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College Students Constructing Collective Knowledge of Natural Science History in a Collaborative Knowledge Building Community

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Abstract This study investigates whether engaging college students ($n = 42$) in a knowledge building environment would help them work as a community to construct their collective knowledge of history of science and, accordingly, develop a more informed scientific view. The study adopted mixed-method analyses and data mainly came from surveys and student online discourse recorded in a database. Findings indicate that students' knowledge building activities were conducive to the development of their online collaboration as a learning process and the effective collective knowledge work concerning natural science history as a learning outcome. Moreover, students were able to attain a more constructivist-oriented epistemic view that sees scientific theories as invented, tentative, and improvable objects. Finally, based on course reflection, students also regarded their collective learning experiences in this course as meaningful and productive.

Keywords Collaborative learning · Knowledge building · Natural science history

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Introduction

According to Descartes (1960), there are two essential epistemic entities in scientific inquiry—the object of knowledge, that which scientists seek to know (e.g., scientific theory), and the subject of knowledge, that is, the scientists. In science instruction, these two epistemic entities represent two different forms of knowledge. One is the scientific knowledge and theories progressively developed by scientists. The other is pertaining to the knowers whose knowing is inextricably related to cultural historical context which they developed their work in the science community. Literature, however, indicates that formal science education tends to focus on the teaching of scientific content knowledge while overlooking related historical and contextual knowledge. For example, as noted by Galili and Hazan (2001), despite the intensive discussions about the necessity of including history of science in science instruction for over a 100 years, it is still seldom implemented. Consequently, students often suffer from the lack of a holistic understanding of science as a social enterprise and a human endeavor, and are inclined to see scientific knowledge as fragmented and unrelated (AAAS 1989; Hurd 1973; Wang and Marsh 2002). Accordingly, their understanding of the nature of science is also quite limited (Abd-El-Khalick and Lederman, 2000; Ryan and Aikenhead 1992; Sandoval 2005). For example, studies have shown that most students' understanding of the nature of science is still largely confined to the idea of individual genius scientists carrying out their research in a circumscribed lab environment (Buck et al. 2002; Driver et al. 1996; Howes and Cruz 2009; McAdam 1990; Rahm 2007). They do not realize that the development of scientific theories is often a sustained process of collaborative knowledge work among scientists (Duschl 1990; Hong and

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Lin-Siegler 2012). This may cause students in overlooking opportunities to work collaboratively with others like real scientists do.

The primary purpose of this study is to explore whether engaging students in a knowledge building environment would help them: (1) work more like a scientific community and be able to collaboratively construct their collective knowledge of natural science history; (2) develop a more constructivist-oriented epistemic view that sees scientific theories as tentative and improvable; and (3) appreciate more of their collaborative learning experience in this course.

Scientific Views

In general, there are two dominant scientific views; one refers to the materialistic view (cf., e.g., Brush 1989; Griffin 1988; Harmon 1988) and the other the humanistic view (cf., e.g., Donnelly 2002, 2004; Moheno 1993; Newton 1986; Stinner 1995; Wang and Marsh 2002). Underlying the former is an epistemic belief that sees knowledge as objective and scientists as detached observers seeking absolute knowledge (cf. Kirschner 1992) or "justifying knowledge" as Duschl (1990) called. As such, this view regards science as a collection of empirically verified facts that are objectively linked or correlated. In contrast, the humanistic view is undergirded by an epistemic belief that regards knowledge as subjective (Feyerabend 1993; Jacobs 2000; Polanyi 1962; Wong 2002) and scientists as active participants involved in the innovation and theorization of knowledge (cf. Kirschner 1992; Polanyi 1962). Scientific theories are, therefore, not seen as absolute truth but as "invented realty" (Roth and Lucas 1997), and science as a discipline is treated as a human endeavor and a social enterprise that is value laden and deeply influenced by the collective minds of the scientific community.

Different views are associated with different instructional approaches. Under the support of a materialistic view, knowledge acquisition is usually highlighted in the goal of science teaching (Kirschner 1992)—usually by helping students to make sense of existing science knowledge (e.g., textbook knowledge). On the other hand, humanistic-oriented science teaching tends to highlight knowledge construction (Kirschner 1992)—usually by means of engaging students in self-directed exploration, inquiry, and progressive problem solving. Building on Kuhn's concept of the paradigm shift (1970), the type of knowledge that is included or excluded in the formal science curriculums and science textbooks can be deeply influenced by the dominating paradigm in science. With the materialistic view being widely accepted as the prevailing view in formal education, most science textbooks also tend to emphasize scientists' scientific discoveries, while overlooking scientists' theory-building processes (Hong and Lin-Siegler, 2012). Previous study by Liu and Tsai (2008; see also Liu et al. 2011) indicates that even science majored students can hold more materialistic epistemic views that see scientific knowledge as static, objective, and universal. Apparently, if science education wants to help more students to understand how scientists actually build their theories and advance scientific knowledge, it is necessary to provide students with opportunities to experience not only the materialist view, but also the humanistic view (Duschl 1990).

Stories About Scientists and Theories

There are two general ways to understand scientists and the scientific theories they developed (Hong and Lin-Siegler 2012). One is relatively more formal and superficial: for example, providing brief information about scientists' intellectual experiences, successes, and achievements across life. Often, science textbooks present such scientist's profile with a photograph image attached. The other is to provide rich narratives about scientists' struggle, including their underlying motives, personal values, and challenges and obstacles when they were developing scientific theories. Science textbooks, however, are more likely to present scientists' stories in the former way (i.e., outcome or achievement-oriented stories) rather than the latter way (i.e., process or struggle-oriented stories). Moreover, most textbooks tend to include only successful scientists' stories, while excluding the detailed context such as those failed attempts during the theory-building process. As argued by Dagher and Ford (2005), "Biographies of historic scientists were characterized by a relative absence of description of how scientists arrived at their knowledge, especially in books addressing younger readers," (p 377). The inadequate narratives about scientists in general, coupled with how pop culture portrays scientists such as those in the comics (see Van Gorp and Rommes 2014) and didactic classroom experiences, are likely to hinder learners in developing well-informed image of scientists that could facilitate deep learning in science. As a case in point, Zhai et al. (2014)recent study of Singaporean students' images of doing science reveals that children may not understand how scientist work well. While Singapore is well known for its science learning results, the authors caution that students' understanding of how scientist work could shape their attitude toward science.

The overlooking of scientists' struggles seems especially unfortunate, as knowing how scientists progressively solve problems and develop theories may help students develop a more humanistic view of science. It may also help students realize that scientists are like ordinary professionals with committed attitude, rather than some godlike genii. Science educators have suggested that the use of scientists' stories can be a great knowledge resource that can motivate science learning (Eshach 2009; Haven 1997; McKinney and Michalovic 2004). For example, in a review of 350 or so studies selected from 15 different fields of science, Haven (1997) found that stories are "an effective and efficient vehicle for teaching, for motivating and for general communication of factual information, concepts, and tacit information" (p 4). Mandler and colleagues' (e.g., Mandler 1984; Mandler and Johnson 1977) studies also found that people tend to remember information better in the form of stories.

As argued by Bruner (1996), "all knowledge has a history" (p 61). In the context of science learning, this history documents a close relationship between scientists and the theories they developed. The biographies or stories of scientists contain rich humanistic knowledge regarding how they transform their initial science ideas into testable theories by means of repeated hypothesizing and refining in order to develop explanatorily more coherent theories and to advance scientific knowledge.

Community Knowledge Building

Our society is increasingly knowledge based (Drucker 1968; UNESCO 2005). This is especially obvious in the way information communication and technology (ICT) is utilized in our daily lives. ICT not only provides new ways of connectivity for information exchange among knowledge groups, but also reconceptualizes the notion of learning from individual knowledge growth to collaborative knowledge work (Scardamalia 2002; Hong et al. 2010). In response to this societal change, an emerging line of learning research has been focusing on designing effective web-based learning models to support collaborative knowledge work. In Paavola et al. (2004) paper, they reviewed some contemporary models of collaborative knowledge creation and identified three prominent models that support knowledge creation, including Nonaka and Takeuchi's (1995) knowledge spiral, Engestrom's (1999) expansive learning, and Scardamalia and Bereiter (2006) knowledge building community. To foster knowledge co-construction, the design of web-based learning environments should be able to foster meaningful knowledge interactions and produce collective understanding in a group or a community. Nevertheless, while the importance of collaborative knowledge work is gaining recognition, there is still much to learn about how to pedagogically support different web-based environments to engage students in creative knowledge collaboration. As argued by Kreijns et al. (2002), current web-based collaborative learning environments still do not entirely meet expectations on supporting social construction of knowledge. An essential challenge in research is to understand how to better design more effective instructional approaches to support collaborative knowledge work. In the present study, Scardamalia and Bereiter (2006) knowledge building model is implemented and tested for its capacity to support collaborative knowledge work.

Knowledge building is a social process aimed at advancing community or collective knowledge via sustained improvement of ideas or knowledge claims (Bereiter 2002; Scardamalia and Bereiter 2003, 2006). To understand what community or collective knowledge is, it is necessary to distinguish it from individual or personal knowledge. The latter refers to a psychological concept that sees knowledge as private possession contained in the individual mind (cf. Hyman 1999; Popper 1972). The former, however, represents a social concept that sees knowledge as epistemic artifacts or objects that have a public life (Popper 1972; Bereiter 2002; Hyman 1999). Community knowledge is therefore regarded as public knowledge or intellectual property accessible to all members in that community.

The importance of community knowledge in a knowledge building environment is equivalent to public knowledge in "creative commons" or an open space (e.g., a community's discussion space or forum), characterized by continuously producing and improving tentative knowledge claims or ideas via a community's open discussion (Hong and Scardamalia 2014). Within such open space, ideas can exist independently of their contributors. Once contributed and documented in the open space, they can be subjected to further development by any community member. The sustained development in which one's ideas or thoughts are gradually improved to become community knowledge thus requires community participants to play an active role in monitoring who is addressing what problem by collaborating with one another; in order to attain the overall benefit of the community knowledge advancement (Hong and Lin-Siegler 2012). Working within such a learning environment, advancing community or collective knowledge becomes essential while individual learning becomes a by-product; collaborative learning becomes the norm for the community's collective understanding of the subject or theme being investigated (Scardamalia 2002). Eventually, community knowledge becomes reified knowledge as it is progressively and collaboratively improved (Merton 1973). When a community is developing its collective understanding in a knowledge domain, their writing or posted notes would serve as the essential building blocks for sustained community knowledge advancement. One important thing to note is that community knowledge building is not individual learning through social processes with each individual having a separate learning goal. Rather, community knowledge building is collective in nature with a clear communal goal (Scardamalia and Bereiter 2010).

The Present Study

Previous research suggests that stories about natural sciences can be useful to enhance science learning (Hong and Lin-Siegler 2012). For example, having around ten percent of US students selected as participants, Conant (1957) conducted a nation-wide study with historical stories about natural sciences carefully integrated into science textbooks. The results showed that students' learning motivation to study science was significantly enhanced (Klopfer 1969). As also suggested by McKinney and Michalovic (2004), "by using a wide variety of biographies and histories teachers can stimulate student interest, provide role models for all students, and generally give a more complete picture of the nature of scientific work" (p 46). Research also suggests that stories about scientists' struggles during their knowledge building processes can be useful in improving students' understanding of how scientific theories are conceptually related to one another (Hong and Lin-Siegler 2012; Klassen and Klassen 2014). Prior research concerning knowledge building practice suggests that it is useful in enhancing student learning in various subject areas, for example, science learning (Hakkarainen 2004; Scardamalia and Bereiter 1991), mathematics learning (Moss and Beatty 2006), language learning (Sun et al. 2010), and graphical literacy (Gan et al. 2010). Furthermore, studies also indicate that knowledge building activities enhance students' general epistemological understanding (Hong and Lin 2010; Hong et al. 2011). Knowledge building is a collaborative process focused on sustained community knowledge advancement. The nature of its process emulates scientists' knowledge-creating process in their scientific community. Therefore, it is posited that engaging students in collaborative knowledge work, in particular, building their collective understanding of natural science history via story writing activities (that illustrate how scientists in their community develop theories over time) should have effects on the development of students' scientific views. Yet, such an assumption remains to be tested.

Method

Participants and Context

The participants were 42 college students (with 30 females and 12 males) who took an introductory course on natural sciences at a university in Taiwan. The course was elective and regarded as a part of the general education curriculum. The participants' age ranged from 19 to 22 years. As a fundamental course to foster general education, the main instructional goal designed in this course was to help students learn to collaboratively build knowledge about natural science history as a community. Underlying this explicit goal, however, it was also expected that students could develop a more constructivist-oriented sense of science by understanding that scientists develop scientific theories in an evolutionary and collaborative way. To this end, students were required to complete the following tasks. First, each student had to select at least one specific scientist or theory as the anchor for his or her story writing. Particularly, they were prompted to focus on how scientists work to develop theories. Second, students were required to read one another's stories in order to avoid unnecessary repetition and to make connections between scientists and theories during their story writing process. It is expected that students would enhance their social and historical understanding of the scientific history by sharing and reading stories collectively. Third, students were also required to work in an online knowledge building environment called Knowledge Forum (KF) (Scardamalia and Bereiter 2003; Scardamalia 2004).

Knowledge Building Environment

To elaborate, KF is a multimedia platform designed to support community knowledge work. In the present study, community members shared a collective goal to construct collective knowledge about natural science history. To this end, they were required to study scientists' intellectual lives. Then, they posted what they read about their selected scientists' theory-developing stories in the form of a note in the database. At the same time, they read about one another's stories, or could search for particular scientists or theories that were of interest to them in the database. At the end, they tried to finalize their stories by integrating all the pieces of information that they had posted online, over time, in the database, into a complete story as a final report for this class. KF can run on a graphics mode in which students' notes are depicted as interconnected in the open discussion space in which the development of stories can be easily traced. As shown in Fig. 1, notes posted by students are organized in terms of discussion thread in a KF view (i.e., the open discussion space). With the help of a graphical view, it is easy for members to monitor their top-level community goal of constructing their collective knowledge about natural science history. By contributing diversified story content, linking different scientists and theories in stories, exchanging knowledge, and integrating various story elements, students tried to work together as a community. To this end, students in the present study have to write and share all stories collaboratively. They did so by investigating how scientists as knowledge workers work together to develop scientific theories.

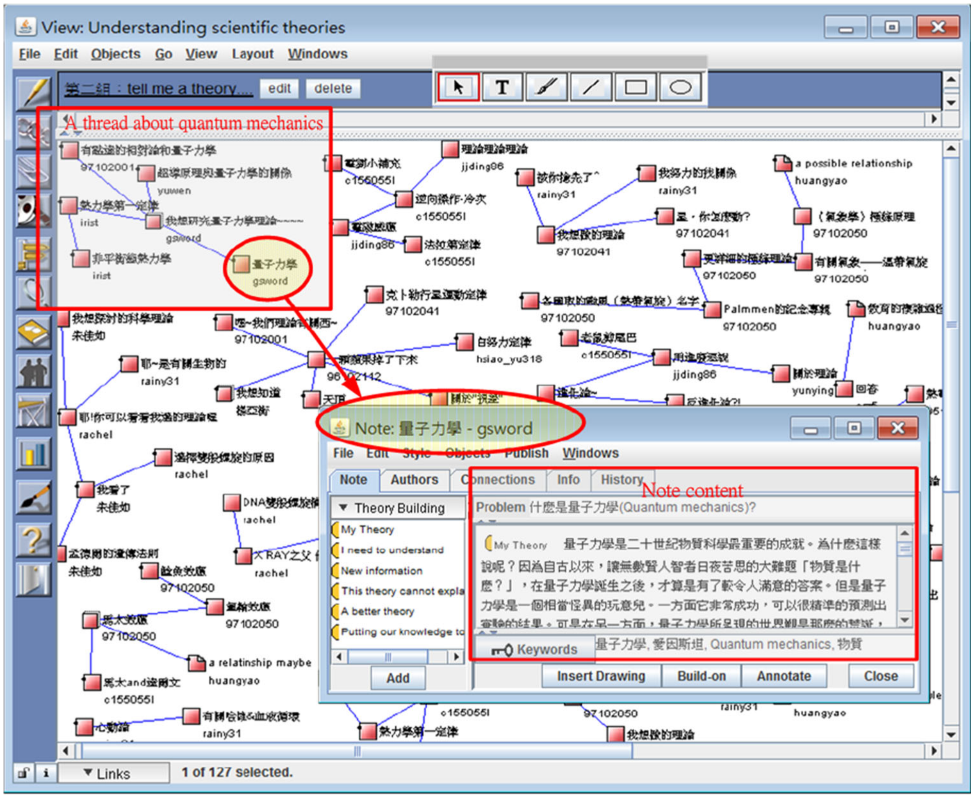


Fig. 1 Example of a Knowledge Forum view—a virtual space where students wrote and shared their pieces of stories about natural science history. Note: Each *square* here represents a note and a *link* represents a collaborative relationship (e.g., a building-on relationship); the *box* in the *upper left-hand corner* represents threaded discussion of a story piece about quantum mechanics; and *inside the box*, the *circled* note is a sample note which is shown as a pop-out window

Data Source and Analysis

Data mainly came from students' online discourse about natural science stories recorded in a KF database, a pre-post survey, and students' end-of-course reflection. First, regarding online discourse, descriptive analysis was used to provide a general picture of how students worked collaboratively online. Then, a two-level analysis was employed. The first was an overall analysis used to identify all stories, scientists, and scientific theories that students contributed in the community's discourse space, using the following indicators: (1) the total number of stories collectively constructed by the students and (2) the frequencies of appearance of each scientist and each scientific theory in these stories. As the manifestation of relevant contextual and historical understanding can be reflected through students' description of relationships between people (scientists) and theories (Hong and Lin-Siegler 2012), the focus of the other more detailed level of analysis was to identify the relationships (1) between scientists, (2) between scientific theories, and (3) between scientists and scientific theories, as depicted by the students in their stories. Two inter-coders independently read and re-read all stories to code the above-named three types of relationships in the posted stories. The computed inter-coder agreement (using Cohen's Kappa) was 0.89.

Second, regarding the pre-post survey, it consisted of only five question items (related to the "scientific theory" dimension) adopted from the View on Science and Education Questionnaire (VOSE) originally developed by Chen (2006). This five-point instrument (0 = strongly disagree and 4 = strongly agree) has been empirically validated and has a test–retest correlation coefficient of 0.82 (Chen 2006). The "scientific theory" dimension assesses whether scientific theories are a representation of absolute truth, or ideas invented by scientists to interpret and describe natural phenomena (Chen 2006). Additionally, students were asked to qualitatively describe what they think the source is of a scientific theory, with each of their responses being coded into either "discovery oriented" (for one point) or "invention oriented" (for one point) or "not available" (for zero point). This open-ended question item was particularly included to triangulate students' responses to the five quantitative survey items. The survey was administered in the beginning and at the end of the course. For the purpose of analysis, the quantitative data based on students' ratings were analyzed statistically while the qualitative responses were content analyzed using the same coding themes (i.e., discovery oriented and invention oriented) suggested by the original VOSE questionnaire with the unit of analysis being each individual student; then, *t* tests were conducted to assess whether students changed their scientific views.

Third, students were required to write a reflection essay regarding the most important things they had learned from their online activities in the course. A coding scheme was used to analyze the content of students' reflection (see Table 1), using each reflective statement as unit of analysis, with three main themes emerging from the coding process. To secure the accuracy of coding, two trained coders independently examined all students' reflective statements; then, categorized each of them into one of the three themes. The inter-coder reliability (Cohen's kappa) was computed to be 0.90. The average number of counts for reflective statements was further used for analysis. A one-way ANOVA test was conducted, followed by Scheffe's post hoc test, to examine whether there were any significant differences between the three main themes.

Results and Discussion

Community Knowledge Building Processes and Outcomes

Knowledge Building Processes

To answer the question of whether knowledge building enables students to pursue a top-level goal of community knowledge advancement in natural science history, we first analyzed the knowledge building activities in KF. In this particular class, the main online activities in KF included number of notes contributed, number of notes read, number of notes built-on to others' notes, and annotations. First, in terms of note contribution, there were in total 609 notes posted throughout the whole semester. The average number of notes contributed was 14.5 (SD = 6.9). Students used note contribution mainly to post various story elements about scientists and scientific theories. Second, in terms of reading activity, students read notes to be aware of related stories posted by others and to monitor the overall progress of the natural science history co-constructed in the database as the community's top-level goal. Students on average read 279.1 notes (SD = 164.1). Reading activities also allowed students to gain a more complete understanding of the collective knowledge represented in the community, and to know who might be writing about which scientist or theory at that time so they could jointly provide more information about the same scientist or theory. This also helped the community produce a more complete picture of the natural science history from a broader social and cultural context. As a result, each student on average read a mean number of 279.1 notes (i.e., 26.9 %) of all 609 notes in the community. Third, in terms of building-on and annotation activity, each student on average had six notes

Table 1 Reflection on the most important things learned from the course

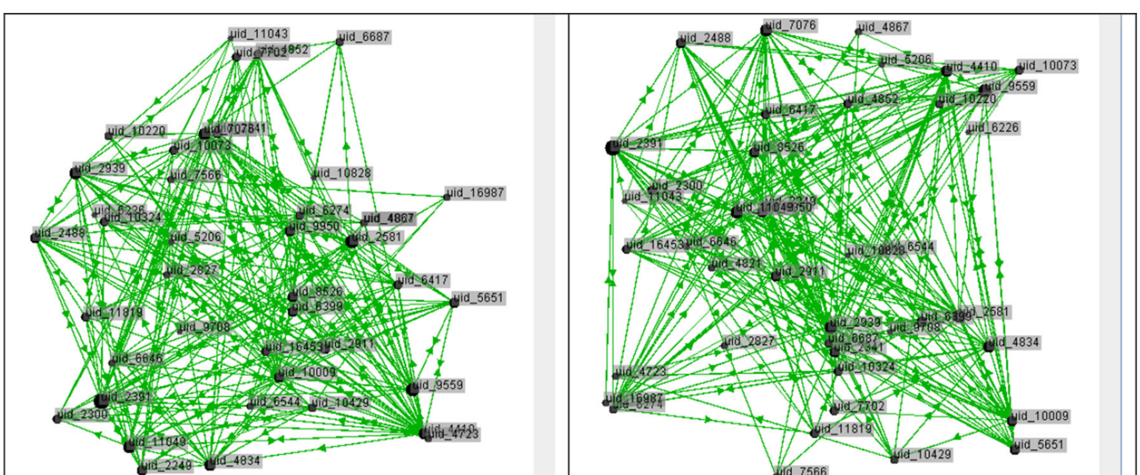
Theme	Example
Individual knowledge growth	—In this course, I gained some scientific knowledge by means of searching for, reading about, and selecting story information and materials. In particular, I learned about the scientist Robert Hooke's personal life and his [Hooke's] law, and some other knowledge related to the use of springs that can be usually found in watch and microscope. (S26)
	—[I learned] how to transform the information I searched into my own knowledge…after reading and re-reading many story materials, I gained many insights from writing my story. During writing, I was able to piece different events together. I also became more familiar with many concepts related to the scientific theories that I wrote in my story. (S25).
Knowledge exchange	—I felt a lot of pressure when taking this course because I am not very good at science as a subject and I am used to learning science only to pass exams…. But this course changed my view of natural sciences as it emphasizes group inquiry and it also encouraged us to express our own thoughts and to discuss and share these thoughts with other classmates
	(S07)—Another thing I learned from this course is the importance of idea exchange and discussion. I used to feel that it is embarrassing to show half-baked ideas. Now I think that all ideas are worth further reflecting and improving. Only when ideas are shared can they be more fully discussed to help deepen our understanding. (S16)
Collective knowledge improvement/advances	—Scientific theories do not appear suddenly out of nowhere. These theories were developed by means of studying other scientists' ideas, searching for new information…, interacting continually with other scientists, and improving the original ideas, in order to propose an even more coherent theory. This refining process is not only true in the field of science but also true in our learning experiences. The online activities made me realize the importance of collaborative "improvement". Only through sustained improvement can our life become even better. (S39)
	—The theories proposed by scientists may be wrong…I used to believe everything scientists said because they are experts and all their statements have been proven to be true. But after the collective work in this course, I realized that this may not always be the case. There are many things that remain unknown to us in the scientific discipline. An existing theory may be revised or falsified if it cannot help explain the newly found scientific evidence. (S23).

(i.e., 47.2 % of all notes; SD = 3.93) building on others' notes, and 5.3 (SD = 5.75) annotations being created to help peers reflect further on their story content. All these efforts were to help achieve the community's top-level goal of building a collective understanding of the natural science history. As an example, Fig. 2 shows how students read one another's notes in KF before the midterm and after the midterm with the network density (which is defined as the proportion of links/connections in a network relative to the total number possible; the higher the density is, the stronger the social dynamics of a community) increased from 10.1 to 16.6. Basically, the descriptive statistics showed that students' online collaborative activities were fairly consistent. As a student said reflectively in the end-of-course survey: "The online forum provides us a space to reflect our epistemic value. Such open learning opportunity is valuable to me…by constantly contrasting with others' stories/ideas and then reflecting on my own stories/ideas, I was able to reconstruct my own belief system [about theories] again." (S10).

In the following, we further analyze the story content recorded in the database and used several graphical representation to map out the stories that were being collectively constructed. First, an overall analysis revealed that there were in total 35 stories being collectively constructed in the community. Introduced inside these stories were in total 73 scientists and 45 scientific theories. As students were collectively constructing these stories, they tried to relate scientists to scientists (i.e., who collaborated with or influenced whom), theories to theories (i.e., which theory informed or was modified by which theory), and scientists to theories (i.e., which scientist is the main contributor for the development which theory). On average, there were two to seven scientists' experience ($M = 4.54$; SD = 3.04) and two to five scientific theories ($M = 3.17$; SD = 2.59) being elaborated in each story. For example, in one story describing Earth and other planets in the solar system, there were four scientists described as intellectually related, namely Nicolaus Copernicus, Tycho Brahe, Johannes Kepler, and Isaac Newton; and there were four scientific theories expounded to be conceptually related, namely heliocentrism, Kepler's laws of planetary motion, Newton's laws of motion, and the laws of gravitation. It is common to see the same scientists and scientific theories being repeatedly referred to in different stories. In the following section, we further analyzed the relationships elaborated in these stories so as to understand better the collective knowledge of natural science history represented in the community space.

Collective Knowledge Building Outcomes

Further analysis looked into the collective knowledge work in KF, i.e., the natural science history collaboratively represented by students as related stories. As the writing of these stories mainly centered on scientists and the theories these scientists developed, the analysis looked into three types of contextual relationships, including: (1) scientist-to-scientist, (2) theory-to-theory, and (3) scientist-to-theory. Figure 3 illustrates these relationships. In the figure, each circle represents a scientist, each square represents a scientific theory, and each link represents an intellectual or conceptual relationship. For example, in one story about the big bang theory, it was identified that Gamow further expanded Hubble's work by revealing the fact that the early Universe must have been much smaller, denser, and



First half of the semester (Network density=10.1) | Second half of the semester (network density=16.6)

Fig. 2 Students' interactions in Knowledge Forum from the first to the second half of the semester. *First half* of the semester (network density=10.1). *Second half* of the semester (network density=16.6) hotter than it now is (i.e., a scientist-to-scientist relation). Other story examples were Newton's laws of motion informing the development of the special theory of relativity (i.e., a theory-to-theory relation) and Darwin proposing the theory of evolution (i.e., a scientist-to-theory relation). As shown in Fig. 3, from a knowledge building

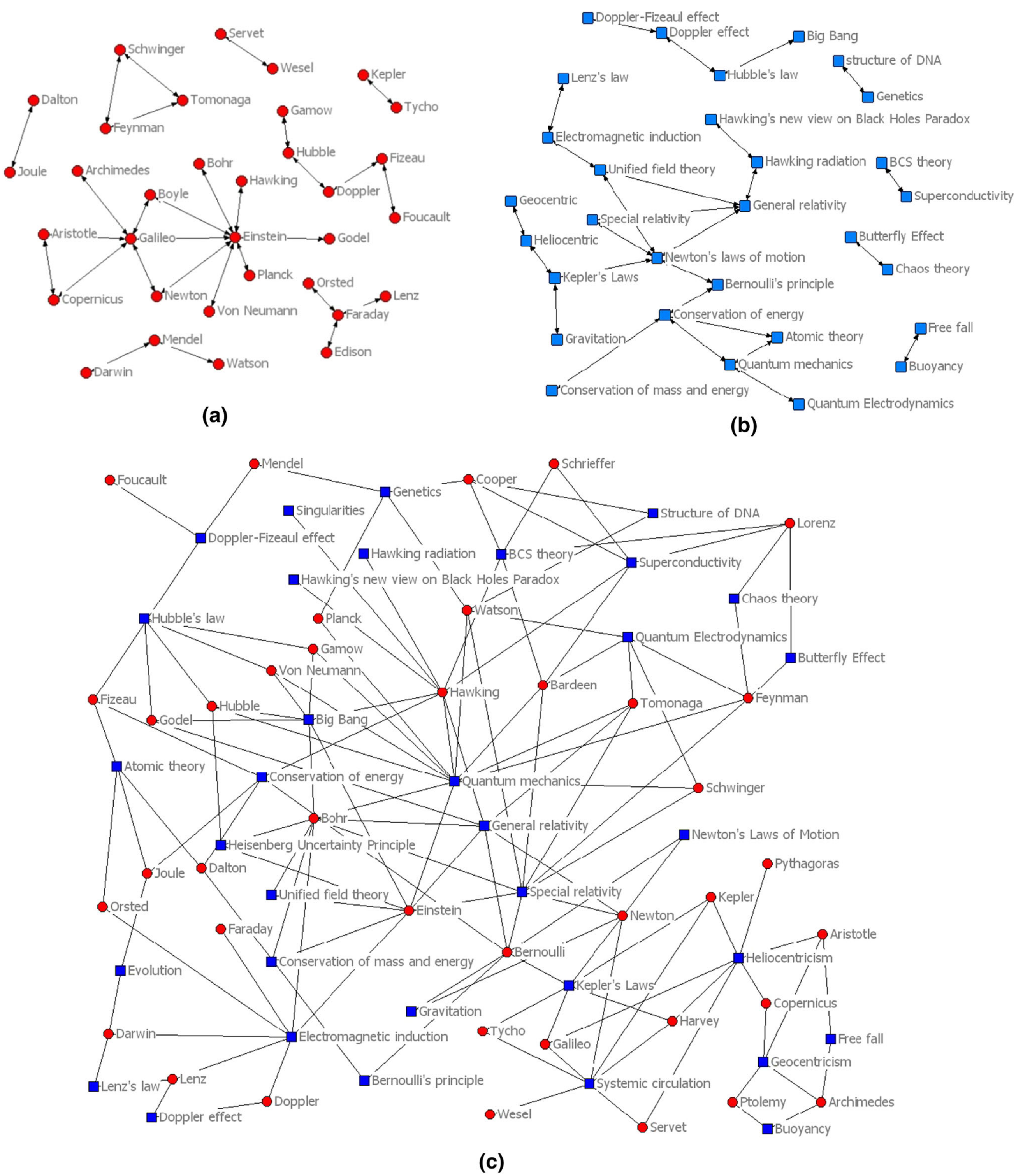


Fig. 3 Relationships between scientists (**a**), between theories (**b**), and between scientists and theories (**c**) elaborated in students' collective story writing about natural science history

perspective, these relationships suggest that students were working toward the top-level community goal of constructing a collective knowledge of natural science history. This would not be possible if students were not engaged in collaborative writing, and sharing stories together.

The analysis shows that the evolving and tentative nature of scientific theories was embedded in students' stories that illustrate sustained theory development and improvement among scientists beyond the limitations of time and space. The content of these collected stories also showed that scientific theories can only be regarded tentatively as the best explanations for certain natural phenomena at a given time. Also, these theories were usually not discovered by a given science genius, but developed by the collective efforts of a community of scientists over a long period of time. Apparently, the manifestation of these relationships would not be possible if the students were not able to collaborate and interact with one another's stories and share collective responsibility to construct their community knowledge of natural science history. It is, however, not clear whether such exercise would be able to help them develop more informed epistemic view. In the following section, we examine further whether students were able to see scientific theories, not so much as absolute truth, but as invented reality, after their collective knowledge work of re-constructing natural science history via story writing.

Students' Views on the Nature of Scientific Theories

To answer the question of whether engaging students in collective story writing helps them develop a more constructivist-oriented epistemic view of the nature of scientific theories, we examined the data collected from the pre-post survey. Table 2 summarizes the results. Overall, our pre-survey results based on the quantitative data showed that students were more inclined to consider theory as discovered ($M = 2.7$; $SD = 0.87$) than as invented ($M = 2.1$; $SD = 0.70$). In the post-survey, however, the results showed the opposite; students became more inclined to consider theory as invented ($M = 2.6$; $SD = 0.71$) than as discovered ($M = 2.0$; $SD = 0.86$). There were significant pre-post differences in students' view of theory as discovered ($t = 4.24$, $p < 0.001$) and their view of theory as invented ($t = -3.50$, $p < 0.01$).

Moreover, we looked into the results derived from students' open-ended responses. In the pre-survey, it was found that students were also more inclined to consider theory as discovered ($M = 0.21$; $SD = 0.42$; with M referring to the average number of students who embraced a given epistemic view) than as invented ($M = 0.24$; $SD = 0.43$), and like the qualitative findings, in the post-survey, the results

Table 2 Pre-post changes in terms of students' views on nature of scientific theories

Dimensions	Pre-test		Post-test		t value
	M	SD	M	SD	
Quantitative response					
Discovered	2.7	0.87	2.0	0.86	4.24***
Invented	2.1	0.70	2.6	0.71	−3.50**
Qualitative response					
Discovery oriented	0.21	0.42	0.24	0.43	−1.00
Invention oriented	0.21	0.42	0.93	0.26	−10.12***

** $p < 0.01$; *** $p < 0.001$

also showed that the students became more likely to consider theory as invented ($M = 0.21$; $SD = 0.42$) than as discovered ($M = 0.93$; $SD = 0.26$). Statistically, however, it was found that there was no significant pre-post difference in students' view of theory as discovered ($t = -1.0$, $p > 0.05$) in terms of their qualitative elaboration. For example, a student insisting a discovery-oriented view in the post-survey said the following: "Before taking this course, I thought that theory was discovered because it is something that already exists in the nature, not something that appears out of nowhere…and I prefer a discovery-oriented view for things that already exist" (S7). As another example, a student said: "To me, if something exists, it exists, regardless of whether I can see, feel, or understand it or not. Scientific theories are the same. They already exist somewhere in the universe waiting to be discovered" (S23).

In contrast, it was found that there was significant pre-post difference in students' view of theory as invented ($t = -10.12$, $p < 0.001$). For example, a student who later decided to embrace an invention-oriented view in the post-survey said: "I now think that scientific theories were invented. If they were discovered, they would represent some absolute truth and would never change. But from the fact [I learned in stories] that theories are sometimes proved wrong, revised after some period of time, or interpreted differently by different scientists, it is clear to me that theories were more like something that is invented [by scientists]" (S41). As another instance, a student also said something similar: "Different from what I thought in my pre-survey, I now tend to think that scientific theories were invented. This is because the making of a theory is not possible without the involvement of a scientist's personal value, beliefs, imagination, etc." (S27).

The fact that there was no significant pre-post difference in the discovery-oriented aspect from students' qualitative responses indicates that some students were not developing deep understanding for the view that sees theory as invented, even though their quantitative ratings showed that their view changed to be invention oriented. However, it may also come from the fact that the number of qualitative explanations provided by students was very low so the difference between the pre- and post-surveys was less likely to be significant. In contrast, in terms of invention-oriented view, the fact that most students were able to articulate why they embraced alternative epistemic position for a change suggests that these students were able to achieve deeper understanding about this particular invention-oriented stance that sees science more like some "invented reality" (Roth and Lucas 1997), rather than some "absolute truth" fortuitously discovered by some scientists.

Course Reflection

Using the coding scheme mentioned earlier as the analytical framework for statistics, the mean value and standard deviation of three main themes that appeared in students' self-reflection essays are as follows: individual knowledge growth ($M = 0.76$; $SD = 1.10$), knowledge exchange ($M = 1.64$; $SD = 2.41$), and collective knowledge improvement/advances ($M = 3.33$; $SD = 3.57$). While all three themes are considered equally important, it was especially interesting to find that collective knowledge improvement/advances was the most frequently referred theme by most students as an important learning outcome. A one-way ANOVA test further showed there was a significant difference among the three themes ($F = 10.88$, $p < 0.001$; $\eta^2 = 0.89$). Post hoc analysis further showed that the "collective knowledge improvement/advances" theme outperformed the other two themes ($p < 0.01$).

Moreover, the findings also indicate some interesting correlations between students' online learning activities and the above three key reflective themes. As shown in Table 3, it shows no statistically relationships between students' personal knowledge growth in this course and their collaborative online activities of reading ($\rho = 0.19$, $p > 0.05$) and writing ($\rho = 0.25$, $p > 0.05$). In contrast, the more the students highlighted the importance of knowledge exchange for learning in their reflection, the more likely they would be aware of, and would read, others' notes ($\rho = 0.42$, $p < 0.01$), but they might not contribute as much their knowledge to others' notes (e.g., adding more information in stories) ($\rho = 0.23$, $p > 0.05$). Furthermore, for students who highly emphasized collective knowledge improvement/advances in their reflection, not only were they more likely to read others' notes ($\rho = 0.35$, $p < 0.05$) but they were also more likely to contribute notes in the community ($\rho = 0.50$, $p < 0.01$).

Table 3 Correlation between students' reflective learning outcomes and online activities

Reflective learning outcomes	Note contribution	Note reading
Individual knowledge growth	0.25	0.19
Knowledge exchange	0.23	0.42**
Collective knowledge improvement/advances	0.50**	0.35*

* $p < 0.05$; ** $p < 0.01$

Discussion and Suggestions

In summary, the findings suggested that students' knowledge building experiences in the present course were quite productive and constructive in several ways. First, the results showed that students were able to work interactively and collaboratively to pursue a top-level goal of constructing community knowledge about natural science history. Second, students were able to develop progressively a constructivist-oriented epistemic view that regards scientific theories more as invented, improvable explanations of certain natural phenomena, rather than as discovered, absolute truth that exists indefinitely. Third, they seemed to enjoy the collaborative knowledge work required in the course.

Previous literature on education reform and innovation has highlighted the importance of transforming individualistic-oriented learning environments into more collaboration-oriented knowledge-creating communities (Bereiter 2002; Hargreaves 1999; Sawyer 2006, 2007; Scardamalia and Bereiter 2006; Stahl 2006). The various twenty-first century learning frameworks have also featured collaboration as a common theme (Voogt and Roblin 2012). The empirical findings of the present study confirm that with the guidance of a top-level goal to develop a collective understanding of natural science history in a web-based community, it is possible to engage college students in collaborative knowledge work. As we are becoming a highly collaborative and knowledge-based society (UNESCO 2005), more and more attention has been focusing on collaborative knowledge work and group learning (Stahl et al. 2006). As cogently argued by Ann Brown (1997), collective knowledge advances should be the goal of future education, and promoting learning and knowledge building at a community level should help students develop higher-level thinking and collaborative abilities. As also noted by Stahl (2006), group learning and cognition has become a dominant research theme in the field of learning sciences and of computer supported collaborative learning. These new themes also reflect the larger societal interest in creative knowledge work from the perspective of collective knowledge construction, rather than in identifiable growth of individual knowledge. It is therefore important for future research to continually study how to engage learners in collaborative knowledge work.

Moreover, previous studies related to the role of stories in learning also suggest that stories about scientists can serve as a powerful learning resource for enhancing students' interest in science learning (Eshach 2009; Haven 1997; McKinney and Michalovic 2004; Rowcliffe 2004; Solomon 2002; Stinner 1995). In addition, literature indicates that stories can be used as a form of contextual knowledge to facilitate memory and learning in many ways (Broudy 1977; Mandler 1984). For example, Mandler (1984) maintains that story context can serve as an organizing structure to help students create new learning experiences and knowledge, and this contextual knowledge gives students additional opportunities to create meaning and deepen their prior knowledge gained from formal learning. As also noted by Wells (1986), "constructing stories in the mind or storying, as it has been called, is one of the most fundamental means of making meaning; as such it is an activity that pervades all aspects of learning" (p 194). Hong and Lin-Siegler's study (2012) indicates that merely learning science from a textbook is likely to result in decontextualized learning; this is particularly true when the main goal of learning is to focus on scientific theories because these theories are often taught in lesson units that are conceptually independent of one another. As such, students often faced difficulties in relating different scientific theories learned in different science lessons. In contrast, providing students with relevant contextual information in the form of stories may help students in identifying the relationships between different scientific concepts and theories. Overall, the findings in the present study support that engaging college students in collaborative story writing about natural science history represented a useful instructional approach to help students better understand the relationships of scientists and how scientific theories are evolutionarily related to one another. Moreover, the findings also suggest that deeper understanding of the evolving relationships among different scientific theories seems to enable students to view theories as invented from a more constructivist-oriented epistemic perspective.

This study makes several suggestions for science instruction. First, as a type of contextual knowledge, stories about scientists can make these scientists more approachable. Science education can provide students with more opportunities to get to know more about real scientists, rather than just focusing on learning abstract scientific theories. Alternatively, the science curriculum can consider transforming traditionally person-neutral science learning by including in the theory textbooks some relevant scientists' real-life stories. Or perhaps students can also learn to build knowledge about the scientist's story as part of their scientific inquiry. Doing so may help students better understand how the scientific theories/knowledge they learn from textbooks actually developed over time. Further, an issue in science education has been students' negative stereotype of scientists, for example, scientists are antisocial nerds and like to work alone in their lab (Van Gorp and Rommes 2014). This study suggest that by learning more about scientists' intellectual lives, students can get to know them better and see how they collaborate with others to develop scientific theories and create knowledge. It is possible that such understanding can help lessen students' negative stereotype of scientists which often derives from the influence of mass media and popular culture. Moreover, another related issue is students' lack of interest in majoring in science (Osborne et al. 2003). To address this challenge, it may be worthwhile for science educators to also think about how to humanize the highly content-based curriculum design. As argued by Dewey (1913), an important type of learning interest is students' interest in people (e.g., scientists in this case). Allowing students to get to know more about scientists would increase students' social interests in these scientists (Hong and Lin-Siegler 2012).

This study represents a first step in understanding how knowledge building about natural science history can inform the development of students' scientific views. Admittedly, there are several limitations. The first is its generalizability. As a case study conducted among Asian students within a university context, it is not clear whether the results are generalizable to different sociocultural contexts. Second, while the results based on VOSE survey provided some evidence for significant increase in scores in the "theory-as-invented" perspective, the numerical increase is not as strong as expected since the mean scores were found to be between the range of "2" (i.e., neutral) and the range of "3" (i.e., agree). This may have to do with the instructional time as the present study only lasted for a semester. It would be helpful to replicate this study in a longer period of timeframe. Moreover, this study only investigated students' views of scientific theories. For future research, it may be fruitful also to look at students' views of scientific laws and see whether some misconceptions were developed during students' self-initiated and self-directed inquiry activities (e.g., students regarding laws as holding a higher status in science than theories). Moreover, this study employed a mixed method for analysis and used surveys for data collection. For future research, other more qualitatively intensive methods such as in-depth interview or ethnographic observations may be conducted in order to explore more deeply the process of how students actually change their scientific views during their online learning and collaboration activities.

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