Computers & Education 98 (2016) 1–13

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

Exploring the development of college students' epistemic views during their knowledge building activities

Huang-Yao Hong [a,*], Bodong Chen [b], Ching Sing Chai [c]

[a] National Chengchi University, Taiwan, ROC
[b] University of Minnesota, USA
[c] National Institute of Education, Nanyang Technological University (NIE/NTU), Singapore

A R T I C L E   I N F O

Article history:
Received 31 August 2015
Received in revised form 18 January 2016
Accepted 9 March 2016
Available online 12 March 2016

Keywords:
Computer-mediated communication
Collaborative learning
Interactive learning environments
Learning communities

A B S T R A C T

Exploring students' epistemic views is important as it should help to better understand how they acquire and work with knowledge. This case study investigated how college students' epistemic views relate to their collaborative inquiry activities in an online knowledge-building environment. Findings based on a mixed-method analysis on students' online discourse and open-ended survey questions suggested that students' knowledge-building activities were positively related to the development of their epistemic views. In particular, when students were able to engage in more productive and effective group inquiry activities, they were more likely to develop a more sophisticated epistemic view that was conducive to sustained idea improvement for advancing knowledge. The study has implications for understanding how students' views on the nature of knowledge creation and the manner in which collaborative inquiry is conducted in an online environment affect each other.

1. Introduction

The need for novel ideas and new knowledge to solve emerging societal problems is ever-increasing (Csikszentmihalyi & Wolfe, 2014; Drucker, 2011). As ideas are essential for problem-solving and knowledge-creation and humans are by nature capable of generating ideas, it has become ever more important for education to consider how to nourish students' creative capacity to produce and work innovatively with ideas (Koh, Chai, Wong, & Hong, 2015). The challenge for knowledge creation, however, is how sustained effort for idea improvement can be maintained (Scardamalia & Bereiter, 2003; 2006). Traditional education tends to highlight the importance of acquiring knowledge from authoritative sources (e.g., textbooks and instructors), but neglects the importance of guiding students towards generating and improving ideas for knowledge work (Chen, Scardamalia & Bereiter, 2015). Papert (2000) calls this phenomenon “idea aversion” (i.e., the dislike of ideas), and argues that most traditional learning environments are inclined to withhold approval from students who have their own ideas, while being in favour of direct instruction by teachers (cf. Kirschner, Sweller, & Clark, 2006, Sawyer, 2004; 2011). Students' self-initiated ideas are less valued and appreciated (than textbook knowledge) in most learning environments, and much less are students encouraged to devote themselves to improving their ideas to advance knowledge. To address this concern, the present study attempted to engage students in the sustained production and improvement of ideas in a

* Corresponding author. National Chengchi University, Taiwan No.64, Sec.2, Zhinan Rd., Wenshan District, Taipei 11605, Taiwan, ROC.
E-mail address: hyhong@nccu.edu.tw (H.-Y. Hong).

http://dx.doi.org/10.1016/j.compedu.2016.03.005
0360-1315/

knowledge-building environment. The main aim was to help students develop a more constructivist-oriented view that sees ideas as having an important role for solving real-world problems and at the same time creating new knowledge. In the following, we first discuss the essential role of ideas in knowledge creation from a theoretical perspective, based on Popper's (1978) three-world epistemology. Next, we describe knowledge-building pedagogy as a possible pedagogical approach for the transformation of students' epistemic view of ideas, so that they see ideas as fundamental epistemic objects for knowledge creation. Finally, we report our findings and discuss important implications for education and future research.

2. Theoretical background

2.1. Epistemological views concerning idea-centered knowledge work

The important role ideas play in a knowledge society may be best explained by Popper's (1972) three-world epistemology. Popper postulates three different forms of ontological reality to explain how the three epistemic worlds come into being. The three epistemic worlds are: (1) the natural/physical world (World 1), (2) the spiritual/psychological world (World 2), and (3) the humanly-constructed conceptual world (World 3). In brief, World 1 refers to natural or physical reality, and can exist by itself with no human presence. World 2 considers reality as a mental state created in the human mind. It is a private world consisting of a person's personal thoughts and feelings, and the experiences of his or her perceptions and interpretations of World 1. Finally, World 3 conceives reality as being constructed by man-made “ideas” as conceptual artefacts; these in turn give form to all other humanly-constructed, materialistic artefacts that further substantiate the existence of World 1. In contrast to *Cartesian dualism*, which recognizes World 1 and 2, Popper especially highlights the important contribution to human civilization by World 3 in that it enables humans' exceptional imaginary capacity to work with and act upon ideas—ideas that are readily existent or emergent—and to transform them into feasible solutions and accepted knowledge for solving problems.

As witnessed in history, ideas are essential for creating the knowledge to solve societal problems. The monumental inventions of the wheel, the printing press, the light bulb, the aeroplane, etc. were instances of ideas. Without the continual generation and further improvement of ideas to address real-world issues, the progress of human civilization would be substantially limited. World 3 is uniquely valuable to mankind as it consists of the sustained efforts of humans to produce and develop ideas. World 3 is also uniquely important because it serves as an essential repository for all existing human ideas and knowledge. The recognition of World 3, in addition to Word 2, also extends beyond traditional individualist view of knowledge to include social aspects of knowledge and knowing. Once recorded in World 3, ideas are embodied with a social and public presence, and therefore can be shared and exchanged, as well as examined and investigated. With proper development, ideas can become more refined and can be explained in a coherent way (Thagard, 1989), and are thus more likely to become reliable and valid knowledge—such as a tested theory in the natural sciences, a valid claim or hypothesis in the social sciences, or a feasible solution in the fields of art or design. Unfortunately, as argued by Bereiter (2002; see also Bereiter & Scardamalia, 2014), traditional school education tends to value change in a student's mind-as-a-container (i.e., psychological processes in World 2) (e.g., by delivering knowledge from authoritative sources such as textbooks and teachers to the student), but neglect the importance of initiating students into a World 3, idea-centered, knowledge-building culture. The question of how to enrich a heavily World 2-oriented education by exposing students to a World 3 perspective remains an open pedagogical challenge.

2.2. Knowledge building pedagogy

Knowledge building is defined as a collaborative process that is focused on continuous work with ideas of value to a community (Scardamalia & Bereiter, 2006; 2014). Knowledge building can be characterized by three distinctive pedagogical design features: it is idea-centered, principle-based, and community-focused. First, building on Popper's (1972) epistemological framing of World 3, knowledge building emphasizes the value and importance of ideas as epistemic entities for human knowledge construction, and considers idea improvement to be at the centre of all learning activities. Bereiter (1994) also argues that ideas should be treated as conceptual artefacts—as being similar to real-life, material objects that can be felt, touched, and refined. As such, once ideas are contributed to and recorded in a public space (e.g., a discussion forum), they are embodied with a social life in their own right for further inquiry and development.

Bereiter, Scardamalia and van Merrienboer (2003; Bereiter, Scardamalia, 2014) elaborated the need to engage students in working with conceptual artefacts (in World 3) in a design mode rather than a belief mode. Essentially, the design-mode of working with ideas is concerned with making the ideas ever better. This entails theorizing, inventing, revising and assessing promisingness of ideas (Chen, Scardamalia, & Bereiter, 2015). The belief mode however is concerned with justification of the ideas, i.e., establishing true and justified beliefs. While both mode of working with ideas are necessary and educationally worthwhile, the design mode entails a broader consideration of ideas than the exclusive concern about true/false knowledge claims as postulated by the belief mode. The design mode has been advocated by Bereiter and Scardamalia (2014) as more powerful for the contemporary knowledge society given that current “classroom work with ideas … is almost exclusively carried out in belief mode” (p. 39). Engaging students in design mode is likely to enculturate students to look for opportunities of idea improvement—not only warranted beliefs—which is more inductive to coherent explanations or solutions to complex problems.

To facilitate idea improvement, it is necessary to consider the following two critical aspects: quantity and quality. Increasing the quantity of ideas would require continuous idea generation and diversification, and one should therefore look into how ideas are contributed, shared, and/or exchanged in a community's problem space. In contrast, improving the quality of ideas would require the sustained articulation and elaboration of ideas, and one should therefore examine how community members collaborate to articulate, clarify and/or elaborate ideas (Hong & Sullivan, 2009). More importantly, it is necessary to take both aspects into close consideration, in order to integrate ideas together systematically for progressive problem-solving, as idea improvement is an emerging process that is collectively defined by all community members (Prehofer & Bettstetter, 2005).

Second, knowledge building employs a principle-based–rather than a procedure-based–pedagogical design to ensure the sustained improvement of ideas (Zhang, Hong, Scardamalia, Teo, & Morley, 2011). This design is very different from a highly structured, procedure-based instructional design for guiding classroom practices (Reigeluth, 2013). A pre-specified procedural design usually prescribes classroom activities in advance. Teachers are sometimes even required to carry out their instruction using certain teaching scripts (see Sawyer, 2004). In contrast, a principle-based approach only employs a number of guiding pedagogical principles to ensure maximum flexibility so that students can work adaptively with their self-generated ideas. For example, the knowledge-building principle of “idea diversity” highlights the fact that diversified ideas are essential to sustained knowledge advancement, “… just as biodiversity is essential to the success of an ecosystem. To understand an idea is to understand the ideas that surround it, including those that stand in contrast to it. Idea diversity creates a rich environment for ideas to evolve into new and more refined forms” (Scardamalia, 2002, p. 79). In facilitating principle-based teaching, the role of the teachers is not to implement certain lockstep learning procedures but to apply relevant principles opportunistically to foster a favourable socio-cultural environment for knowledge building/knowledge creation. Technological tools, such as Knowledge Forum (see Fig. 1 in the Method section for detail), designed under these guiding principles also play an important role. For example, tool features in Knowledge Forum such as idea search and keywording are provided for “linking ideas and for bringing different combinations of ideas together in different notes and views” (Scardamalia, 2002, p. 79), in order to promote interactions between ideas for the purpose of idea diversity.

Third, knowledge building highlights community-oriented, rather than individual-oriented, knowledge practice. While ideas must be generated by individuals, continuous improvement of ideas relies on a whole community's collaborative effort. In particular, the quantity and quality of the ideas being enriched and refined are highly dependent on the effectiveness of social interactions in the community. There are two essential types of social interaction within a knowledge-building community, participant interaction and idea interaction (Hong, Scardamalia, & Zhang, 2010), because participants and

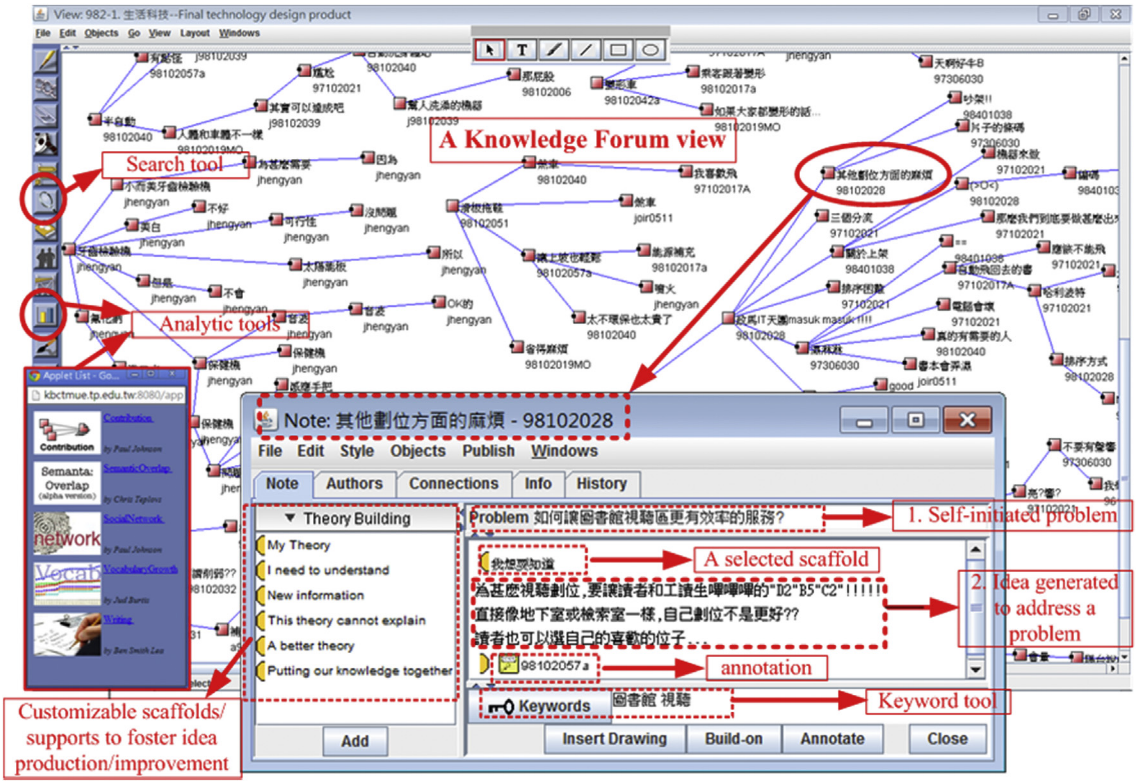


Fig. 1. Some selected Knowledge Forum activities to illustrate how participants engage in sustained idea improvement.

ideas represent the two fundamental epistemic entities—subjects and objects of knowledge—according to Descartes (1960). As a result of the different social interactions, four possible kinds of group dynamics may be formed. The first kind features low participant and low idea interaction, and it represents the group with the least knowledge-building capacity. For instance, when a group's activities are mainly focused on social talk/chat rather than knowledge collaboration and idea exchange, the group tends to fall into this category. The second type features high participant interaction but low idea interaction, and the third type is its opposite. For these two types, the group's knowledge-building capacity is either weakened by a lack of fresh ideas or perspectives due to low idea interaction (Chubin, 1976; Granovetter, 1983), or restrained by the weak participant collaboration that means that the value, coherence, and utility of ideas is not enhanced (Kling & Rosenberg, 1986). Either way, the intensity of the social interaction in the community needs to be strengthened. In contrast, a better type of group dynamics for knowledge building is characterized by both high participant interaction and high idea exchange. An example of such a networked community is the group of open source programmers, who work collaboratively and opportunistically with epistemic artefacts (i.e., open source code) emerging from the Internet to design and redesign software (Evans & Wolf, 2005).

To summarize, knowledge building is fundamentally idea-centered and is facilitated by means of principle-based teaching assistance and community-oriented collaborative efforts. Ideas are placed in the centre for all knowledge-building activities, the emerging process of idea improvement is then guided by the knowledge-building principle, and the quantity and quality of ideas being improved is also highly dependent on the community's collaborative effort.

3. The present study

Previous studies have primarily focused on exploring the relationships between epistemic beliefs and individual learning (e.g., see Chiou, Lee, & Tsai, 2013; Lin, Liang, & Tsai, 2012; Muis, 2007; Yang, 2016), particularly in the online learning environment (e.g., see Ding, Wei, & Wolfensberger, 2015; Psycharis, 2013), rather than the relationships between epistemic views and knowledge building/knowledge creation. Learning or knowledge telling is, however, different from knowledge building in that the former mainly emphasizes individual knowledge acquisition or growth (i.e., changes in World 2) while the latter highlight sustained production and improvement of ideas for collective knowledge advancement (i.e., advancing World 3) (Hong & Sullivan, 2009; Scardamalia & Bereiter, 2015). In addition, the epistemic beliefs explore in extant studies cited above are usually about beliefs about whether external authorities are the source of knowledge and whether knowledge are evolving and certain (see Lin et al., 2012). In other words, current studies of epistemic beliefs are in essence operating within the boundary of belief mode. Chai, Hong, Liang, Yan and Tsai (2015) has recently pointed out that study of personal epistemology from knowledge creation perspective may need attention. Given the importance of fostering students' capacity to produce and work innovatively with ideas for knowledge work, the present study attempts to investigate (1) whether sustained idea improvement in a knowledge-building environment is related to an idea-centered World 3 epistemic view that is essential for creative knowledge work, and, specifically, (2) whether the development of a more informed World 3 epistemic view is related to online group activities. A typical stereotype held by students is that only smart people (e.g., scientists) can create knowledge (Carey, Evans, Honda, Jay, & Unger, 1989; Dweck, 2010; Hong & Lin-Siegler, 2012). Students do not usually believe that they can act as knowledge workers and engage in progressive inquiry and problem-solving to advance knowledge (Hong & Lin-Siegler, 2012; Roth, van Eijck, Hsu, Marshall, & Mazumder, 2009). This scepticism about one's potential for knowledge creation is further exacerbated by a conventional epistemic view that sees learning mainly as acquiring and accumulating knowledge from existing authoritative sources. This is in contrast with a World 3 knowledge advancement epistemic view that highlights the evolving processes through which ideas are generated and progressively improved. Previous study by Chan and Chan (2011) suggest that students' views of collaboration and online participation are positively correlated. Hong and Chiu's (2016) study also suggest that students can benefit from a more productive view that encourages them to think and act more like knowledge workers, capable of contributing and working innovatively with ideas. It is therefore posited that viewing ideas as World 3 epistemic objects for the purpose of knowledge creation should also help to foster students' collaborative and creative capacity (e.g., see Hong & Lin-Siegler, 2012; Hong & Scardamalia, 2014; Lin & Bransford, 2010; Lin, Schwartz, & Bransford, 2007). Accordingly, the main purpose of this study is to explore the differences between students' engagement in knowledge-building activities and the development of their epistemic view—i.e., a more informed view that sees ideas not merely as abstract World 2 entities, but as concrete World 3 objects.

4. Method

Using a case study method, this research aims to examine in a class environment the detailed process of how students engage in online collaborative knowledge building activities and how such group activities are related to the development of a more knowledge-creation-oriented epistemic view. While it is often a concern regarding the small sample size from a case study, some research has demonstrated that case study can still lead to generalizable findings to inform the interpretation of instruction in similar context (Yin, 2013).

4.1. Pedagogical design and learning environment

Participants in this study were forty-one undergraduate students from a national university in Taiwan. The course, lasting for one semester (18 weeks), was offered by the teacher-education program in the university to students who planned to teach about natural sciences and living technologies at primary schools after they graduate from university. The university is a research university which had received a grant from the Ministry of Education to transform didactic modes of teaching into more constructivist-oriented teaching practices. This reform created an opportunity for the knowledge building theory and technology to be introduced. The participants in this course were 41 teacher-education students (20 females), whose ages ranged from 18 to 20. To foster a knowledge building environment, the students in this course were required to solve technology problems of their choice by designing a technology product (e.g., a better shoe product). To achieve this, they have to generate ideas and keep working on their ideas so as to address the design problems at issue; and in the beginning of the class, 11 small groups were formed with each group consisting of 2–5 members ($M = 3.73$; $SD = 1.19$). The main goal of the course was to help these teacher-education students develop a better understanding of the roles of ideas in knowledge creation so that they will be better prepared to teach the subject of living technologies in a more creative manner when they become formal teachers. To this end, they were guided to engage in knowledge-building processes themselves, with a goal to design some living (real-world) technology products for enhancing the quality of people's daily lives. To facilitate student learning, knowledge-building principles (e.g., "idea diversity", as discussed above) were employed to enable cycles of progressive idea improvement, with four key types of activities described as follows:

(1) Idea generation for problem defining and solving: Based on the knowledge building principle of "authentic problems, real ideas", students were guided to identify some real-world, authentic problems (e.g., air pollution) that they personally experienced in their daily lives. These problems were generated by the students themselves and were not directly taken from textbooks or assigned by teachers. The identification of these problems represented an important part of students' efforts to understand the world. The students then moved on to generate ideas to tackle the problems that interested them. As the problems and the ideas were all produced by the students, the students could better develop a sense of ownership of, and strong motivation to work with, the problems/ideas for meaningful knowledge construction. Knowledge Forum was used throughout the semester. Fig. 1 shows a snapshot of a Knowledge Forum view as a community's problem-solving space, a Knowledge Forum note, and some tool features. It gives a simple illustration of how participants may engage in problem identification and idea generation by using some of the features embedded in Knowledge Forum.

(2) Idea diversification and sharing for productive collaboration: Building on the knowledge building principle of "idea diversity", students were guided to advance knowledge by making ideas more diversified. As the participating students searched, discussed, exchanged, and criticized one another's ideas within the group, the chances of knowledge advancement also increased. This helped them to gain a deeper understanding of their own ideas and the connections between the different ideas recorded in the online problem-solving space. The enactment of this principle in the course also helps democratizing knowledge in the community. Just as biodiversity is essential for a wholesome ecosystem, idea diversity is essential to productive collaborative knowledge-building (Scardamalia, 2002). Fig. 1 also illustrates some tools (e.g., the search tool and the keyword tool) that can be used to identify similar and contrasting ideas so that they can be further shared and annotated.

(3) Idea elaboration and reflection activities: In line with the "improvable ideas" principle, once ideas have been contributed to and recorded in a public space, they are subjected to collective examination and criticism by all community members, who can do further work to articulate, clarify, explain, or refute them in order to enhance their quality (e.g., their feasibility, viability, and desirability). For example, students often work collaboratively to criticize, elaborate on, revise, modify, clarify or explain ideas in Knowledge Forum by posting new notes or building on existing notes, or they employ analytical tools (e.g., the semantic overlap tool) to trace how a key idea is continually referred to and elaborated over time.

(4) Idea Integration: Based on the "rise above" principle, students work progressively towards more comprehensive integration of their ideas for addressing knowledge problems. At this stage, the community would expect to achieve some consensus or to initiate another round of problem identification and idea generation. To this end, participants work collectively and try to achieve higher-level formulations of the problems at issue, and also try their best to synthesize the existing ideas into possible solutions to a problem that gives a more coherent explanation. Specifically for this course, this requires further advanced work to give careful consideration to all the ideas in order to re-conceptualize the living technology product to be designed and make some of its design features more innovative. In other words, the participants needed to move beyond current best practice to higher levels of understanding. With the help of Knowledge Forum at this stage, all key ideas or concepts can be summarized using the "rise-above" or "publishing" tool features and/or exported to a new "view" (i.e., a new problem-solving space), to initiate a new idea improvement cycle by addressing a different aspect of the problem for a technology artefact.

All course requirements for the online activities were specified in the course package. To give participants the maximum freedom to engage in progressive problem-solving and self-directed idea improvement cycles that were supported by a principle-based knowledge building environment, the instructor (who is the first author) intentionally abstain himself from posting in the Forum. This is in part because instructor participation could at times restrict or foreclose discussion as they are perceived as the authoritative sources.

In summary, in the whole process of knowledge building, the participants worked in groups and tried to solve the problems they identified collectively by continually generating, diversifying, elaborating, and integrating ideas. Through cycles of sustained idea improvement, each group worked collaboratively and innovatively to achieve the overarching goal of designing a better technology product.

4.2. Analytical framework

A two-level analysis was employed in this case study. First, an overall analysis of the learning outcomes and processes for the whole class as a community was conducted. Then, a fine-grained analysis of the group performance was employed.

4.2.1. Overall analysis of the whole community

A pre-post survey on students' epistemic views, focusing on the nature of ideas and using the following open-ended questions, was employed: What are "ideas"? What are the criteria for a good idea? Why? Where do ideas come from? Can ideas be improved? If so, why can they be improved and how can they be improved? If not, why could they not be improved? As shown in Table 1, a coding scheme was developed using Popper's (1972) three-world epistemology to score students' responses to the above questions (Strauss & Corbin, 1990). If a response matched with a given coding category of an epistemic view (i.e., a World 2 or World 3 view), one point was given, with the maximum number of points for each of the two epistemic views being three. Inter-coder reliability, computed using the Kappa coefficient, was 0.90. *T*-tests were conducted to compare the differences between World 2 and World 3 epistemic views to see whether there is any change in students' views among students over time after they engaged in knowledge practice for a semester. In addition, summary statistics of the whole community's interactions in Knowledge Forum were calculated to provide a basic understanding of participants' online behaviour and learning processes (e.g., the average number of notes contributed, read, built on, etc.). Furthermore, social network analysis was applied to examine the change of network density in the community.

4.2.2. Analysis of group-level performance

In this study, the survey/questionnaire was completed by individual students. So the analysis of group-level performance in this section was based on aggregated group results. First, to better understand how different groups of participants conducted their inquiries in the Knowledge Forum, the class were divided into two bigger groups using the average score of students' epistemic views attained from the surveys: (1) "less-informed" groups with lower epistemic view scores, and (2) "more-informed" groups with higher epistemic view scores. A less informed view regards ideas as exclusively mental representations in individual minds (World 2), while a more informed view would see ideas as having a public life and improvable through collective effort (World 3) (see Table 1 for details). To examine potential relationships between epistemic views and inquiry

Table 1
Coding scheme based on Popper's conceptualization of ideas.

Theme	Code	Example
World 2 view of ideas (considering ideas as abstract thoughts existing in one's mind; seeing ideas as one's own viewpoint, or subjective opinion; or viewing ideas as something derived from individual thinking).	1. Abstract concepts	Ideas are abstract concepts existing in one's mind. (S41) An idea is a kind of abstract thought produced from thinking. (S19)
	2. Reflection	Ideas are one's opinions and viewpoints based on subjective reasoning. (S26) Ideas are one's personal points of view about something. (S10)
	3. Personal knowledge growth	Working with ideas is good for training our brains. (S36) Ideas can help improve one's intelligence. (S23)
World 3 view of ideas (defining ideas as an accumulation of experiences and external stimuli to improve the quality of life; seeing ideas as a means for people to solve problems; seeing ideas as collective creations generated from group discussion, communication and/or sharing for co-constructing community knowledge; or viewing ideas as public (rather than personal) entities that can be exchanged and improved, just like real-life objects).	4. Concrete object	[An] idea is a product through the thinking process; but it can become a concrete object via group discussion. (S39) After being put into practice, ideas can be presented in multiple forms such as a plan, a study, a real-life object, a commercial product, etc. (S24)
	5. Interaction with the world	Ideas can derive from one's interactions with books, TV, magazines, or other people. (S33) Ideas can be formed from prior or present experiences in daily life. (S20)
	6. Collaborative endeavour for knowledge advancement	Through sharing ideas of others, we can … integrate these ideas to become a better idea. (S16) Ideas are usually improved after idea interaction and group discussion. (S02)

Note: The World 2 view sees ideas as being possessed within an individual's mind-as-a-container, like personal property, whereas the World 3 view emphasizes the social nature of ideas as public property that is of value to a community. From this perspective, ideas are viewed as conceptual artefacts/objects with a social life of their own and can be continually improved through collaborative efforts in a public space (Bereiter, 1994).

activities, we compared two groups in terms of (1) statistics of online interactions (e.g., the number of notes contributed, read, built on, etc.; explained above), and (2) quality of inquiry activities. In particular, Garrison, Anderson, and Archer's (2001) practical inquiry model was employed as the coding scheme to evaluate the quality of group inquiry. This model specifies four levels of online inquiry activities: triggering event, exploration, integration, and then resolution. This model is widely used to assess depth of knowledge building in the online environment (e.g. Tirado, Hernando, & Aguaded, 2015). Knowledge building activities concerned with sustained idea improvement employed in this study are highly relevant to the four types of activities in this inquiry model. For example, "idea generation" can be seen as a method for the "triggering event" activity; "idea diversity" and "idea elaboration" are methods for the "exploration" activity; and "idea integration" refers to the "integration" and "resolution" activities in the model. This particular analysis was used to investigate the quality of group inquiry. Table 2 shows the coding scheme and examples. Using a note as the unit of analysis, each note was categorized into one of the above four types of inquiry activity. Inter-coder reliability (using the kappa coefficient, for nominal scales) was calculated to be 0.89. In terms of statistical method, one-way ANOVA was conducted to compare between the less-informed and more-informed groups, in terms of various types of online activities and the four different inquiry stages.

5. Results

5.1. Overall analysis

5.1.1. Epistemic view

To examine students' epistemic views, a survey was administered in the beginning and at the end of the semester. As Table 3 shows, in the beginning of the semester, the participants' understanding of the nature of ideas was quite limited (using pre-survey for assessment), as their epistemic view scores (i.e., 0.62 for World 2 views and 0.73 for World 3 views; all three aspects combined) were way below the middle value (which is 1.5, with the maximum score being 3.0). Although a multivariate analysis (MANOVA) test indicated that there was a significant overall difference between World 2 and World 3 views (Wilk's $\lambda = 0.24$, $F = 81.61$, $p < 0.001$, $\eta2 = 0.76$), when looking into the three aspects, no significant differences were found between the two different World views in each of the three aspects. In contrast, in the end of the semester, it was found that there was a change in students' World 3 views, as their epistemic view score for the World 3 view increased from 0.73 to 1.67 (with all three aspects combined), while their World 2 views of ideas remained very much the same. Using a multivariate analysis test, it was found that there was a significant overall difference between World 2 and World 3 views (Wilk's $\lambda = 0.24$, $F = 83.44$, $p < 0.001$, $\eta2 = 0.76$), with significant differences also being found between the two different World views in each of the three aspects. This suggests that, after working collaboratively with ideas for a semester, students became more aware of the important role of ideas as epistemic entities for sustained knowledge creation. In particular, there were significant increases in the scores for each of the three coding aspects of the World 3 epistemic view. The participants tended to see that: (1) ideas can be treated not merely as abstract concepts, but as concrete objects that can be tinkered with and modified; (2) ideas can be derived not just from reflective thinking within one's mind-as-a-container, but from interaction with the physical world

Table 2
Practical inquiry model.

Inquiry activity	Description	Example
Triggering event	Identifying an issue, dilemma, or problem that emerges from experience.	I would like to know whether there are any new ways to keep mosquitoes away, in addition to using a mosquito zapper. (S26) I want to know if it is possible to design a kind of slipper that will dry itself quickly as it is very uncomfortable to wear a wet slipper, especially after taking a shower. (S09)
Exploration	Working between the private, reflective world of the individual and the social exploration of ideas.	What makes mosquitoes buzz? I found out that the buzzing sounds are actually caused by the vibration of its wings – the beating of the wings against the air. (S19) My hypothesis is that we can be more environmentally friendly by harvesting tiny energy from daily living, such as energy created by walking [in-shoe device]. (S16)
Integration	Constructing meaning from the ideas generated in the exploratory phase.	Putting our ideas together, I think the main problem is ventilation. An ill-ventilated shoe is not a good design. (S25) It is necessary to redesign the bus routes so that double-decker buses can pass certain tunnels, or to redesign the buses and make them single-decker. (S39)
Resolution	Transforming ideas into a solution to the target dilemma or problem by means of direct or vicarious action.	Regarding space design, it is a good idea to consider double-decker buses. It would make more space by designating a standing area while making the sitting area transformable so the space can be more flexible for different accommodation needs. (S39) We should design a set of correction liquids/tapes with various colours. This way, not only can the tool kit be used for correction on different coloured papers but it can be used for artwork, too, like crayon. (S23)

Source: Garrison, D. R., Anderson, T., & Archer, W. (2001). Critical thinking, cognitive presence, and computer conferencing in distance education. *American Journal of Distance Education, 15*(1), 7–23.

Table 3
Comparisons between World 2 and World 3 epistemic views using multivariate analysis test (N = 41).

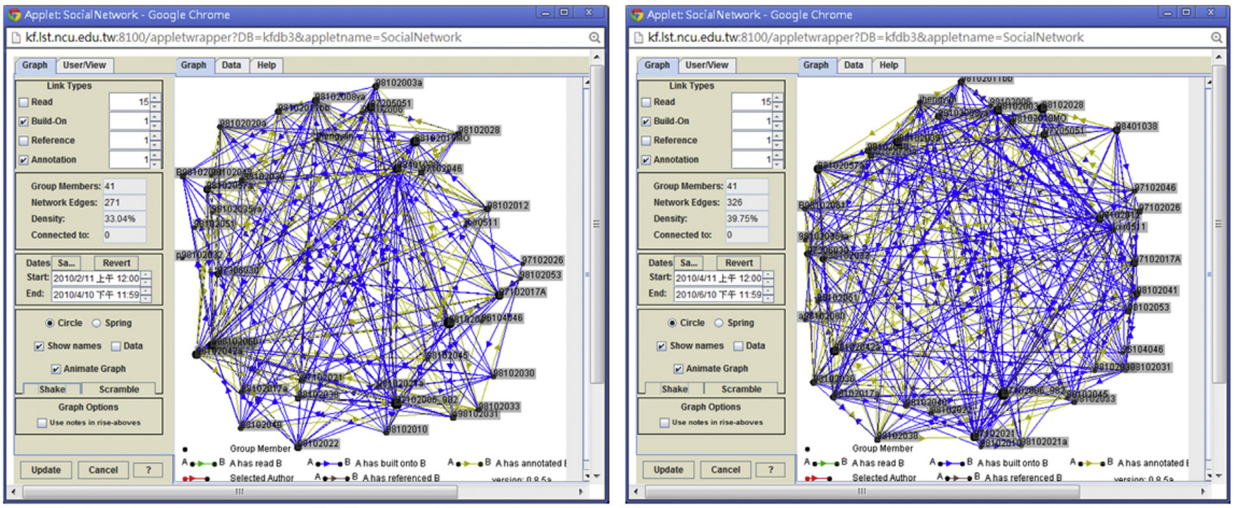
Test	Aspects of epistemic view	World 2 view		World 3 view		*F*-value
		M	SD	M	SD	
Survey in the beginning of semester	abstract vs. concrete	0.34	0.48	0.32	0.57	0.44
	reflective vs. interactive	0.93	0.82	1.17	0.92	1.61
	personal vs. collaborative	0.59	0.67	0.71	0.93	0.46
	three aspects combined	0.62	0.30	0.73	0.47	
Survey at the end of semester	abstract vs. concrete	0.32	0.47	1.44	1.00	42.15***
	reflective vs. interactive	0.61	0.67	1.66	1.28	21.74***
	personal vs. collaborative	0.44	0.55	1.90	1.05	34.53***
	three aspects combined	0.46	0.31	1.67	0.81	

***$p < 0.001$.

(e.g., by interacting with the environment); and (3) not only can ideas be used for personal knowledge growth, but they can be collaboratively and innovatively improved to advance community knowledge. Overall, the findings suggest that students started to develop a more informed World 3 epistemic sense that is critical for collaborative knowledge building.

5.1.2. Overall online interaction and inquiry activities

As mentioned earlier, in order to design technology products, students engaged in cycles of sustained idea improvement that required problem identification, idea generation, idea diversification, idea reflection, and idea synthesis. They usually began this process by identifying authentic problems derived from their personal life experience ($M = 13.90$, $SD = 9.17$ for the mean number of problems identified). They then moved on to produce initial ideas of how to address their problems of interest by posting notes online ($M = 27.49$, $SD = 18.80$ for the mean number of notes contributed). To diversify their ideas, they read and/or built on one another's notes ($M = 397.85$, $SD = 225.67$ for the mean number of notes read; and $M = 20.83$, $SD = 18.75$ for the mean number of built-on notes). In the meantime, to facilitate idea search and exchange for diversification, they marked keywords within notes ($M = 18.22$, $SD = 15.06$ for the mean number of notes that contained keywords). To reflect on and improve the ideas further, they tried to build on, annotate and/or revise one another's notes ($M = 8.15$, $SD = 9.65$ for the mean number of annotations; $M = 4.22$, $SD = 4.02$ for the mean number of revisions). They also used customizable scaffolds to facilitate the inquiry process ($M = 22.41$, $SD = 21.09$ for the mean number of scaffold use), with the purpose of integrating ideas for the eventual improvement of their technology products. All the online activity measures were found to be significantly correlated with one another ($0.60 < r < 0.99$, $p < 0.01$), suggesting that the more actively the participants were engaged in one online inquiry activity, the more likely they were to engage in another activity as well. As an illustration, Fig. 2 shows participants' online interaction patterns with an enhanced network density from an early stage (33.04%; before mid-term) to a later stage (39.75%; after mid-term) of knowledge building, demonstrating a gradually stronger sense of community effort for collaborative knowledge work. As the learning activities were mainly in groups, it is



a. Early inquiry stage (before mid-term) with network density of 33.04%

b. Later inquiry stage (after mid-term) with network density of 39.75%

Fig. 2. An example that illustrates participants' online interaction patterns (in terms only of the building-on and annotation activities) at an early and a later stage.

also important to explore further how the groups performed differently and whether this difference is related to their online interaction and inquiry activities (details below).

5.2. Group-level analysis

5.2.1. Comparison between more-informed and less-informed groups

The learning groups in this course were formed based on individual interest in self-identified technology problems. To examine differences in group performance, the average score ($M = 6.90$) of students' epistemic views obtained in the pre-post survey was used as a separation point to divide the groups into more-informed groups (with higher scores) and less-informed groups (with lower scores). As Table 4 shows, it was found that there was a significant difference in terms of epistemic scores between the more-informed groups and the less-informed groups ($F(1, 39) = 6.19$, $p < 0.05$).

Analysis of online performance was conducted, and it was found that there were no statistically significant differences between the more-informed and less-informed groups, although the more-informed groups showed higher values in all aspects of online activities (except for the reading activity). Moreover, the duration of inquiry for each group was counted and then compared, and it was found that there was a significant difference between the more-informed and the less-informed groups ($F(1, 39) = 4.17$, $p < 0.05$), indicating that a longer inquiry time is related to higher epistemic view scores. But even so, the findings here can only suggest that there is only a superficial relationship between the quantity of groups' online activities and their epistemic views.

Further investigation into the quality of the groups' online inquiries was therefore conducted. Using Garrison et al, (2001) practical inquiry model as a coding scheme, with a note being the unit of analysis, a total of 249 notes contributed by all groups were qualitatively examined. As a baseline analysis, it was found that the percentage of notes contributed for each of the four types of inquiry activities was as follows: (1) triggering event (10%); (2) exploration (67%); (3) integration (21%); and (4) resolution (2%). Overall, the majority of notes were contributed for the purpose of exploratory activity.

An ANOVA comparison between the more-informed groups and the less-informed groups was conducted. As the Levene test is significant ($p < 0.05$, i.e., equal variances are not assumed), Welch's F was used for the following statistical test. The result was that there was no significant difference found between the more-informed and the less-informed groups in terms of either "triggering event" ($F(1, 39) = 1.05$, $p > 0.05$) or "resolution" ($F(1, 39) = 1.52$, $p > 0.05$). But, in terms of "exploration," it was found that there is a significant difference: the less-informed groups outperformed the more-informed groups ($F(1, 39) = 6.67$, $p < 0.05$). In contrast, in terms of "integration," it was found that the more-informed groups outperformed the less-informed groups ($F(1, 39) = 9.70$, $p < 0.01$). The results indicate that the less-informed groups tended to engage in more exploratory activities, working towards idea diversification and information exchange. In contrast, while the more-informed groups also spent a large amount of time exploring, they were more likely to move beyond exploration to invest effort in idea integration (i.e., to synthesize ideas in order to make sense of their exploration). It is, however, important to note that both the more-informed and the less-informed groups seemed to spend relatively less time on resolution activities. Nevertheless, this is quite natural, as such activities were mainly found to occur towards the end of the semester when students were trying to finalize their technological products, and also because resolution activities are more challenging than other inquiry activities.

5.2.2. Analysis of a particular group as a case example

As a case example, group 6 was singled out for further analysis. This was because an inconsistency was found only in this group. Group 6 belonged to the less-informed groups, but it showed a high number of online interactions in the Knowledge

Table 4
Analysis of group performance.

Group performance	More-informed groups (n = 18)		Less-informed groups (n = 23)		*F* value
	M	SD	M	SD	
Epistemic view score	8.5	4.062	5.652	3.27	6.19*
Online activities					
# of problems addressed	12.94	7.69	12.96	8.43	0
# of notes contributed	32.33	23.35	23.70	13.67	2.12
# of notes read	352.20	210.00	366.80	202.30	0.05
# of building-on notes	26.28	23.50	16.57	13.01	2.83
# of notes with keywords	17.83	12.43	16.83	14.87	0.05
# of annotations	8.61	11.20	7.78	8.48	0.07
# of revisions	4.22	3.98	4.22	4.15	0
# of scaffolds used	27.22	25.64	18.65	16.33	1.70
Length of inquiry (in days)	41.61	23.83	25.87	25.01	4.17*
Inquiry stage					
Triggering event	0.05	0.16	0.13	0.33	1.05
Exploration	0.55	0.50	0.71	0.46	6.67*
Integration	0.34	0.47	0.17	0.38	9.70**
Resolution	0.08	0.28	0.02	0.15	1.52

*$p < 0.05$ **$p < 0.01$.

Forum. For example, the total number of notes it contributed was 45, which was much higher than the average of all the groups (M = 27.67, SD = 19.55), and its inquiry duration (M = 63 days) was also longer than the average of all groups (M = 37.31, SD = 24.99). In contrast, the online performance of the other groups was consistent. So, more detailed analysis of the online activities and inquiry behaviour of the students in group 6 was carried out. In particular, the quality of ideas related to the improvement of this particular group's technology product (shoes) was examined.

First, in terms of online activities, Table 5 summarizes the five main problem spaces/areas for idea improvement derived from this group's collective effort to design better shoes: replaceability, comfort, waterproof properties, nanotechnology, and aesthetics. Moreover, Fig. 3 shows the complete interactive and collaborative activities for the technology product designed in this group. There were, in total, 45 notes contributed in this Knowledge Forum view. The top-right part of the figure shows the emerging process of five sub-problem spaces (each line shows when, and how frequently, ideas within each problem space were referenced, built on, elaborated, or improved during the inquiry period).

Although the quantitative analysis of online activities indicated that there were diversified ideas produced and discussed in the various problem spaces, further analysis of the content of the inquiries showed that the focus of inquiry was mainly on lower-level inquiry activities. The results showed that the majority of note postings were asking and responding to questions or sharing information, and that the students were not able to move on to higher levels of inquiry activities such as synthesizing/integrating diversified ideas into more coherent explanations, or achieving critical solutions for a better shoe design. It was found that 90% of ideas fell into the category of preliminary inquiry activities of “triggering events” (12%) and “exploration” (78%). Examples of such activities (extracted from the students' notes) included: “Shoes are often made from plastic, and air cannot get through, so it's not comfortable wearing them” (triggering event concerning “comfort”, by S20); “The bottom of the shoes always wears off quickly; if the sole of shoes could be changeable, it could save money” (exploration concerning “replaceability”, by S15); “The shoes will not be wet easily if we invent some waterproof spray that can form a thin layer on shoes” (exploration concerning “waterproof properties”, by S35); “Is it possible to invent shoes that are both beautiful and practical, especially for wearing on rainy days?” (exploration concerning “aesthetics”, by S30). Only 10% of ideas, such as, “Using nanotechnology to make shoe surfaces waterproof!” (integration concerning “nanotechnology and waterproof properties”, by S35) fell into the category of “integration”. Finally, it was found that none (0%) of the ideas contributed to achieving a “resolution”—i.e., a higher level of the inquiry process.

A further ANOVA test investigating the differences among all the groups also confirmed that there was a significant difference in terms of integration activity (Welch = 2.71, $p < 0.05$). A post hoc comparison (using the Games-Howell test) further showed that, in terms of “integration”, group 1 (M = 0.39, SD = 0.49), which was the most highly informed of all the groups, outperformed group 6 (M = 0.10, SD = 0.31), indicating that group 6 tended to have the fewest meaning-making and integrating inquiry activities of all the groups. The reason why group 6 was one of the relatively less-informed groups may have something to do with the lack of quality of its inquiry activities. So, even though there were frequent online activities during the inquiry process, their epistemic view scores remained low.

6. Discussion

In summary, the findings based on the pre-post survey of epistemic views suggested that there was a significant positive relationship between students' engagement in online knowledge-building practice and the development of their more innovation-oriented, World-3 epistemic view. Specifically, it was found that: (1) students had a relatively less well-informed epistemic view at the beginning of the semester than at the end of the semester; (2) after engaging in collaborative knowledge-building activities for a semester, students' World 2 epistemic view remained similar; this implies that knowledge building did not reinforce the view that ideas and knowledge are possessed only within individual minds-as-a-container; (3) however, students' World 3 epistemic view became better informed, as they were more likely to treat ideas as real objects that can be tinkered with for improvement in order to advance group knowledge in a community. In addition, the findings based on an analysis of group performance showed that (4) groups with a better informed World 3 epistemic view tended to spend more time on online interaction and inquiry (in terms of inquiry days); and that (5) it was the quality of idea improvement, rather than the quantity of ideas, that played an essential role in influencing students’ World 3 epistemic views.

As mentioned earlier, previous research has mainly focused on investigating the relationships between epistemic views and learning (e.g., see Chiou et al., 2013; Lin et al., 2012; Muis, 2007; Yang, 2016). An important value added to this line of research is to better understand the relationships between epistemic views and knowledge building, and to specifically

Table 5
Five main problem areas related to the improvement of shoe technology addressed by group 6.

	Average# of notes contributed	Duration of inquiry (in days)	Average# of notes read (per person)	# of collaborators
Idea1: Replaceability	19	62	35.84	14
Idea2: Comfort	6	43	39.17	6
Idea3: Waterproof properties	9	50	24.63	6
Idea4: Nanotechnology	8	36	31.63	5
Idea5: Aesthetics	3	50	35.33	3
Total	45	241	166.6	34

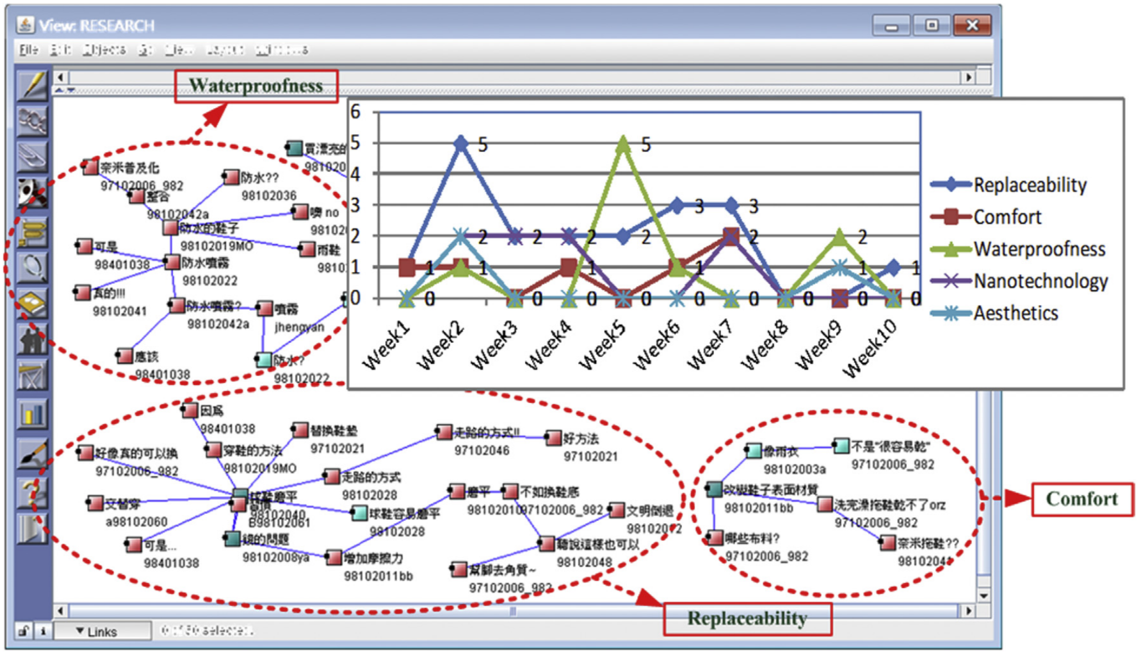


Fig. 3. Idea improvement processes in different problem areas related to shoes (such as replaceability and aesthetics).

suggest that highlighting sustained production and improvement of ideas can lead to a better understanding of the epistemic role of ideas for collective knowledge advancement (Hong & Sullivan, 2009; Scardamalia & Bereiter, 2015). In addition, research that investigates the World 2 and World 3 epistemic views could be carried out among primary, secondary and postsecondary school students when they are engaged in design-oriented knowledge creation as part of their curriculum. In particular, path or structural equation models could be tested when there are enough participants to further unpack the influence of World 2 and World 3 epistemic views on various forms of knowledge creation activities. This is a much needed area for research given the current emphasis on cultivating knowledge creator (see Koh et al., 2015; Chai et al., 2015). Moreover, given the fact that the scope of this study is correlational, we did not empirically make clear whether participation in knowledge building would develop people's epistemic beliefs or whether this is rather the other way around. Therefore, further research should be conducted to explore the potential direction of the assumed relationships between students' engagement in knowledge-building activities and the development of their epistemic view. Particularly in terms of the epistemic role of ideas, idea generation is essential in all forms of knowledge creation (Paulus & Yang, 2000), and effective idea diversification and exchange can make this creative process more effective (Garrison et al., 2001), especially when there is proper tool support (Ardaiz-Villanueva, Nicuesa-Chacón, Brene-Artazcoz, de Acedo Lizarraga, & de Acedo Baquedano, 2011). Clearly, for the proliferation of ideas, there is an important reciprocal relationship between idea generation and idea diversification, as these are both concerned with the quantity of ideas. Previous research suggested that the quantity of ideas generated was an effective measure of their quality (e.g., see Diehl & Stroebe, 1987; Osborn, 1953), meaning that ideas of high quality are more likely to be produced if an adequate number of ideas can be generated. This finding, however, is inconsistent with those of other studies (e.g., Connolly, Jessup, & Valacich, 1990; Graham, 1977; MacCrimmon & Wagner, 1994) that indicate that the correlation between the quality and the quantity of ideas is fairly low or insignificant, and is sometimes even negative. Related to this line of research, the present study also suggested that the diversification of ideas does not necessarily guarantee improvement for the quality of ideas. Sustained improvement in the quality of ideas, rather than increase in the quantity of ideas, is more necessary for group knowledge creation. Therefore, while it is still important that group interaction and collaboration should be facilitated to foster idea exchange and diversification (Garrison et al., 2001), it is perhaps even more critical to guide students towards the goal of improving their ideas by means of elaboration and integration.

To conclude, knowledge-building pedagogy, with a focus on sustained idea improvement, seemed to be useful as a means to help students to develop a better informed, World 3 epistemic view for knowledge advancement. However, if students only focus on lower-level idea exchange and sharing activities for knowledge building, their epistemic views may not change much. This is clearly seen in the groups with less well-informed epistemic views, as their inquiries tended to remain at the lower levels of exploring and information sharing. One important thing to note is that, because knowledge-building activities are principle-based, no pre-specified procedures were employed in this course. But perhaps it is also necessary to re-examine the principles and see whether some more concrete guidance may be needed to help the less well-informed groups make the necessary transfer into higher-level inquiry. There is still room for students in such groups to enhance their high-level inquiry skills in order to become more effective knowledge builders. Further studies will look into this instructional gap to help us to identify more effective instructional know-how.

The results derived from this study have some implications for the development of group knowledge construction. First, a challenge in implementing knowledge-building pedagogy has been how to help learners to develop more effective group dynamics for their knowledge work. The findings suggest that merely encouraging students to engage in more online activities does not guarantee quality knowledge work. In order to attain more productive knowledge work, students need to engage in persistent idea improvement and in-depth inquiry, and this requires more challenging idea integration activities. Second, the instructional design, which was focused on enabling a guiding cycle of sustained idea improvement, was helpful for providing students with a guideline for working progressively with the problems/ideas in which they were interested. The process of sustained idea improvement allows participants to work in a way similar to the actual knowledge workers who engage in a knowledge-creating process. Clearly, this would not be possible if the course implemented some pre-specified learning procedures or highly structured activities (similar to those in an assembly line in a factory). Third, the implementation of knowledge-building pedagogy also implies that the design of the curriculum needs to be flexible enough to allow emergent understanding to occur. With a more adaptable curriculum structure, group inquiry is not limited within a body of pre-specified knowledge and skills. Instead, the students engaged group inquiry can be prompted to develop a strong sense of what is promising, i.e., a sense of those ideas or knowledge that are more promising (or problematic) for solving a given problem. A possible direction for future research is to explore diversified instructional and technological designs and see whether they can guide learners to better develop this sense of what is promising–a sense that is often found in more diverse, distributed expert teams (Lin et al., 2007). Finally, the proposed knowledge-building design also points to the important concept of "learning by group", rather than "learning in group", or individual learning through social processes (Hong & Scardamalia, 2014). This view of group knowledge work goes beyond the traditional view of learning to enhance personal knowledge, and highlights the critical notion of viewing a group as an important and complete learning unit in a class community. Understanding how to create the necessary conditions for facilitating such group-based, collaborative learning is also important for future research.

Acknowledgments

Support for writing this article was provided, in part, from a Taiwan Ministry of Science and Technology grant (MOST#104-2511-S-004-001-MY3) and from a Top University Project grant funded by Taiwan Ministry of Education.

References

Ardaiz-Villanueva, O., Nicuesa-Chacón, X., Brene-Artazcoz, O., de Acedo Lizarraga, M. L. S., & de Acedo Baquedano, M. T. S. (2011). Evaluation of computer tools for idea generation and team formation in project-based learning. *Computers & Education, 56*(3), 700–711.

Bereiter, C. (2002). *Education and mind in the knowledge age*. Routledge.

Bereiter, C. (1994). Constructivism, socioculturalism, and Popper's world 3. *Educational Researcher, 23*(7), 21–23.

Bereiter, C., & Scardamalia, M. (2014). Knowledge building and knowledge creation: one concept, two hills to climb. In S. C. Tan, H.-J. So, & J. Yeo (Eds.), *Knowledge creation in education* (pp. 35–52). Singapore: Springer.

Bereiter, C., & Scardamalia, M. (2003). Learning to work creatively with knowledge. In E. De Corte, L. Verschaffel, N. Entwistle, & J van Merrienboer (Eds.), *Powerful learning environments: Unraveling basic components and dimensions (Advances in learning and instruction series* (pp. 55–68). Oxford: Elsevier Science.

Carey, S., Evans, R., Honda, M., Jay, E., & Unger, C. (1989). An experiment is when you try it and see if it works. *International Journal of Science Education, 11*(5), 514–529.

Chai, C.-S., Hong, H.-Y., Liang, J.-C., Yan, Z.-M., & Tsai, C. C. (2015, Nov). *Exploratory factor analysis for the survey of epistemic beliefs for discipline-based knowledge creation*. Proceedings of the 23rd International Conference on Computers in Education—ICCE2015 (pp. 295–299). Hangzhou, China: Asia-Pacific Society for Computers in Education.

Chan, C. K., & Chan, Y. Y. (2011). Students' views of collaboration and online participation in knowledge forum. *Computers & Education, 57*(1), 1445–1457.

Chen, B., Scardamalia, M., & Bereiter, C. (2015). Advancing knowledge-building discourse through judgments of promising ideas. *International Journal of Computer-Supported Collaborative Learning, 10*(4), 345–366.

Chiou, G. L., Lee, M. H., & Tsai, C. C. (2013). High school students' approaches to learning physics with relationship to epistemic views on physics and conceptions of learning physics. *Research in Science & Technological Education, 31*(1), 1–15.

Chubin, D. E. (1976). The conceptualization of scientific specialties. *The Sociological Quarterly, 17*, 448–476.

Connolly, T., Jessup, L. M., & Valacich, J. S. (1990). Effects of anonymity and evaluative tone on idea generation in computer-mediated groups. *Management Science, 36*(6), 689–703.

Csikszentmihalyi, M., & Wolfe, R. (2014). New conceptions and research approaches to creativity: implications of a systems perspective for creativity in education. In *The systems model of creativity* (pp. 161–184). Netherlands: Springer.

Diehl, M., & Stroebe, W. (1987). Productivity loss in brainstorming groups: toward the solution of a riddle. *Journal of Personality and Social Psychology, 53*(3), 497–509.

Ding, N., Wei, J., & Wolfensberger, M. (2015). Using epistemic synchronization index (ESI) to measure students' knowledge elaboration process in CSCL. *Computers & Education, 80*, 122–131.

Drucker, P. F. (2011). *The age of discontinuity: Guidelines to our changing society*. Transaction Publishers.

Dweck, C. S. (2010). Even geniuses work hard. *Educational Leadership, 68*(1), 16–20.

Evans, P., & Wolf, B. (2005). Collaboration rules. *Harvard Business Review, 83*(7), 96–104.

Garrison, D. R., Anderson, T., & Archer, W. (2001). Critical thinking, cognitive presence, and computer conferencing in distance education. *American Journal of Distance Education, 15*(1), 7–23.

Graham, W. K. (1977). Acceptance of ideas generated through individual and group brainstorming. *Journal of Social Psychology, 101*, 231–234.

Granovetter, M. (1983). The strength of weak ties: a network theory revisited. *Sociological theory, 1*, 201–233.

Hong, H.-Y., & Chiu, C.-H. (2016). Understanding how students perceive the role of ideas for their knowledge work in a knowledge-building environment. *Australasian Journal of Educational Technology, 32*(1), 32–46.

Hong, H.-Y., & Lin-Siegler, X. (2012). How learning about scientists' struggles influences students' interest and learning in physics. *Journal of educational psychology, 104*(2), 469.
Hong, H.-Y., & Scardamalia, M. (2014). Community knowledge assessment in a knowledge building environment. *Computers & Education, 71*, 279–288.
Hong, H.-Y., Scardamalia, M., & Zhang, J. (2010). Knowledge society network: toward a dynamic, sustained network for building knowledge. *Canadian Journal of Learning and Technology, 36*(1).
Hong, H.-Y., & Sullivan, F. R. (2009). Towards an idea-centered, principle-based design approach to support learning as knowledge creation. *Educational Technology Research & Development, 57*(5), 613–627.
Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: an analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86. http://dx.doi.org/10.1207/s15326985ep4102_1.
Kling, S., & Rosenberg, N. (1986). An overview of innovation. In R. Landau, & N. Rosenberg (Eds.), *The positive sum strategy: Harnessing technology for economic growth* (pp. 275–305). Washington, DC: National Academy Press.
Koh, J. H. L., Chai, C. S., Wong, B., & Hong, H.-Y. (2015). *Design thinking for education*. Singapore: Springer.
Lin, X. D., & Bransford, J. D. (2010). Personal background knowledge influences cross-cultural understanding. *Teachers College Record, 112*(7), 1729–1757.
Lin, Y. C., Liang, J. C., & Tsai, C. C. (2012). The relationships between epistemic beliefs in biology and approaches to learning biology among biology-major university students in Taiwan. *Journal of Science Education and Technology, 21*(6), 796–807.
Lin, X. D., Schwartz, D., & Bransford, J. D. (2007). Intercultural adaptive expertise: explicit and implicit lessons from Dr. Giyoo Hatano. *Human Development, 50*(1), 65–73.
MacCrimmon, K. R., & Wagner, C. (1994). Stimulating ideas through creativity software. *Management Science, 40*(11), 1514–1532.
Muis, K. R. (2007). The role of epistemic beliefs in self-regulated learning. *Educational Psychologist, 42*(3), 173–190.
Osborn, A. F. (1953). *Applied imagination* (1st ed.). , New York: Scribner.
Papert, S. (2000). What's the big idea: towards a pedagogy of idea power. *IBM Systems Journal, 39*(3–4).
Paulus, P. B., & Yang, H. C. (2000). Idea generation in groups: a basis for creativity in organizations. *Organizational Behavior and Human Decision Processes, 82*, 76–87.
Popper, K. R. (1972). *Objective knowledge: An evolutionary approach. Oxford*. Clarendon Press.
Popper, K. (1978). *Three worlds*. Paper presented at the Tanner Lecture on Human Values, University of Michigan, April 7, 1978.
Prehofer, C., & Bettstetter, C. (2005). Self-organization in communication network: principles and design paradigms. *IEEE Communications magazine, 43*(7), 78–85.
Psycharis, S. (2013). Examining the effect of the computational models on learning performance, scientific reasoning, epistemic beliefs and argumentation: an implication for the STEM agenda. *Computers & Education, 68*, 253–265.
Reigeluth, C. M. (2013). In *Instructional-design theories and models: A new paradigm of instructional theory* (Vol. 2). Routledge.
Roth, W.-M., van Eijck, M., Hsu, P.-L., Marshall, A., & Mazumder, A. (2009). What high school students learn during internships in biology laboratories. *The American Biology Teacher, 71*(8), 492–496.
Sawyer, R. K. (2004). Creative teaching: collaborative discussion as disciplined improvisation. *Educational Researcher, 33*(2), 12–20.
Sawyer, R. K. (2011). *Structure and improvisation in creative teaching*. Cambridge University Press.
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. (2003). Beyond brainstorming: sustained creative work with ideas. *Education Canada, 43*(4), 4–7, 44.
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.
Scardamalia, M., & Bereiter, C. (2014). Knowledge building and knowledge creation: theory, pedagogy, and technology. In K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 397–417). Cambridge, MA: Cambridge University Press.
Scardamalia, M., & Bereiter, C. (2015). Education in an open informational world. *Emerging Trends in the Social and Behavioral Sciences: An Interdisciplinary, Searchable, and Linkable Resource*, 1–15.
Strauss, A. L., & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. Newbury Park, CA: Sage Publications.
Thagard, P. (1989). Explanatory coherence. *Behavioral and Brain sciences, 12*(3), 435–502.
Tirado, R., Hernando, Á., & Aguaded, J. I. (2015). The effect of centralization and cohesion on the social construction of knowledge in discussion forums. *Interactive Learning Environments, 23*(3), 293–316.
Yang, F. Y. (2016). Learners' epistemic beliefs and their relations with science learning—exploring the cultural differences. In *Science education research and practices in Taiwan* (pp. 133–146). Singapore: Springer.
Yin, R. K. (2013). *Case study research: Design and methods*. Sage publications.
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. *The Journal of the Learning Sciences, 20*(2), 262–307.