideas as a class community and working towards more coherent explanations and ideas (Thagard 1989). In a knowledge-building environment, the evolution of knowledge begins with the generation of ideas and continues through sustained improvement of those ideas; there is no end to this process (Hong and Sullivan 2009). In a knowledge-building environment the teachers also need to foster a safe and open atmosphere that allows students to tinker and experiment with new or different ideas and to share, question, discuss and improve these ideas in interactions with their peers. The development of a successful knowledge-building environment is a process of enculturation or cultural transformation which can greatly influence the efficacy of students' knowledge-building activities.

The present study

Traditional instructional approaches in Taiwan tend to: (1) emphasize individual learning; (2) emphasize knowledge acquisition and mastery of textbook knowledge; (3) deprecate the use of new technologies/tools. To address these issues, the government has encouraged a constructivist-oriented, instructional reform movement that supports all forms of computer-supported collaborative learning. As a consequence many educators are looking for innovative ways of engaging students in active and constructive collaborative learning rather than individual learning, and inquiry-based learning rather than textbook-based learning (Palloff and Pratt 2002). To support this reform movement we investigated knowledge-building via Knowledge Forum (KF), a technology-enhanced learning environment (Scardamalia and Bereiter 2006; Scardamalia 2002; Scardamalia and Bereiter 2003). Previous research indicates that knowledge building promotes student engagement in more active forms of learning and in self-directed learning (Hong and Lin 2010) and fosters students' higher-level thinking skills (Hong et al. 2011, 2014; Zhang et al. 2011). However, whether and how engaging students in a knowledge building environment facilitates idea-centered collaboration and thus improves science learning outcomes remains an open pedagogical challenge to be addressed by knowledge building researchers. The purpose of this study was to investigate whether engaging elementary students in KF, used as a knowledge-building environment, would help them (1) to learn together as a whole community (rather than individuals) and engage in idea-centered, collaborative learning and (2) to develop better knowledge and deeper understanding of the scientific topics into which they inquired (i.e., greenhouse effects and energy-saving) collectively.

Research method

Study design, context, and participants

This study employs a case study because of its exploratory nature (Creswell and Creswell 2017) that is suitable for this research to explore a new pedagogical approach (i.e. idea-centered collaboration) for students' science learning in a small class within a particular Taiwanese cultural context. Although the small sample size from a case study is often seen as a concern, some researchers (e.g., Yin 2013) argue that the results of a case study can still be generalizable to inform teaching and learning in similar context. The participants were 34 grade-five students in one class of an elementary school in Taipei, Taiwan. They spent one class session (i.e., 40 min) per week inquiring two main science topics at issue in this study. The two topics and the duration of each inquiry topic were as follows: the greenhouse effect (with 9 weeks being spent in the first semester) and energy conservation (with another 9 weeks being invested in the second semester). The typical classroom culture in Taiwan values more traditional teaching methods such as lecture and small group project, or team work. The science teacher in this study is also highly skilled in using traditional teaching methods in his science class. However, as a seed teacher for promoting innovative teaching, he had also been using KF for 1 year right before the start of this study, so in a sense, he was also trying to facilitate a transformative move from traditional teaching methods to adopting new pedagogical approaches. As for the students and the classroom setting, they had never used KF before, and the classroom was a standard, Internet-connected science classroom equipped with 12 laptops. The students were free to use these laptops to work on their inquiry ideas in KF.

Instructional design

Three knowledge-building principles were used to engage the participants in sustained knowledge-building activities via KF. (1) Authentic problem and real ideas: through discussion in KF, students were encouraged to identify a core problem related to the inquiry topics and to generate initial ideas for addressing this problem. KF provides "scaffolds" such as "My idea/theory" to make it easier for students to generate ideas. (2) Idea diversity: students were encouraged to exchange ideas for evidence-based solutions to problems of interest. KF scaffolds relevant to this phase of inquiry include "I need to understand", which can be used to request scientific facts or explanations and "New information", which can be used to provide useful information. (3) Idea improvement:

students were prompted to use the remaining KF scaffolds—"This idea/theory cannot explain…", "A better idea is…", and "Putting our knowledge together…" to reflect on, elaborate, modify and refine ideas. Thus they engaged in iterative improvement of ideas as part of a progressive process of problem-solving and inquiry. KF lessons lasted 40 min and took place weekly. At the beginning of the lesson the teacher spent a few minutes discussing some of the notes that had been posted in the forum. For the rest of the lesson students were free to carry out autonomous online inquiries, collaborations and discussion in KF. In these lessons the teacher served as a guide, encouraging the students to work creatively with ideas in accordance with the knowledge-building principles set out above. There were no lectures. Table 1 shows sample activities guided by different principles and facilitated by different scaffolds.

Knowledge Forum

KF was developed on the basis of knowledge building theory as a way of helping students to generate and improve ideas as part of collaborative knowledge construction (Scardamalia and Bereiter 2003). The customizable scaffolds embedded in KF are designed to facilitate productive discussion and knowledge advancement in the community. Supported by KF, ideas posted in the community can be visualized as a knowledge object and target of collaborative improvement (Zhang et al. 2011; Scardamalia 2004). Research shows that when use of KF is explicitly guided by knowledge-building principles it can be an even more effective method of supporting class-based knowledge construction activities (Hong et al. 2015; Hong and Sullivan 2009; Chan et al. 2012; Zhang et al. 2011). Figure 1 shows a sample screenshot of a KF view (a problem-solving and inquiry space) and a pop-up sample KF note with customizable scaffolds (at the bottom of the figure).

Table 1 Activities guided by knowledge building principles and knowledge forum scaffolds

Knowledge-building principles	KF scaffolds	Instructional activities
Authentic problem, real idea	My Idea/Theory is…	Students are prompted to identify problems of collective interest and to generate ideas to address the problem they have identified using the "My idea/theory" scaffold
Idea diversity	I need to understand…	Students are prompted to identify gaps in knowledge and possible ideas or solutions relevant to the problems in which they are interested
	New information…	Students are prompted to look for additional information or evidence to support their ideas for knowledge advancement
Idea improvement	This idea/theory cannot explain…	Students are prompted to reflect on their ideas and decide whether they help to fill gaps in knowledge or solve problems and then to identify additional areas on which they need to focus to improve their ideas and understanding
	A better idea/theory is…	Students are prompted to generate alternative, competing, or contrasting ideas and theories that may help them to address the problem at issue more effectively
	Putting our knowledge together…	Students are prompted to re-conceptualize the problem under consideration and to integrate and synthesize their various ideas to advance the knowledge of the community as a whole

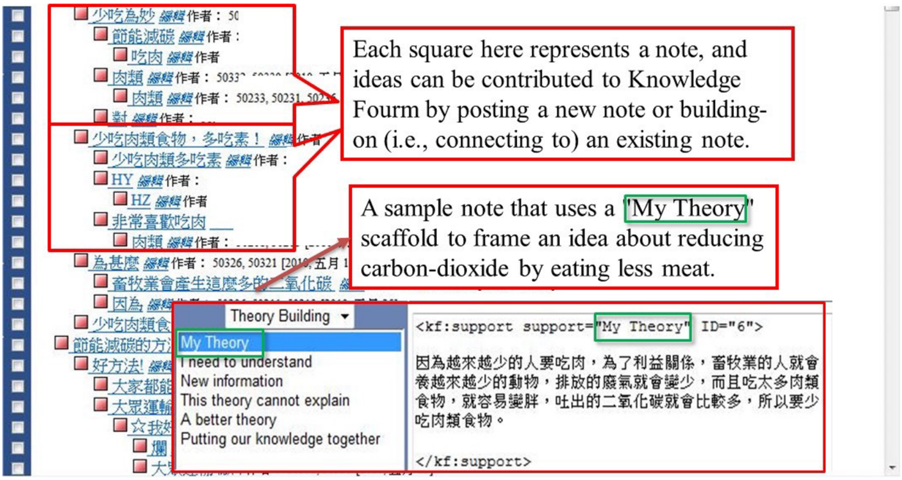

Fig. 1 A screenshot of a Knowledge Forum (KF) view and an example KF note (*Note*: **a** the Chinese text within the KF note as shown in the pop-out window at the bottom of the Figure is the content of an idea written by a student; **b** the note content is about how to encourage people to eat less meat for better environment; **c** on the left side of the figure shows a long list of Chinese titles for all the notes in this KF view)

Data collection and analysis

Data came from several sources, primarily the students' online activity logs in a KF database. First, we carried out a general analysis of online activities based on the numbers of notes students contributed and read. We also looked at two ways of categorizing notes. They were classified according to whether they were written by a single author or co-authored and also according to whether they were non-build-on (non-collaborative) notes or build-on (collaborative) notes. Second, we analyzed idea-related activities based on open coding (Strauss and Corbin 1990) of the notes by two independent coders. The conceptual framework of the coding scheme was validated by Hong and Sullivan (2009) in a published paper and includes four codes: social talk, idea generation, idea sharing and idea improvement (see Table 2); its inter-coder reliability calculated was .96. Creativity was assessed using Guilford's (1967) validated model of creativity that recognizes four aspects of creativity, namely fluency, flexibility, originality and elaboration. All online notes were examined. Table 3 lists definitions and examples for each code. The coding job was done by two independent researchers and the inter-coder reliability was .92.

Third, we analyzed online discussion of important topics related to the two main topics of inquiry, the greenhouse effect and energy-saving, via the following steps. (1) Content analysis of all notes recorded in the database. Figure 2 shows the coding categories and sample concepts in each category; coding was carried out independently by two researchers and inter-coder reliability was .92. (2) All the concepts identified in the KF records were then compared with the concepts listed in the curriculum guidelines from the official EcoLife website of the Environmental Protection Administration in Taiwan (http://ecolife.epa.gov.tw/Cooler). The concepts from the official website were coded by the same two independent raters. Inter-coder reliability for the concepts in the curriculum guidelines was .95.

Table 2 Scheme for coding students' ideas about the greenhouse effect and energy saving

Category	Scaffold	Conception	Example
Social talk	(None)	Social language, no mention of any topic of online inquiry	You've proposed fewer ideas than me! Cheer up! (A22) You did not organize the information you provided. Who knows what you are trying to say! (A21)
Idea generation	1. My idea	Generating ideas about topics of inquiry	My idea: We should take mass transportation more often. (A03) I think greenhouse will result in the raising of the sea level. (A21)
Idea sharing	2. I need to know	Questions about the topics of inquiry	Are there any other types of gases that also contribute to the greenhouse effect? (A16) I need to know: How much carbon is produced in making a children's toy? (A01, A04, A07)
	3. New information	Providing or sharing useful information (from, e.g., website, books, other people…) that is relevant to the topics of inquiry	I found this website that provides some energy-saving ideas: http://sfs.hles.ylc.edu.tw/ee/ (A04) I found that (new information) there are four kinds of gases that contribute to global greenhouse effect. Raising livestock for the production of meat, eggs, milk, fur, and the like can generate three of these gases: carbon dioxide, nitrous oxide and methane (source of information: Yahoo) (A22)
Idea improvement	4. This idea cannot explain	Questioning and criticizing ideas in order to improve them	What if people live on very high floors? Is it still feasible to climb stairs to save energy? (A21) What if the distance is too far to walk? (A07, A05, A16)
	5. A better idea	Proposing better or more coherent explanations	Alternatively, if you live on a very high floor, of course you should take elevator. (A28) If it is not far, you should always walk; if it is too far to walk you can use mass transport or ride a bike to reduce the emission of carbon dioxide. (A09, A10, A14)
	6. Putting our knowledge together	Synthesizing ideas to provide a deeper understanding	To combine with what you mentioned, there are indeed many solutions, like driving less, eating less meat, watching less TV etc.… (A11) To integrate our ideas together means people should drive less and make more use of mass transportation. (A31)

Table 3 Coding scheme for the four aspects of creativity

Aspect	Description	Grading	Examples
Fluency	Number of ideas	Total number of ideas contributed by students to address an issue concerned	For example, student A28 proposed 3 ideas, including eating less meat, reducing the frequency with which people eat out and using heat-preserving containers. The score is 3
Flexibility	Number of idea categories	Total number of idea categories	The 3 ideas listed above were assigned to three categories: "meat and food", "dietary preference" and "food container", yielding a score of 3
Originality	Uniqueness and novelty of an idea relative to the community pool of ideas	Number of ideas that are different from all other ideas in the same idea category	For example, the idea to "decrease the frequency of barbecue activities" was mentioned by only one student and was thus given 1 point
Elaboration	Extent to which an idea is elaborated	More detailed description that makes an idea or explanation more persuasive or more coherent	For example, the idea of "eating more domestic agricultural products" (A29, A26, A23) was elaborated with the following explanation: "…therefore it can help reduce the emission of carbon dioxide…" (A22, A21, A24)

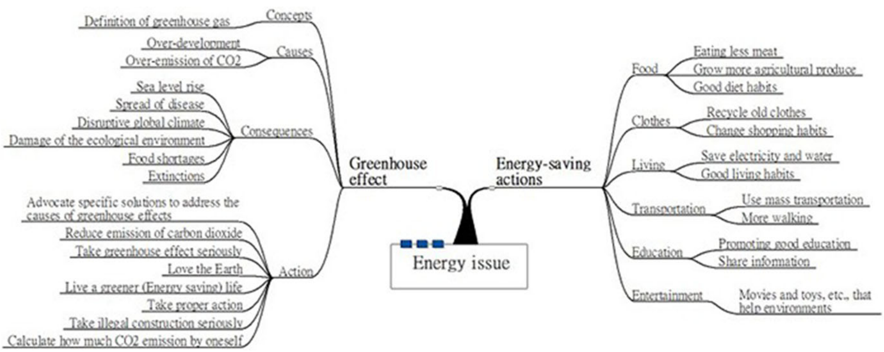

Fig. 2 Main discussion categories under the two inquiry topics: greenhouse effects and energy-saving

While the nature of this research is a case study, in order to better assess students' learning outcomes, analytically we tried to capitalize on all possible data sources in order to help better understand students' learning achievement. To this end, we compared the learning of the class in this study that follows the knowledge-building approach with another class (n = 33) that happens to be taught by the same science teacher using conventional group learning method featured by division of labor. Doing such comparison would help us address a possible criticism that many of the significant differences observed within the single case class may be explained by students becoming more involved in the unit of study as the study progresses.

To proceed with this assessment, students in both classes completed the same test of understanding of the two topics of inquiry. This final open-ended assessment test was self-developed by the science teacher in the class but was content-validated by a science teacher-educator who teaches natural sciences related courses in college. The test required students to express and elaborate what they had learned about *concepts* in relation to energy-saving, to give and elaborate *reasons* as to why it is necessary and important to preserve energy and to suggest and elaborate *strategies* for energy preservation. Two aspects of responses were scored: the richness or quantity of the concepts described (criteria: number of concepts, reasons, and strategies provided) and depth or quality of understanding (criteria: level of detail in the descriptions and explanations). Table 4 gives detailed information about the two grading factors. Two researchers independently rated students' learning outcome based on the two grading factors and the Inter-rater reliability, using Spearman correlation efficiency, was computed to be 0.94.

Results and discussion

Knowledge-building processes

Overall online activities

In total 360 notes were posted on the KF, with each student contributing on average 10.69 notes (SD = 7.50). The notes were categorized in two ways: (1) by authorship (one author; multiple authors); (2) by build-on status (non-build-on; build-on). Most notes had one

Table 4 Criteria for grading the final assessment test

Question	Grading criterion	Example
Concepts	Richness/quantity: Gets one point for providing a concept Depth/quality: Gets one point for every concept with additional information being further elaborated	Richness/quantity: Do recycling (B01) Depth/quality: Try to recycle renewable energy in order to reduce the emission of carbon dioxide (A27)
Reasons	Richness/quantity: Gets one point for providing a reason Depth/quality: Gets one point for every detailed reason	Richness/quantity: Because of global warming, icebergs are melting and the sea level is rising. (A10) Depth/quality: If we continue to waste a lot of energy there will be energy shortages, and if we produce too much carbon dioxide the icebergs in the Antarctic will melt even faster, causing the sea level to rise and resulting in loss of animals' habitats. (A14)
Actions	Richness/quantity: Gets one point for providing an action strategy Depth/quality: Gets one point for every strategy that is explained in detail	Richness/quantity: Eat more domestic food. (B22) Depth/quality: Eat more domestic agricultural products in order to reduce the emission carbon dioxide. (A21)

author (66.94%), but 33.06% were co-authored. There were more build-on notes (61.67%) than non-build-on notes (38.33%). So, although there were more single-author notes than co-authored notes, the alternative method of categorization showed that the online activities were nevertheless highly collaborative, as build-on notes made up the majority. This is understandable as single-author notes could also be build-on notes and it implies that students were able to engage in highly interactive online activities in this class community. Moreover, the high mean for notes read per student ($M = 72.44$; $SD = 44.99$) also indicates that students were willing and able to follow up each other community members' ideas.

Table 5 summarizes the increase, in descriptive terms, in note-writing and -reading activities from the first to the second KB stages. Overall, *t* tests showed that students read and wrote similar numbers of notes in the first and second stages, but we also carried out separate *t* tests on the numbers of single-author notes, co-authored notes, non-build-on notes and build-on notes. The numbers of single-author notes decreased from Stage 1 to Stage 2 ($t = 3.09$, $p < .05$) whereas the number of co-authored notes (i.e., notes contributed by multiple authors who share ideas after discussion) increased ($t = -3.49$, $p < .01$). A similar pattern was observed in the analysis of build-on and non-build-on notes. Significantly fewer non-build-on notes were written in Stage 2 ($t = 3.67$, $p < .05$) and there was a non-significant increase in build-on notes ($t = -0.08$, $p = 0.93$). A possible reason for increased collaborative activities such as the increase in co-authored notes (i.e., notes contributed by "multiple authors") or the decrease in "non-build-on notes", from Stage 1 to Stage 2, may be because of the knowledge building scaffolds. For example, in order to persuade group members that "this idea cannot explain…" (scaffold #4) something clearly, or to form "a better idea" (scaffold #5), or to "put our knowledge together" (scaffold #6) for a more coherent explanation of a new idea, students in a group need to progressively work and discuss in a more intensive and collaborative manner. This may be why significant changes in the numbers of the "co-authored notes" (by multiple authors) and the "non-build-on notes" were observed. In a related manner, the non-significant increase in "Build-on notes" may be also related to this observation because

Table 5 Online collaborative activities in the forum

	Stage 1		Stage 2		*t* values
	M	*SD*	*M*	*SD*	
Overall online activities					
Notes contributed	5.97	5.48	4.62	3.21	1.60
Notes read	31.65	29.32	40.79	31.33	− 1.31
Build-on status of notes					
Non-build-on notes	2.73	2.36	1.32	1.36	3.67**
Build-on notes	3.23	4.17	3.29	2.90	− 0.08
Authorship of notes					
Single author (i.e., only one author)	4.88	4.87	2.21	2.84	3.09*
Multiple authors (i.e. with co-authors)	1.09	1.50	2.41	2.26	− 3.49**
Social network analysis					
% of notes built-on	41.71	32.30	61.74	29.57	− 3.46*

*$p < .05$, **$p < .01$

students' effort/time was diverted to for intense discussion that eventually contributed to higher number of "co-authored notes".

In summary, the decrease in the number of single-author notes and the increases in the numbers of co-authored notes and build-on notes imply a gradual shift from more individual-oriented knowledge work, to more collective knowledge advancement and idea improvement activities. These collaborative activities carried out in the KF environment were different from traditional educational activities in Taiwan, which emphasize individual learning and knowledge acquisition. To corroborate the statistical findings we also carried out social network analysis (SNA) to illustrate the patterns of social interaction in the KF community. Figures 3 and 4 show the patterns of "note-building-on" in KF. They show that the number of connections between notes increased from Stage 1 to Stage 2 ($t = -3.46$, $p < .05$). Below we report additional analyses that were carried out to explore whether these quantitative changes were reflected in qualitative changes in the way students interacted over, and improved their ideas.

Specific idea-centered activities

Table 6 showed idea-related online activities among students. Social talk was classified as a less productive idea-related activity than idea improvement. There was a decrease in use

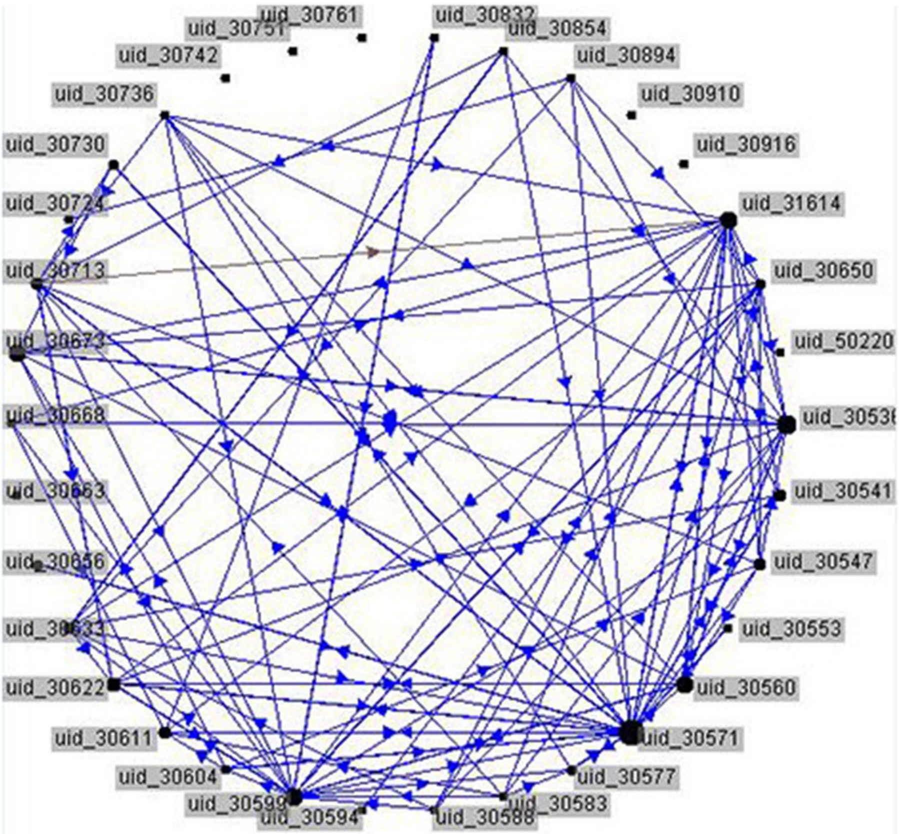

Fig. 3 Stage 1 pattern of note-built-on among students

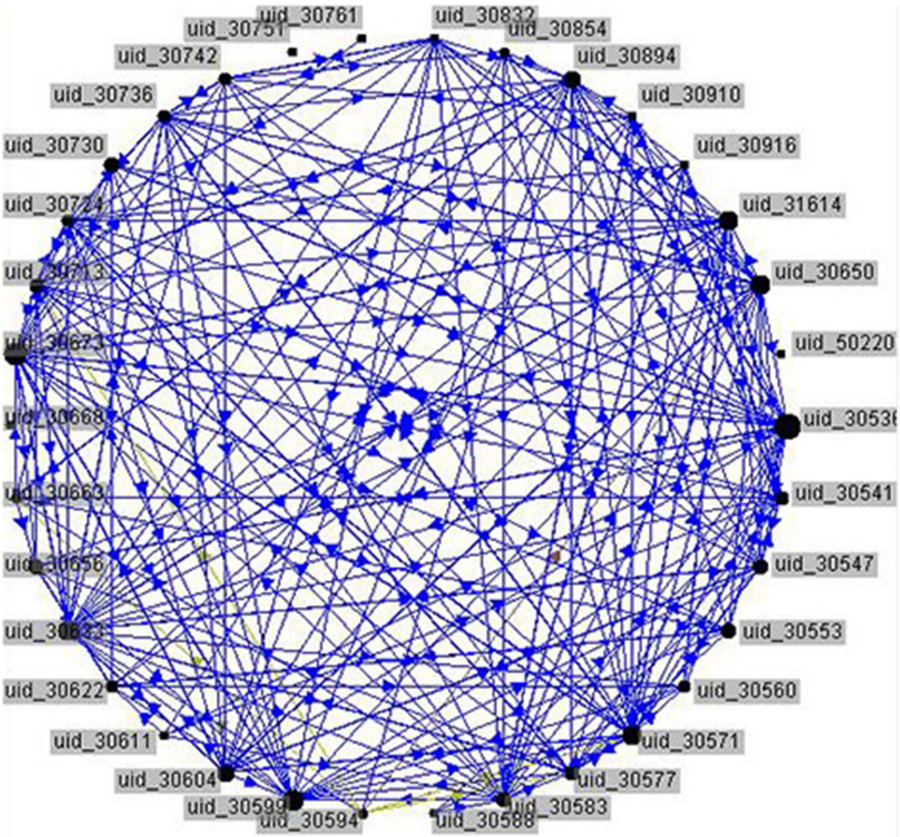

Fig. 4 Stage 2 pattern of note-built-on among students

Table 6 Quality of idea-related activities and development of creativity

Idea-related activity and creativity level	Stage 1		Stage 2		*t* values
	M	*SD*	*M*	*SD*	
Idea-related activity					
Social talk	0.94	2.12	0.06	0.24	2.63*
Idea generation	4.55	3.99	4.39	2.86	0.21
Idea diversification	1.33	1.85	1.82	2.11	− 1.17
Idea improvement	0.73	1.44	2.30	2.19	− 3.90***
Aspects of creativity					
Fluency	4.65	4.38	11.56	8.29	− 5.65***
Flexibility	3.09	2.59	6.91	4.01	− 6.45***
Originality	0.15	0.44	0.74	1.60	− 2.15*
Elaboration	0.79	1.07	2.76	2.19	− 5.37***

*$p < .05$, ***$p < .001$

of less productive activities, such as social chatting, from Stage 1 to Stage 2 ($t = 2.63$, $p < .05$). In contrast, the use of more productive activities, i.e., idea improvement, increased from Stage 1 to Stage 2 ($t = -3.90$, $p < .001$). The two other types of idea-related activity, idea-generation and idea-diversification, were essential for knowledge-building activities and their volume remained consistent across the stages (idea generation: $t = 0.21$, $p = 0.84$; idea diversification: $t = -1.17$, $p = 0.25$). This may be because, under the guidance of the knowledge building scaffolds, students progressively got more involved and engaged in effortful collaborative discussion. This is indeed very likely the case as this finding is in agreement with the above finding about online Knowledge Forum activities (e.g., see changes in the increased co-authored activities and decreased non-build-on activities) showing that students tend to spend more time and effort working on "idea improvement" rather than merely on idea generation and exchange. Overall, the findings indicate that during the course students gradually got used to playing the role of knowledge workers and began to work more creatively or more productively with improving ideas about the topics of inquiry (greenhouse effects and energy saving) as the course progressed. Analysis of the four types of idea-related activities indicated that KF was used as a knowledge building environment rather than a place for social chat, and it did allow students to propose and discuss ideas as a community. More importantly, the environment gave students a big incentive to keep improving their ideas, collaborating on them and integrating them with those of other students, rather than working as individual, non-collaborative learners.

Moreover, we also assessed the four aspects of creativity and showed that displays of all four aspects of creativity increased from Stage 1 to Stage 2 (fluency: $t = -5.65$, $p < .001$; flexibility: $t = -6.45$, $p < .001$; originality: $t = -2.15$, $p < .05$; elaboration: $t = -5.37$, $p < .001$). This additional evidence on creativity corroborates and substantiates the other results that suggest that students were able to work creatively with ideas in KF. Similarly, the reason why development of creativity is improved is likely because of the guidance of the knowledge-building scaffolds. As shown in the above two coding schemes, the scaffolds are concerned with not only the quantity of ideas (e.g., "My idea…" and "New information…") but also the quality of ideas (e.g., "A better idea…"). In contrast, among the four dimensions of creativity, "Fluency" (measured by number of ideas) and "Flexibility" (measured by number of idea categories) are more concerned with the quantity of ideas, while "Originality" (i.e., uniqueness of an idea) and "Elaboration" (i.e., extent to which an idea is better explained) are more concerned with the quantity of ideas. Therefore, students' overall creativity was also enhanced.

Knowledge-building outcomes

Breadth of concepts inquired online

Figure 2 in the "Research method" section shows all the main categories related to the two inquiry topics (greenhouse effects and energy saving) and some coding examples based on student notes discussed in the database. The increasing numbers and progressive quality development of categories and concepts, regarding greenhouse effects, discussed inquired in KF suggests that students' online discussion had a particular structure, starting with definitions, then moving on to causes and consequences and concluding with notes about practical actions that might solve the problems. The discussion of energy-saving encompassed a range of important categories including "food", "housing", "transportation", "clothing", "education" and "entertainment" that were salient in students' everyday lives.

It was unclear, however, whether the scope of the categories and concepts that emerged from the discussion represented sufficiently rich learning outcomes for their grade level. To address this concern we compared the set of concepts discussed online in KF by the participating grade-five students with the set of concepts covered in a middle-school curriculum designed by the Environmental Protection Authority, a government agency. A Chi squared test was used to compare the coverage of greenhouse effect-related concepts and energy-saving-related concepts in the KF discussion and EPA-designed curriculum. Table 7 shows that the KF discussion covered a wider range of concept than the EPA-designed curriculum ($\chi^2 = 19.97$, $p < .001$). Specifically comparing related concepts discussed or covered in these two content sources, it was found that most fundamental concepts such as the definition of greenhouse effect, gas of greenhouse effect, over-development, amount of CO_2, rise of sea level, damage to global climate, etc., were covered by both sources. Other concepts, however, such as "global mean temperature", "economical loss", "Kyoto protocol" and "Montreal protocol", were covered only by the EPA curriculum but not in the students' KF discussion. Alternatively, as with energy saving, students discussed a far greater number of concepts than are mentioned in the EPA curriculum.

Depth of understanding

Table 8 below shows students' knowledge building outcomes as measured by the final-term assessment. The results were graded in terms of two factors: richness/quantity of concepts described, and depth/quality of understanding of the two main topics of inquiry. First of all, Levene's Test for Equality of Variances is performed and the results show that there is no difference in the variances between the groups for the richness/quantity aspect (F = 1.4, $p > .05$); but there is a difference in the variances between the groups for the depth/quality aspect (F = 7.76, $p < .01$). So, the Brown-Forsythe test (with adjusted F value) is used in the following ANOVA statistics tests. As a result, it shows that there is no significant difference in terms of the richness of topics described in the final assessment between the students from the comparison class who engaged in fixed-group collaboration and the students from the idea-centered, knowledge-building class (F= 0.36, $p > .05$). However, in terms of depth of understanding, which was assessed as quality of elaborated explanations, the knowledge-building class outperformed the comparison class ($F = 16.11$, $p < .001$). Moreover, analysis of correlations showed that students' creativity score was correlated with both their richness of description score on the final assessment ($r = .38$*) and their depth of understanding on the final assessment (r = .34*).

To sum up, the enhanced knowledge outcomes were reflected in two measures: increased conceptual breadth and deep conceptual understanding. Similar to the improved knowledge building processes discussed above, the reasons of positive outcomes may also have to do with the instructional design focusing on the use of knowledge building

Table 7 Comparison of the concepts discussed in the KF and listed in the EPA curriculum

	KF	EPA curriculum	Chi squared
Concepts included	94	40	19.97***
Concepts not included	11	65	

***$p < .001$

Table 8 Performance on the final assessment: richness of description and depth of understanding

Grading factor	KF class		Comparison class		*F* value
	M	*SD*	*M*	*SD*	
Richness of description	3.43	1.73	3.19	1.24	0.36
Depth of understanding	2.03	0.93	1.23	0.61	16.11***

*** $p < .001$

scaffolds. As the design of these scaffolds is idea-centered, students work collaboratively and innovatively with group members on sustained idea generation, exchange, diversification, reflection, and refinement, etc.; doing so enables the concepts inquired by students gradually went beyond the circumscribed scope of inquiry content predefined in the textbooks and curriculum guidelines. Accordingly, students' conceptual understanding of the energy-related topics inquired was also greatly deepened.

Conclusion and implications

In summary, analysis of students' online interactions in KF indicated that they were able to work collaboratively with ideas as a community. This implies the effectiveness of our instructional design of using knowledge building scaffolds to promote collaborative activities. The theoretical underpinnings of these scaffolds are the three design principles (see Table 1 for detailed explanation). Our findings are in agreement with empirical studies showing that properly designed socio-cognitive scaffolding is conducive to fostering productive collaboration and group learning (for examples, see a review by Vogel et al. 2017). In addition to the abovementioned effective collaboration, the quality of knowledge building were also reflected in students' enhanced idea-related activities, particularly in terms of idea improvement, and their enhanced creativity level among students. Moreover, regarding the richness of KF content, analysis showed that the set of concepts discussed online by these grade-five students was comparable to, or perhaps richer than the set of concepts in a middle-school curriculum developed by a Taiwanese government agency, the Environmental Protection Authority. As for the depth of conceptual understanding, in an end-of-course assessment, the knowledge-building class outperformed a comparison class taught by the same teacher using group-based learning methods. Clearly, all these improvement have to do with the pedagogical design via the use of the KF principles and related scaffolds which enabled the students to deploy higher-level thinking skills that supported sustained idea-centered collaboration and progressive improvement in conceptual understanding.

An important implication of the study is that engaging students in knowledge building may help to promote collaborative learning and inquiry-based learning. Another implication is that idea-centered knowledge work can encourage students to go beyond learning based on only textbooks. When students are taught using traditional methods their learning is limited to material covered in textbooks and they have few opportunities to learn by inquiry or by working creatively with ideas. Knowledge-building pedagogy can encourage students to engage in more autonomous and authentic learning through generating and continually improving their own ideas and thoughts in order to address authentic, real-life problems. The KF environment encourages students to behave as collaborative knowledge workers and to learn from multiple knowledge sources, not just teachers and textbooks.

There are several benefits to engaging students in knowledge building in KF. First, allowing students to freely explore and inquire in KF, as contrasted with passively acquiring knowledge from textbooks, can greatly help motivate students to become self-directed learners. According to Collins (1996), most conventional learning is usually too serious and not fun or motivating enough to transform students into more active and participating knowledge workers. The interactive design of KF, however, seems to be able to help balance the passive and serious aspects of traditional science learning in Taiwan. Second, KF allows students to avoid traditional fixed-group based learning methods that rely on division of labor. Instead, KF allows students to develop a strong sense of themselves as a knowledge community and it emphasizes emergent, idea-centered collaboration and sustained production, reflection, modification and refinement of ideas. Third, KF also allows students to develop a strong sense of autonomy that emphasizes intentional learning in an improvisational manner, rather than merely following certain predefined instructional procedures (Hong and Sullivan 2009). In addition, KF also encourages productive knowledge conversation, rather than social chatting or information exchange. Productive knowledge-related conversations are valued because they contribute to the community's knowledge, and this, rather than personal knowledge acquisition and growth, is the focus of KF activities. For instance, the participants in this study started by discussing concepts related to the greenhouse effect, then moved onto inquiring into its causes and consequences and then discussed solutions. Their discussion appeared to grow organically and systematically, whilst progressing from more general to more specific concepts. This implies that teachers should value and trust in students' ability to construct ideas and knowledge collaboratively; it follows that they should design and make good use of environments that support autonomous learning.

Admittedly, there are limitations to this study. First, the learning outcomes were the result of team work and so individual performance was not particularly evaluated. Our analysis focused on the process of student collaboration and its outcomes. Second, this was a case study and some of the qualitative results are not generalizable. Readers are advised to use caution when interpreting the results and further research should also be carried out to replicate our findings via multiple methods (for example, by conducting a more naturalistic, perhaps longer term, classroom study).

Acknowledgements Funding for this research was in part provided by a NCCU university grant and by the Ministry of Science and Technology in Taiwan (Grant #: MOST 104-2511-S-004-001-MY3 & MOST 106-2511-S-004-008-MY2). The opinions expressed in this article are those of the author only and do not reflect the opinions of the MOST. We own special thanks to the students for their participation in this study and the research opportunities enabled by their work.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Aronson, E., & Patnoe, S. (1997). *The Jigsaw classroom.* New York: Addison Wesley Longman.

Bereiter, C. (2002). *Education and mind in the knowledge age*. Mahwah, NJ: LEA.

Biehl, J. T., Baker, W. T., Bailey, B. P., Tan, D. S., Inkpen, K. M., & Czerwinski, M. (2008). Impromptu: A new interaction framework for supporting collaboration in multiple display environments and its field evaluation for co-located software development. In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 939–948). New York: ACM Press.

Boyes, E., & Stanisstreet, M. (1993). The greenhouse-effect—Childrens perceptions of causes, consequences and cures. *International Journal of Science Education, 15,* 531–552.

Brown, A. L., & Campione, J. C. (1990). Communities of learning and thinking, or a context by any other name. In D. Kuhn (Ed.), *Developmental perspectives on teaching and learning thinking skills* (pp. 108–126). Basel: Karger.

Chan, C. K., Lam, I. C., & Leung, R. W. (2012). Can collaborative knowledge building promote both scientific processes and science achievement? *International Journal of Educational Psychology, 1*(3), 199–227.

Collins, A. (1996). Design issues for learning environments. In S. Vosniadou, E. De Corte, R. Glaser & H. Mandl (Eds.), *International perspectives on the psychological foundations of technology-based learning environments* (pp. 347–361). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Thousand Oaks, CA: Sage.

Cuseo, J. (1992). Cooperative learning vs. small-group discussions and group projects: The critical differences. *Cooperative Learning and College Teaching, 2*(3), 5–10.

Deutsch, M. (1949). An experimental study of the effects of cooperation and competition upon group processes. *Human Relations, 2,* 199–231.

Dias, R. A., Mattos, C. R., & Balestieri, J. A. P. (2004). Energy education: Breaking up the rational energy use barriers. *Energy Policy, 32*(11), 1339–1347.

Dillenbourg, P. (2002). Over-scripting CSCL: The risks of blending collaborative learning with instructional design. In P. A. Kirschner (Ed.), *Three worlds of CSCL. Can we support CSCL?* (pp. 61–91). Heerlen: Open Universiteit Nederland.

Dillenbourg, P., Baker, M., Blaye, A., & O'Malley, C. (1996). The evolution of research on collaborative learning. In E. Spada & P. Reiman (Eds.), *Learning in humans and machine: Towards an interdisciplinary learning science* (pp. 189–211). London: Elsevier.

Evans, P., & Wolf, B. (2005). Collaboration rules. *IEEE Engineering Management Review, 33*(4), 50–57.

Fischer, F., Kollar, I., Mandl, H., & Haake, J. M. (Eds.). (2007). *Scripting computer-supported collaborative learning: Cognitive, computational and educational perspectives* (Vol. 6). New York: Springer.

Fischer, F., Kollar, I., Stegmann, K., & Wecker, C. (2013). Toward a script theory of guidance in computer-supported collaborative learning. *Educational Psychologist, 48*(1), 56–66.

Guilford, J. P. (1967). *The nature of human intelligence*. New York: McGraw-Hill.

Hansen, J. K. P. (2010). Knowledge about the greenhouse effect and the effects of the ozone layer among norwegian pupils finishing compulsory education in 1989, 1993, and 2005—What now? *International Journal of Science Education, 32,* 397–419.

Hewitt, J. (2002). From a focus on tasks to a focus on understanding: The cultural transformation of a Toronto classroom. *Computer Supported Cooperative Learning, 2,* 11–41.

Hong, H.-Y., & Beyond Group Collaboration. (2011). Facilitating an idea-centered view of collaboration through knowledge building in a science class of fifth-graders. *The Asia-Pacific Education Researcher, 20*(2), 248–262.

Hong, H.-Y., Chang, Y. H., & Chai, C. S. (2014). Fostering a collaborative and creative climate in a college class through idea-centered knowledge-building. *Instructional Science, 42*(3), 389–407.

Hong, H.-Y., Chen, F. C., Chai, C. S., & Chan, W. C. (2011). Teacher-education students' views about knowledge building theory and practice. *Instructional Science, 39*(4), 467–482.

Hong, H.-Y., & Lin, S. P. (2010). Teacher-education students' epistemological belief change through collaborative knowledge building. *The Asia-Pacific Education Researcher, 19*(1), 99–110.

Hong, H.-Y., & Scardamalia, M. (2014). Community knowledge assessment in a knowledge building environment. *Computers & Education, 71,* 279–288.

Hong, H.-Y., Scardamalia, M., Messina, R., & Teo, C. L. (2015). Fostering sustained idea improvement with principle-based knowledge building analytic tools. *Computers & Education, 89,* 91–102.

Hong, H.-Y., & Sullivan, F. R. (2009). Towards an idea-centered, principle-based design approach to support learning as knowledge creation. *Educational Technology Research and Development, 57*(5), 613–627.

Huang, C. C., & Lin, P. H. (1996). *Cooperative learning*. Taipei: Wunan.

Johnson, D. W., & Johnson, R. T. (1993). *Cooperative learning*. Hoboken, NJ: Wiley-Blackwell.

Kirschner, P. A. (2001). Using integrated electronic environments for collaborative teaching/learning. *Learning and Instruction, 10,* 1–9.

Kukkonen, J. E., Kärkkäinen, S., Dillon, P., & Keinonen, T. (2014). The effects of scaffolded simulation-based inquiry learning on fifth-graders' representations of the greenhouse effect. *International Journal of Science Education, 36*(3), 406–424.

Lipponen, L. (2000). Towards knowledge building: From facts to explanations in primary students' computer mediated discourse. *Learning Environments Research, 3*(2), 179–199.

Moreno, M., Vivacqua, A., & de Souza, J. (2003). An agent framework to support opportunistic collaboration. In J. Favela & D. Decouchant (Eds.), *Lecture notes in computer science* (pp. 224–231). Berlin: Springer.

Noroozi, O., Biemans, H. J., Weinberger, A., Mulder, M., & Chizari, M. (2013a). Scripting for construction of a transactive memory system in multidisciplinary CSCL environments. *Learning and Instruction, 25,* 1–12.

Noroozi, O., Weinberger, A., Biemans, H. J., Mulder, M., & Chizari, M. (2013b). Facilitating argumentative knowledge construction through a transactive discussion script in CSCL. *Computers & Education, 61,* 59–76.

Palloff, R. M., & Pratt, K. (2002). *Lessons from the cyberspace classroom: The realities of online teaching*. New York: Wiley.

Rycroft, R. W. (2003). Technology-based globalization indicators: the centrality of innovation network data. *Technology in Society, 25*(3), 299–317.

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. (2004). CSILE/Knowledge Forum®. In A. Kovalchick & K. Dawson (Eds.), *Education and technology: An encyclopedia* (pp. 183–192). Santa Barbara: ABC-CLIO.

Scardamalia, M., & Bereiter, C. (2003). Knowledge building. In J. W. Guthrie (Ed.), *Encyclopedia of education* (2nd ed., pp. 1370–1373). New York: Macmillan Reference.

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

Scheuer, O., McLaren, B. M., Weinberger, A., & Niebuhr, S. (2014). Promoting critical, elaborative discussions through a collaboration script and argument diagrams. *Instructional Science, 42*(2), 127–157.

Skamp, K., Boyes, E., & Stanisstreet, M. (2013). Beliefs and willingness to act about global warming: Where to focus science pedagogy? *Science Education, 97*(2), 191–217.

Slavin, R. E. (1995). *Cooperative learning: Theory, research, and practice* (2nd ed.). Massachusetts: Allyn & Bacon.

So, H. J., & Brush, T. A. (2008). Student perceptions of collaborative learning, social presence and satisfaction in a blended learning environment: Relationships and critical factors. *Computers & Education, 51*(1), 318–336.

Solbes, J., Guisasola, J., & Tarín, F. (2009). Teaching energy conservation as a unifying principle in physics. *Journal of Science Education and Technology, 18*(3), 265–274.

Stahl, G. (2006). *Group cognition: Computer support for building collaborative knowledge*. Cambridge, MA: MIT Press.

Strauss, A. L., & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. Newbury Park, CA: Sage.

Tchounikine, P. (2016). Contribution to a theory of CSCL scripts: Taking into account the appropriation of scripts by learners. *International Journal of Computer-Supported Collaborative Learning, 11*(3), 349–369.

Thagard, P. (1989). Explanatory coherence. *Behavioral and Brain Sciences, 12,* 435–502.

Tsai, P. S., Chai, C. S., Hong, H.-Y., & Koh, J. H. L. (2017). Students' conceptions of and approaches to knowledge building and its relationship to learning outcomes. *Interactive Learning Environments, 25*(6), 749–761.

van Dijk, A. M., Gijlers, H., & Weinberger, A. (2014). Scripted collaborative drawing in elementary science education. *Instructional Science, 42*(3), 353–372.

Vogel, F., Kollar, I., Ufer, S., Reichersdorfer, E., Reiss, K., & Fischer, F. (2016). Developing argumentation skills in mathematics through computer-supported collaborative learning: The role of transactivity. *Instructional Science, 44*(5), 477–500.

Vogel, F., Wecker, C., Kollar, I., & Fischer, F. (2017). Socio-cognitive scaffolding with computer-supported collaboration scripts: A meta-analysis. *Educational Psychology Review, 29*(3), 477–511.

Yin, R. K. (2013). *Case study research: Design and methods*. Thousand Oaks, CA: Sage.

Zhang, J., Hong, H. Y., Scardamalia, M., Teo, C. L., & Morley, E. A. (2011). Sustaining knowledge building as a principle-based innovation at an elementary school. *Journal of the Learning Sciences, 20*(2), 262–307.

Zografakis, N., Menegaki, N. A., & Tsagarakis, P. K. (2008). Effective education for energy efficiency. *Energy Policy, 36,* 3226–3232.

Huang-Yao Hong is a professor in the Department of Education, National Chengchi University, Taiwan. He received his Ed.M. and Ed.D. in the area of instructional technology and media from Teachers College, Columbia University, New York, United States. He currently teaches courses about instructional design, learning technology, and knowledge building theory, and his research focuses on knowledge building in computer supported multimedia environments and related design issues.

Pei-Yi Lin is a Post-doctoral fellow in University of Toronto, Ontario Institute for Studies in Education. Her research interests include design thinking, knowledge building and creativity in education.