INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, 2018
VOL. 40, NO. 6, 668–687
https://doi.org/10.1080/09500693.2018.1435923

Promoting elementary students' epistemology of science through computer-supported knowledge-building discourse and epistemic reflection

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ABSTRACT

This study examined the role of computer-supported knowledge-building discourse and epistemic reflection in promoting elementary-school students' scientific epistemology and science learning. The participants were 39 Grade 5 students who were collectively pursuing ideas and inquiry for knowledge advance using Knowledge Forum (KF) while studying a unit on electricity; they also reflected on the epistemic nature of their discourse. A comparison class of 22 students, taught by the same teacher, studied the same unit using the school's established scientific investigation method. We hypothesised that engaging students in idea-driven and theory-building discourse, as well as scaffolding them to reflect on the epistemic nature of their discourse, would help them understand their own scientific collaborative discourse as a theory-building process, and therefore understand scientific inquiry as an idea-driven and theory-building process. As hypothesised, we found that students engaged in knowledge-building discourse and reflection outperformed comparison students in scientific epistemology and science learning, and that students' understanding of collaborative discourse predicted their post-test scientific epistemology and science learning. To further understand the epistemic change process among knowledge-building students, we analysed their KF discourse to understand whether and how their epistemic practice had changed after epistemic reflection. The implications on ways of promoting epistemic change are discussed.

ARTICLE HISTORY
Received 4 August 2017
Accepted 30 January 2018

KEYWORDS
Scientific epistemology; theory-building; knowledge-building discourse; science learning

Introduction

Fostering sophisticated epistemology of science among students has been an important goal of science education. Despite decades of research and educational reform, it remains very hard to change students' understanding about the nature of science and scientific inquiry (Sandoval, 2014). Previous studies suggest that students have an alternative epistemology that is different from that of the experts; they do not understand the role

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of ideas and the theory-building nature of science, and think the purpose of science is merely to do activities (e.g. making concrete things, collecting data, or testing variables), rather than to make abstract theories to explain natural phenomena and to collectively improve these theories (Carey, Evans, Honda, Jay, & Unger, 1989; Chinn & Malhotra, 2002; Chuy et al., 2010; Sandoval, 2003). Holding such limited epistemic understanding about science, students may have little motivation to learn science; they may not understand how to produce and improve ideas based on evidence or construct a new idea based on existing ideas. Therefore, the current study aims to investigate how a learning environment could be designed to improve young students' epistemic understanding of the idea-driven and theory-building nature of science. We hypothesised that engaging students in computer-supported knowledge-building discourse and letting them reflect about this process could help develop this aspect of students' epistemic thinking about science.

Theoretical background

Epistemology of science

Epistemology of science, how one understands the nature of knowledge and knowing in science, has always been an important part of science education (Elby, Macrander, & Hammer, 2016; Lederman, Antink, & Bartos, 2014). There are different traditions to examine an individual's epistemic understanding about the nature of science. Some research followed and adopted the psychometric tradition (Hofer & Pintrich, 1997; Schommer, 1990), and examined students' understanding about the certainty, source, justification, and development of scientific knowledge (Conley, Pintrich, Vekiri, & Harrison, 2004; Elder, 2002); some focused on the multiple aspects of the nature of science that are consistent with contemporary science education reform (Lederman, 2007; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002), including its empirical, tentative, creative and imaginative, and inferential aspects; some others focused on the evidentiary justification for scientific knowing (Ryu & Sandoval, 2012; Sandoval & Millwood, 2005) and the social- and cultural-dependent nature of science (Tsai & Liu, 2005). These frameworks have captured some important aspects of the epistemology of science, however, less attention has been paid to students' understanding of the progressive and theory-building nature of science. By theory building, we mean the social construction process for the progressive development of theories (explanations), which involves the progression of discourse through negotiation, building-on, and synthesis of ideas and theories (Bereiter, 1994, 2016; Carey et al., 1989). In this study, we followed a tradition initiated by Carey et al. (1989) and Smith, Maclin, Houghton, and Hennessey (2000), and focused on students' epistemic understanding of the idea-driven and theory-building nature of science.

Science is about constructing ever-deeper explanations of the natural world (Carey et al., 1989; Chuy et al., 2010). However, in school science, this idea-driven aspect is usually overlooked, and scientific inquiry is often portrayed as a set of concrete activities or as a means of acquiring sets of skills, such as collecting data and testing variables (Chinn & Malhotra, 2002). In 1989, Carey et al. developed a clinical interview to examine seventh graders' understanding of the idea-driven nature of science. Three general patterns were identified, ranging from viewing science as discovering facts and making inventions, to viewing it as constructing explanations for natural phenomena. Specifically, at Level 1, students make no clear distinction between ideas and activities (e.g. experiments); scientists just do things to see if they work, and the goal is the activity itself. At Level 2, students make a clear distinction between ideas and experiments, and they begin to realise that the purpose of the activity is to test or explore an idea. At Level 3, besides making a clear distinction between ideas and experiments, students also understand the evolving and cumulative nature of science, that is, ideas may change and develop based on results. The goal of science is conceived of as the construction of ever-deeper explanations of the natural world.

Building on Carey et al.'s (1989) work, Smith et al. (2000) did a more elaborate study of two classes of sixth graders' epistemologies of science using the interview protocol adapted from Carey et al. Students were regarded as having more sophisticated epistemology if they were aware of the 'central role of ideas in the knowledge acquisition process and of how ideas are developed and revised through a process of conjecture, argument, and test' (p. 350), and *vice versa*. Continuing this line of research, Chuy et al. (2010) examined fourth graders' epistemology of science using an augmented version of Carey and Smith's nature of science interview with an explicit focus on theoretical progress. Four traits were identified: nature of theoretical progress, theory-fact understanding, role of ideas in scientific inquiry, and invention.

The current study follows this tradition and examines how young students understand science as an idea-driven process, with emphasis on the progressive and theory-building nature of science. Theory building is an important social process for knowledge creation and theoretical progress in science (Bereiter, 2016). We argue that it is important to help students understand the idea-driven and theory-building nature of science, not only because it is an important part of the nature of science, but also, theory building could provide a lens for students to understand the reliable social process for knowledge construction and creation, which is especially important for working in a knowledge-based society.

Knowledge-building discourse and epistemic reflection

The major assumption guiding the instructional design for epistemic development is that if we are to help students understand certain aspects of the nature of science we need to engage them in this aspect of the process and let them reflect upon it (Carey et al., 1989). In this study, to help students understand the idea-driven and theory-building nature of science, we employed knowledge-building pedagogy to engage students in theory-building discourse and encouraged them to reflect on this process.

Knowledge building is a computer-supported collaborative learning model, in which students take *collective cognitive responsibility* for community knowledge advancement (Scardamalia & Bereiter, 2014). Knowledge building values the creation of new ideas and theories that emerge from the interaction of previous ideas (Paavola & Hakkarainen, 2005). Underlying knowledge building is the epistemology that knowledge is socially constructed and that theory-building discourse is a reliable process for achieving knowledge creation. Such epistemic idea is supported by a computer-supported tool, Knowledge Forum (KF), by which a community shares and collectively develops its ideas for the development of progressive inquiry and discourse. KF has different technological and epistemic features that support progressive theory building (Scardamalia, 2004), which include a communal space for community sharing and collective idea development (this working space is called 'View', in which students contribute and build on each

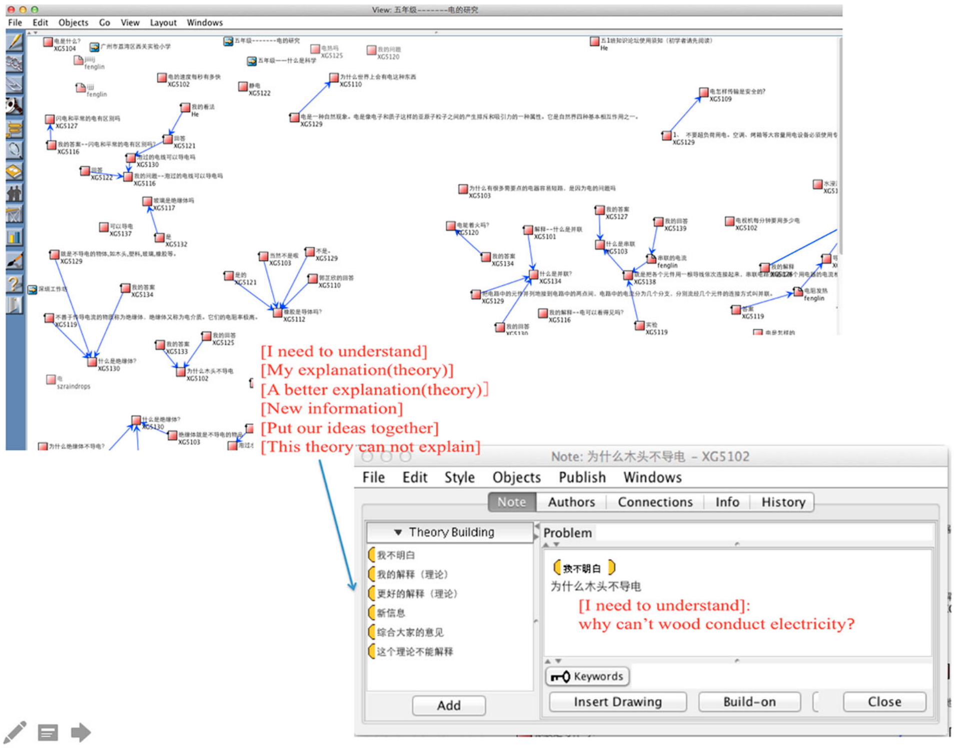

Figure 1. An example of a view and note.

Note: The large window is a view. Squares are different notes posted by students; the lines and arrows represent links to other notes. The small window is a note with theory-building scaffolds on the left and note content in the middle.

other's notes. See Figure 1), scaffolds that support idea-driven and theory-building discourse (e.g. 'I need to understand', 'My theory', and 'A better theory'), tools for establishing connections (links) between ideas, and tools for synthesis and progressively deepening the conceptual discourse (the rise-above view and note).

Besides supporting students' engagement in theory-building discourse, we also propose to embed epistemic reflection in the learning environment to help them understand the theory-building nature of science. By epistemic reflection, we mean the process of reflecting on the ways of producing knowledge. One line of research suggests that to help students understand the nature of science it is not adequate just to engage them in inquiry, rather opportunities to make epistemic reflection (reflect on one's inquiry) need to be provided (Akerson, Abd-El-Khalick, & Lederman, 2000; Brownlee, Schraw, Walker, & Ryan, 2016; Khishfe & Abd-El-Khalick, 2002; Sandoval & Morrison, 2003). For example, Sandoval and Morrison (2003) examined the influence of a four-week technology-supported inquiry-based science class on students' epistemic understanding of the role of ideas in science. They assessed eight students' epistemic understanding with Carey et al.'s (1989) interview protocol before and after the intervention, and did not find epistemic change among students. They suggested that merely engaging students in inquiry might not be enough, and that explicit epistemic discourse was needed to develop students' epistemic understanding. Some researchers (Khishfe & Abd-El-Khalick, 2002) tested this assumption and compared the effects of an explicit reflective inquiry approach and implicit inquiry approach on sixth graders' understandings of the nature of science. In the explicit reflective inquiry environment, they let students reflect and discuss the targeted nature of science aspects immediately after their inquiry. They found that more participants from the explicit reflective inquiry instruction improved their nature of science views after intervention.

In this study, we specifically let students reflect on the epistemic nature of their discourse. Discourse is central for collaborative knowledge work (Scardamalia & Bereiter, 2006); reflecting on one's discourse to understand the epistemic criteria of a good discussion is a way of reflecting on the reliable social process for producing knowledge, and is therefore a type of epistemic reflection. We hypothesised that engaging students in idea-driven and theory-building discourse, as well as scaffolding them to reflect on the epistemic nature of their discourse, could help students understand their own scientific collaborative discourse as a theory-building process, and therefore understand scientific inquiry as an idea-driven and theory-building process.

To iterate, the purpose of this study is to examine the role of computer-supported knowledge-building discourse and reflection in developing students' epistemic understanding about the idea-driven and theory-building nature of science. To examine the intervention effects, we included a regular class as comparison group. Three research questions are addressed:

(1) Did knowledge-building students improve more in their epistemology of science and science understanding than the regular-inquiry students?
(2) Was there a significant difference in students' understanding of collaborative discourse between knowledge-building and regular-class students after instruction? Whether and in what ways did students' understanding of discourse predict their epistemology of science and science understanding?
(3) Did students change towards more sophisticated practice on KF after epistemic reflection, if they did, in what ways had they changed?

Method

Participants and context

One class of 39 fifth graders (18 boys, 21 girls) at an experimental school in Guangzhou, China, participated in this study, using a knowledge-building approach. Another fifth-grade class ($n = 22$, 14 boys, 8 girls), the comparison class, was also recruited and taught by the same teacher using the school's established inquiry approach. All students were 10–12 years old. Both classes had similar pre-intervention academic achievement levels (based on school information), and both studied the same 'electricity' unit for three weeks using similar curriculum materials. The teacher had five years of teaching experience and was familiar with science education pedagogy.

Designing the knowledge-building environment (Intervention)

The knowledge-building class employed pedagogy focusing on theory-building discourse and reflection: students posed questions and constructed explanations on KF for collective inquiry of science ideas. They were also scaffolded to *reflect on their online discourse* to construct epistemic criteria for good discussion. The whole intervention lasted about three weeks.

Initiating inquiry on KF and making ideas public

Initially, the teacher introduced the process of working together to pursue inquiry using KF, and started an initial 'view' for the students to try out. Next, a view about electricity (see Figure 1) was created to allow students to articulate their understanding about electricity. Students posted their questions, constructed explanations, and publicised their ideas as improvable objects. Scaffolds (e.g. I *need to understand, my theory, new information, a better theory*) were provided in the left side of the note as prompt to help them engage in theory-building discourse.

Reflection on KF discourse

After 3 classes, the teacher found that students' KF discourse mostly focused on short question-and-answer exchanges, and that few students were attempting to extend the inquiry and improve ideas. Therefore, a session about what is a good discussion was designed to help students reflect on their discourse. Students were provided with clusters of notes from their KF discussions and from an existing, developed KF database. Then students used these notes as examples to identify and explain the differences between the two kinds of discourse. Specifically, students were first asked to work in groups and document their joint ideas about what makes a good discussion on a poster; then they put the group poster on the blackboard. Other students read the posters and wrote comments on sticky notes to help improve that group's ideas. This was designed to facilitate students' co-construction of epistemic criteria for good discussion. Classroom dialogue took place as students explored characteristics of good discussion and inquiry. The teacher also brought out knowledge-building principles (e.g. improvable ideas, epistemic agency, and community knowledge) to help them reflect on the criteria of good discussion.

Rise above with 'deepening view' and experimentation

As the KF writing continued, different questions, problems, and diverse views emerged. A 'deepening view' was created to allow students to rise above (bringing ideas to a higher conceptual level) and to focus on promising lines of inquiry (see Figure 2). Many students on KF were interested in whether wet wood could conduct electricity; they proposed various theories, and worked in groups to design experiments to test their ideas. Students displayed their experiment designs and commented on the designs needing improvement. After their experiments, students reflected on the new ideas generated and further deepened their discourse on KF. They also continued to work on KF after class and to reflect on their inquiry process.

Instruction in comparison class

The comparison class studied the same curriculum unit on electricity using a regular inquiry-based approach that focused on scientific investigation. The teacher explained key concepts in the curriculum through questioning, and then students discussed in groups. Curriculum-based experiments were demonstrated to, and conducted by,

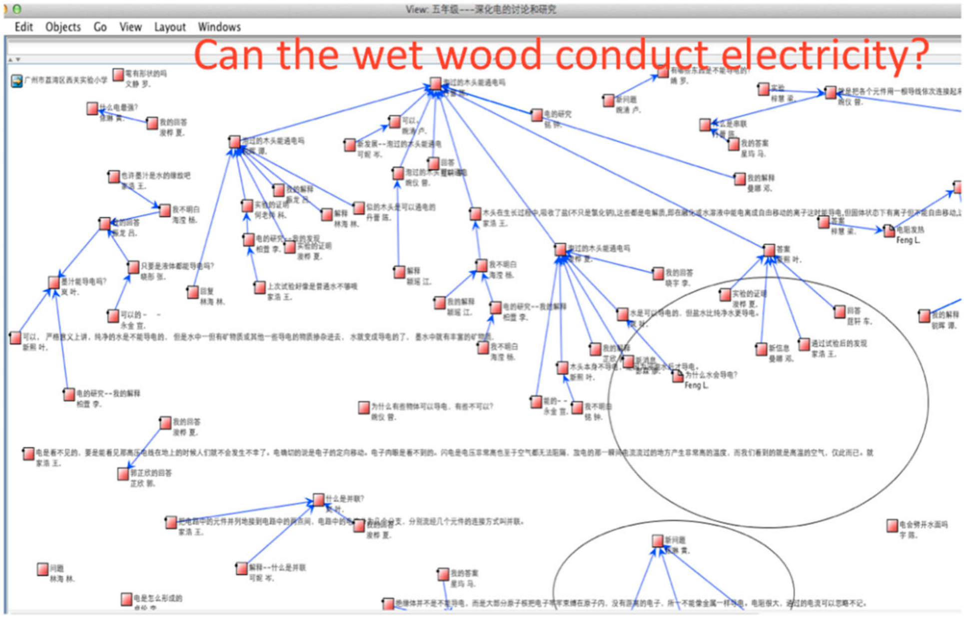

Figure 2. A deepening view: students inquiry on ‘can wet wood conduct electricity?’

students in small groups. The teacher focused on different scientific processes and skills, such as identifying variables, testing hypotheses, and setting up experiments. While both classes generally employed an inquiry approach, the comparison students were not taught using a theory-building approach and did not use KF.

Measures and analysis

Written tests on epistemology of science

Students’ understanding of epistemology of science was measured using a seven-question, open-ended questionnaire adapted from previous research (Carey et al., 1989; Chuy et al., 2010; Lederman & Ko, 2004; Smith et al., 2000). The questionnaire included: (1) *What is science?* (2) *What do scientists do?* (3) *How do scientists do their work?* (4) *Why do you think scientists do experiments?* (5) *How do you think a new theory is developed?* (6) *What are the relationships between theory and fact?* and (7) *Different scientists may have different, even contradictory, ideas; do you think that is good for science?* The questionnaire was administered pre-test and post-test, and required about 30 minutes.

Qualitative analyses were guided by interactive top-down and bottom-up processes (Chi, 1997), and four themes emerged: (1) role of idea, (2) theory revision and development, (3) theory-fact understanding, and (4) social process for scientific progress. Students’ written responses were coded on a four-point scale ranging from off-task responses to those that varied in different levels (see Table 1). Take the ‘theory revision and development’ for example (‘How do you think new theory is developed?’). A Level 1 response regarded scientists’ thoughts, efforts, or objects as the mere sources of knowledge (e.g. ‘Scientists think it out’; ‘It is developed from something around us’). Students at

Table 1. Different dimensions and levels of students' epistemology of science from a theory-building perspective.

	Level 1	Level 2	Level 3
Role of idea	Do not mention role of idea in science, and see science as concrete activities (e.g. merely doing experiments, mixing things together, and inventing things)	Mention that science involves such abstract concepts as understanding, theory, question, and explanation	Not only mention abstract concepts, but also make connection between ideas and experimentation, and allude to social processes
Theory building and revision	Think that new theory solely comes from scientists' thoughts, efforts, or other behavioural sources	Understand the importance of questions and experimentation to theory development	Have some understanding about the role of discourse and theory revision in theory development
Theory-fact understanding	Do not differentiate theory and fact (e.g. theory = fact, or fact comes from theory)	Have some understanding of the nature of theory and fact	Have some understanding about the explanatory nature of theory, and the connection between theory and fact
Social process of scientific progress	Do not appreciate the role of different ideas in scientific progress, or have some superficial understanding of the role of different ideas in science (behavioural reason)	Appreciate the role of communication and interaction in science	Goes beyond appreciating the importance of idea interaction to understanding the role of different ideas and synthesis of ideas in theory improvement in science

Level 2 realised the importance of questions and experiments in theory development (e.g. 'I think it is developed from the questions'). At Level 3, students started to understand the role of discourse and revision in theory development (e.g. 'It comes from the discussion of the previous theories, constant experiment, discussion, and research'; 'It comes from the new question arising from the previous theories … ').

The first author coded all the data. A second rater independently coded 30% of the data. Disagreement was resolved through discussion. Cohen's Kappas varied from .74 to .87 (role of idea, $K = .75$; theory-fact understanding, $K = .74$; theory building, $K = .82$; and social aspect, $K = .87$), indicating good agreement.

Written tests on science understanding

Students' science understanding was measured using a knowledge test on electricity, and was administrated before and after intervention. The test's first part contained 13 forced-choice questions testing students' understanding of the conductivity of different materials (e.g. metal, juice, graphite); the second part consisted of open-ended questions eliciting students' understanding and explanation (e.g. why are some materials conductive and others not). The test lasted 20 minutes. The first part was scored based on correct answers; the second was coded using a three-point scale rating students' explanatory ideas from pre-scientific (one point) to basically scientific (three points). The results were combined into a percentage score as a general measure of science understanding. The first author coded all the data in Part 2. A second rater independently coded 30% of the items, and disagreement was resolved through discussion; Cohen's Kappa was $K = .88$, indicating high-level agreement.

Students' understanding of collaborative discourse

Students' understanding of collaborative discourse was measured with an open-ended question ('what is good discussion') after the intervention. A four-point coding scheme was developed using an interactive bottom-up/top-down approach. Students' understanding of collaborative discourse varied from off-task responses to viewing discourse as a constructive, progressive, and deepening process. Specifically, at Level 1, students focused on the behavioural aspects of discussion, such as responding actively, in detail, longer, or involving more people (e.g. 'try our best to discuss'; 'people discuss carefully'). Level 2 responses mentioned the role of different ideas, questions, or using new information in a discussion (e.g. 'There are different ideas and questioning … in a good discussion'). At Level 3, students regarded a good discussion as a deepening inquiry process, involving questioning, emerging ideas, building-on, and idea improvement ('I think a good discussion should … ask questions, answer the questions, propose different suggestions to the answers; new understanding … build on the previous answers and make an even better answer. … '). The first author coded all the data. A second rater independently coded 30% of the data; Cohen's Kappa was $K = .89$, indicating very good agreement.

KF discourse

Students' KF discourse was analysed for understanding the change of their epistemic practice after reflection. Students' discourse was first parsed into clusters of notes adapted from the notion of inquiry threads (Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007). These note sequences addressing a conceptual problem were coded into four levels (fragmented discussion, knowledge sharing, knowledge construction, and knowledge building) that aligned with levels of knowledge advances (van Aalst, 2009). Specifically, for fragmented discussion, there is no knowledge advancement, and ideas are isolated; for knowledge sharing, there is low knowledge advancement, and ideas and information are shared; for knowledge construction, there is medium knowledge advancement, and the discourse involves idea interaction and construction; for knowledge building, there is high knowledge advancement, and the discourse involves progressive idea development, which moves the current knowledge into a higher level of understanding and abstraction. A second rater coded 35% of the threads with 80% agreement.

After coding the inquiry threads, we sequenced students' notes according to the time they were created, and divided them into two phases (*before and after students' reflection of discourse*). Then we counted the number of notes pertaining to each discourse patterns, and examined if there was change in students' discourse after reflection.

Interview and written artefacts

Interview and written artefacts were collected and analysed in order to examine how students' understanding of collaborative discourse might influence their scientific epistemology. Eight students (recommended by the teacher as representing high, medium, and low achievers) from the experimental class were interviewed about their changed understanding of the nature of science and knowledge-building experience. Additionally, all experimental students were asked to write responses to answer two questions regarding how knowledge building was related to how they think about science after the intervention. The researcher read the interview transcriptions and written responses and coded the responses thematically.

Table 2. Mean scores (SD) of scientific epistemology at pre- and post-tests for knowledge-building and comparison classes.

	Knowledge-building class ($n = 39$)		Comparison class ($n = 22$)	
	Pre-test	Post-test	Pre-test	Post-test
Scientific epistemology				
Role of Idea	1.24(0.43)	1.39(0.51)	0.98(0.31)	1.14(.34)
Theory-Fact	1.26(0.72)	1.62(0.75)	1.45(0.60)	1.37(.49)
Theory Building	1.59(0.64)	1.92(0.87)	1.45(0.51)	1.36(.49)
Social aspect	1.49(0.76)	1.79(0.73)	1.64(0.66)	1.55(.51)
Overall	5.57 (1.75)	6.72 (2.13)	5.52(1.27)	5.41(.94)

Results

Question 1: change in epistemology of science and science learning scores across classes after instruction

Changes in scientific epistemology scores across classes

Table 2 shows the pre-and post-test scores for the four dimensions of scientific epistemology for the knowledge-building and comparison classes. A 2 × 2 (Environment × Time) MANOVA repeated-measures showed the main effects for Environment ($F(4, 56) = 3.30$, $p = .017$, Partial eta$^2 = .191$) and Time ($F(4, 56) = 2.53$, $p = .05$, Partial eta$^2 = .153$), and a significant Time × Environment interaction ($F(4, 56) = 2.63$, $p = .044$, Partial eta$^2 = .158$).

Follow-up univariate tests showed a significant main effect of Time for role of idea ($F\ (1, 59) = 7.46$, $p = .008$, Partial eta$^2 = .112$) and Environment effects on role of idea ($F\ (1, 59) = 6.99$, $p = .011$, Partial eta$^2 = .106$) and theory development ($F\ (1, 59) = 6.39$, $p = .013$, Partial eta$^2 = .100$). Significant Time and Environment interaction were obtained for theory-fact understanding ($F\ (1, 59) = 4.33$, $p = .042$, Partial eta$^2 = .068$) and social process ($F\ (1, 59) = 4.104$, $p = .047$, Partial eta$^2 = .065$). The findings indicate that students in the knowledge-building class changed more from pre- to post-test on theory-fact understanding and social process than students in the regular-inquiry class.

A repeated-measures ANOVA for overall scientific epistemology score showed a significant main effect of Time ($F\ (1, 59) = 6.207$, $p = .016$, Partial eta$^2 = .095$), and a significant Time × Environment effect ($F\ (1, 59) = 9.216$, $p = .004$, Partial eta$^2 = .135$), indicating the knowledge-building students' overall epistemology scores changed more than the regular classroom students' scores.

Changes in science understanding scores across classes

The pre- and post-test science understanding scores were .59 (.08) and .70 (.13) for the knowledge-building class, and .55(.07) and .59(.54) for the regular class. A 2 × 2 (Environment × Time) repeated-measures ANOVA on science understanding scores showed a significant main effect of Time ($F\ (1, 57) = 21.05$, $p < .001$, Partial eta$^2 = .27$). A significant Time × Environment effect was obtained ($F\ (1, 57) = 4.08$, $p = .048$, Partial eta$^2 = .07$), indicating that students in the knowledge-building class improved more on science understanding scores compared to students in the regular class.

Table 3. Correlation among science understanding, epistemic understanding, and understanding of discourse.

	Pre-test science	Post-test science	Pre-test epistemic	Post-test epistemic
Pre-test science				
Post-test science	.265*			
Pre-test epistemic	.227	.464**		
Post-test epistemic	.263*	.666**	.551**	
Understanding of discourse	.244	.465**	.326*	.660**

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

Question 2: class differences in understanding of collaborative discourse, and its prediction on epistemic and conceptual understanding

Class difference in understanding of collaborative discourse

An independent sample t test was conducted to examine the differences in understanding collaborative discourse between the knowledge-building and regular-class after intervention. It showed that knowledge-building students ($M = 1.46$, SD = .98) had significantly higher scores than the comparison students ($M = 1.05$, SD = .21), $t = 2.39$, $p = .021$, indicating that knowledge-building students' understanding of collaborative discourse was more aligned with theory building than the comparison students.

Correlation analysis

Correlation analysis was conducted to examine the relationship among pre- and post-test scientific epistemology, pre- and post-test science scores, and understanding of discourse scores. It showed that students' understanding of discourse was significantly correlated with their post-test science knowledge scores ($r = 456$, $p < .001$), pre-test epistemic understanding scores ($r = .326$, $p = .013$), and post-test epistemic understanding scores ($r = .660$, $p < .001$), and that students' post-test epistemic understanding was significantly correlated with their pre-test science knowledge scores ($r = .263$, $p = .04$), post-test science knowledge scores ($r = .666$, $p < .001$), and pre-test epistemic understanding scores ($r = .551$, $p < .001$) (see Table 3).

Regression analyses

Based on the correlation analysis results, hierarchical regression analysis on post-test scientific epistemology was conducted (see Table 4). When pre-test epistemic understanding was entered, it significantly explained 27.2% of the variance, and adding understanding of collaborative discourse explained an additional 26.8% of the variance. This indicates that over and above prior epistemic understanding, understanding of collaborative discourse predicted students' post-test epistemic understanding.

Table 4. Hierarchical regression on post-test epistemic understanding.

	R	R^2	r^2 change	F change
Pre-test epistemic	.521	.272	.272	20.543***
Understanding of discourse	.735	.540	.268	31.492***

***$p < .001$.

Table 5. Hierarchical regression on post-test science understanding.

	R	R^2	R^2 change	F change
Pre-test science	.278	.077	.077	4.603*
Understanding of discourse	.495	.245	.168	12.016**
Post-test epistemic	.693	.480	.235	23.922***

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

Hierarchical regression analysis was also conducted to examine post-test science understanding (see Table 5). It showed that after controlling pre-test science knowledge scores, understanding of collaborative discourse explained additional 23.5% of the variance; when post-test epistemic understanding was added, a further 23.5% of the variance was explained. This suggests that over and above prior science understanding, understanding of collaborative discourse and post-test epistemic understanding predicted post-science knowledge.

We also conducted qualitative analysis with students' interview and written responses to examine in what ways students' understanding of discourse was related to their scientific epistemology. We found that students related the progressive nature of their KF discourse to the scientific epistemology. For example, the following excerpt shows how students related their understanding of the progressive nature of science to their understanding of the progressive nature of their own KF discourse:

I: (Interviewer): What are the new understandings you have about the nature of science?
S: I thought science is doing observation; but now I think it is observation and doing experiments.
I: What else do you think?
S: It is not even just about experiments, it is about *thinking about new theories*
I: Can you explain that?
S: Um … when you have new questions, you will … try to use some theory to think about this question
I: Tell me more about what you think.
S: Science is like a cycle, after you have solved a problem, you will find other questions, and after you solved that, there may be other questions …
I: Can you tell me what this has to do with your class recently?
S: Our teacher showed us the Forum and we posed our questions there. Later we had another view ('Wet Wood') for us to inquire … and discuss together; then we had more … and um … more questions posed; and then … [from] what we posed, we also wrote new questions for our classmates to respond to.
I: What else?
S: Science is not just carrying out experiments. For example, we think about whether wet wood conducts electricity; the questions on the forum make me think a lot more … .I now think that doing experiments is not just to get the findings … . It is about inquiry … .
S: Also lots of classmates raise questions … and help each other to solve problems …

This excerpt first shows the student's evolving ideas about science – from seeing science as observation and experimentation to seeing it as idea-driven process. Then she attributed her changed epistemic understanding to their KF discussion, and related the progressive process and cyclical nature of science with the progressive discourse on KF.

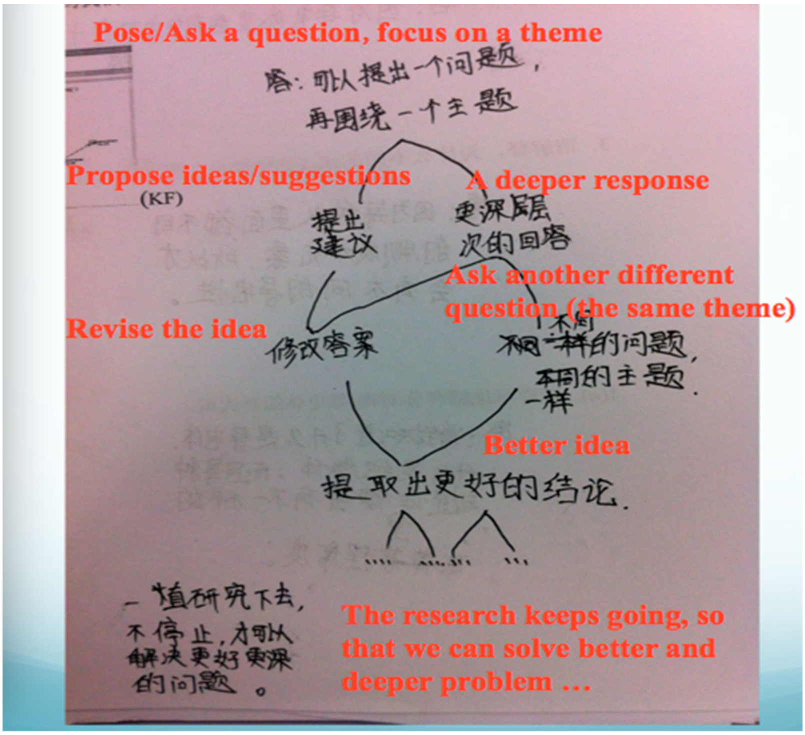

Figure 3. A diagram based on a student's written response to the question of how KF help them become little scientists.

Note: the diagram was drawn by the student with translation from the first author.

The influence of students' understanding of KF discourse on their scientific epistemology was also reflected in students' written responses. For example, when asked how their knowledge-building experience may have helped them to become little scientists, one student spontaneously drew a diagram in the written question (see Figure 3) to illustrate how he thought science and KF discourse were related. The diagram started with the student noting that the process begins with classmates/scientists posing questions focusing on a theme, followed by others proposing ideas for deeper responses and explanation, revising ideas, and asking different questions to bring about even better ideas and conclusions. Finally, the student explicitly wrote that research does not stop and will continue so as to solve better and deeper questions, thereby implying that both KF discourse and the scientific process were cyclical and progressive.

Taken together, these excerpts illustrate how students' understanding of the epistemic feature of their KF discourse might have helped them to develop more sophisticated epistemic understanding of the theory-building nature of science.

Questions 3: evolving into knowledge-building discourse

To further understand how knowledge-building students might have improved their understanding of collaborative discourse and scientific epistemology, we examined students' KF discourse. We hypothesised that students improved their epistemic practice

Table 6. Students' inquiry threads and discourse patterns on KF.

Inquiry thread #	Conceptual problems	# of notes	Patterns of discourse
#0	Fragmented ideas	40	Fragmented discussion
#1	Can we see electricity?	5	Knowledge construction
#2	Can wet wire conduct electricity?	4	Knowledge sharing
#3	Why can't isolator conduct electricity?	8	Knowledge construction
#4	What is conductor?	5	Knowledge construction
#5	What is isolator?	8	Knowledge construction
#6	What is resistance?	11	Knowledge construction
#7	What is the nature of electricity?	24	Knowledge construction
#8	Is electricity hot?	11	Knowledge construction
#9	Is rubber isolator?	7	Knowledge sharing
#10	Can wet wood conduct electricity?	43	Knowledge building
#11	Why can conductor conduct electricity?	4	knowledge construction
#12	How many volts of electricity can kill people?	17	Knowledge sharing
#13	Can ink conduct electricity?	11	Knowledge construction

on KF after their epistemic reflection, which brought about more sophisticated understanding of discourse.

To this end, we first characterised students' discussion on KF. We parsed the whole discussion into thirteen threads (clusters of notes) and coded them into four levels of discourse aligning with collective knowledge advancement, as mentioned in the method section. Table 6 shows the different kinds of conceptual problems students initiated and developed, and the levels of discourse.

We then examined whether there was change in students' discourse over time. We sequenced students' notes according to the time they were created, and then divided the notes into two phases: the earlier and later phase (*the cutting time is before and after students' reflection of discourse*). We calculated the percentage of notes related to four types of discourse patterns. It showed at the earlier phase ($n = 122$), 17.2% of the notes belong to fragmented discussion, 70.5% belong to knowledge sharing discourse, 7.4% belong to knowledge construction, and 4.9% belong to knowledge building. At the later phase ($n = 79$), 15.2% of the notes belong to fragmented discussion, 21.5% belong to knowledge sharing, 16.5% belong to knowledge construction, and 46.8% belong to knowledge building. We performed chi-squared tests of homogeneity of proportions for comparing differences between the two phases. It suggested that there was significantly more proportion of knowledge sharing notes in early phase ($z = 7.91$, $p < .001$), and that there was significantly more proportion of knowledge construction ($z = 1.90$, $p < .05$) and knowledge-building notes ($z = 7.05$, $p < .001$) in the later phase.

These results show that students made significant improvement in their engagement with KF discourse, and that their discourse was more aligned with knowledge building *after their reflection of discourse*. Such evolvement into knowledge-building discourse reflected a change of understanding of collaborative discourses among students. It indicated that students' epistemic reflection of discourse might have brought about their views of discourse as progressive and theory building.

Qualitative analysis of students' KF notes further suggests in what ways students' discourse has evolved. In the early stages, students posted numerous factual or definitional questions in knowledge-sharing discourses. Some students responded by offering intuitive opinions; for example, the question, 'can we see electricity?' drew the response, 'we cannot see it', ending the discussion. Other students responded with information copied from the

Table 7. A portion of a thread on KF.

Student#	Note content	Comments/remarks
XG5103	Can wet wood conduct electricity?	General question
XG5135	It can not	No explanation
XG5137	It can, because water can conduct electricity	Explanation
XG5109	[My explanation/theory] … dry wood originally does not conduct electricity, however, after it is wet by water, some of the impurity of the wood dissolves into the water, the water is no longer pure any more, and can therefore become conductive. It is the water that conducts electricity, not the wood	Deepening Explanation incorporating new information
XG5129	Evidence from the experiment: after the experiment, we found that the wet wood can conduct electricity	Deepening idea with evidence
XG5116	[new information] I found that the salt water made the bulb even brighter	Deepening idea with evidence
XG5129	[a better theory] maybe it is because we did not have enough water in the experiment	Explanation
XG5134	[My theory] water can conduct electricity, but salt water is more conductive	Deepening idea based on evidence
XG5133	Why is salt water more conductive than pure water?	Deep/Sustained question
XG5116	It is because impure water is more conductive.	Explanation
XG5133	Why is impure water more conductive?	Deep/Sustained question
XG5114	[my explanation/theory]salt water is NaCl, it is ionic, and has strong conductivity … normally the reason why water and salt water can conduct electricity is because water has some ions.	Deep Explanation incorporating new information
XG5137	[I don't understand] is it that any kind of water can conduct electricity?	Deep/Sustained question
XG5110	Not all kinds of water can conduct electricity	Deepening idea/explanation with a principle

textbook or Internet; when one student asked, 'what is a conductor', another replied, 'a conductor is a substance that conducts electricity' (a textbook definition), which drew no further responses. This discourse pattern revealed a naïve understanding of discourse, i.e. an inquiry is over when a 'correct' answer is found.

Later discourses shifted into more sustained patterns, as students increasingly posed questions, developed explanations, and built on other students' responses. The question 'can wet wood conduct electricity' attracted much community interest, and its thread is an example of knowledge-building discourse. As Table 7 shows, different explanatory ideas and theories emerged in the discourse that brought about deeper inquiry. To test their ideas, students worked in groups to design experiments on wet wood (with a conductivity tester consisting of a battery, wire, and bulb), and found that dry wood could not conduct electricity, running water allowed some weak light in the bulb, and salt water and wet wood allowed stronger light. These insights raised new questions and helped students think more deeply about whether all kinds of water could conduct electricity and why salt and impure water was more conductive than pure water. They posted their questions and ideas on KF and continued their inquiry, generating still more explanatory ideas and theories. This example shows that students' discourse became more progressive in later phases. The gradual deepening questions and explanations suggest signs of working towards to theory building. These changed epistemic practices indicate a more sophisticated understanding of collaborative discourse, which might have influenced their science epistemology.

Discussion

This study investigated the role of computer-supported knowledge-building discourse and reflection in promoting elementary-school students' epistemic understanding about the idea-driven and theory-building nature of science. Quantitative analyses showed that knowledge-building students outperformed comparison students on epistemology of science and science learning, and that students' understanding of discourse predicted scientific epistemology. Discourse analyses further suggested how students' engagement and understanding of knowledge-building discourse might have contributed to their changed epistemic understanding about the theory-building nature of science. In the following, we will discuss three themes related to the findings of this study.

The major theme is about embedding epistemic reflection in students' engagement with discourse. Previous studies suggest the importance of explicit and reflective instruction in developing students' scientific epistemology (Khishfe & Abd-El-Khalick, 2002). Besides engaging students in inquiry, they also engaged students in reflective discussion of the targeted nature of science aspects, and found that it was a more effective approach than the implicit inquiry-oriented instruction alone. The current study conceptualised such explicit and reflective component as epistemic reflection (i.e. reflection on ways of constructing knowledge) and proposed that embedding such epistemic reflection in students' inquiry could facilitate their epistemic growth. The specific epistemic reflection we designed was about letting students reflect on the epistemic nature of their discourse. Our quantitative findings supported our hypothesis on the positive effects of knowledge-building discourse and epistemic reflection on students' scientific epistemology and science learning (Research Question 1). This finding is consistent with the previous research emphasising explicit and reflective instruction (explicit reflection on one's inquiry) for improving students' nature of science views (Akerson et al., 2000; Khishfe & Abd-El-Khalick, 2002). We furthered this line of research and examined students' reflection of the epistemic nature of discourse.

Additionally, this finding is aligned with the research that advocates promoting epistemic understanding through dialogic discourse (Bendixen, 2016). Some previous studies show the role of argumentation in developing students' epistemic understanding (Ryu & Sandoval, 2012), and we extended this line of inquiry to focus on the role of theory-building discourse in promoting students' scientific epistemology.

The second theme relates to the change of KF discourse. Quantitative analysis of students' KF discourse showed that students' discourse became more aligned with theory building after their epistemic reflection of discourse. Qualitative analysis further suggested in what ways students' discourse patterns had changed: shifted from unsustained one-question-and-one-answer patterns to more sustained and progressive patterns (Research Question 3). This result indicates that knowledge-building students' understanding of collaborative discourse become more aligned with theory building after their epistemic reflection of discourse. It also indicates the positive influence of epistemic reflection on students' epistemic practice.

Even though regular knowledge-building design also involves a cultural change to engage students in epistemic discourse, and the scaffolds on KF (i.e. *I need to understand, my theory, new information, a better theory*, etc.) were designed to promote such change, these epistemic scaffolds were quite implicit. It might take a long time to shift students' epistemic discourse and culture. In our study, we embedded epistemic reflection in the design, and helped students reflect on what makes productive discourse. Students co-constructed epistemic criteria for a good discussion, and we also provided knowledge-building principles to guide their reflection and make the epistemic goal explicit. This could help facilitate and speed up the transformation of students' epistemic practice and understanding. The timing of this epistemic reflection is also quite important. We embedded epistemic reflection in the middle of the intervention process. It took place after students had some experience with KF, which provided the basis for reflection. Then after reflection, with their new understanding about collaborative discourse, they continually worked on KF. This could further deepen their understanding of collaborative discourse, and transform their epistemic practice accordingly.

The third theme is about the relationship between students' understanding of their collaborative discourse and scientific epistemology. The quantitative results supported our hypothesis on the prediction of understanding of collaborative discourse on scientific epistemology (Research Question 2). This suggested that students' understanding of their own collaborative inquiry predicted how they understand scientists' inquiry. Qualitative analysis of students' interview and written responses further suggested how students' understanding of the KF's cyclical and progressive processes were related to their understanding of the progressive and theory-building nature of science.

Students' understanding of collaborative discourse is about students' understanding of their own inquiry, while scientific epistemology is about their understanding of scientists' inquiry. Previous research (e.g. Sandoval, 2005) distinguished students' understanding of their own inquiry and their understanding of scientists' inquiry as two kinds of cognitions, and suggested the need to bridge them. Our study showed the possibility of influencing students' understanding of scientists' inquiry (scientific epistemology) through promoting their understanding of their own inquiry (understanding of their discourse), which provided insights for future intervention on fostering students' science epistemology.

In general, this study illuminates how knowledge-building discourse may facilitate scientific epistemology through focusing on epistemic reflection of discourse. In line with previous research that advocated an explicit approach to fostering epistemic cognition (Khishfe & Abd-El-Khalick, 2002), explicit reflection on discourse could allow students to construct their own epistemic standards and criteria which might facilitate their epistemic practice and promote their engagement in more productive inquiry and discourse. Through engaging in more sophisticated epistemic discourse, students might have developed a better understanding about collaborative discourse which was linked it to the theory-building process of science, and therefore improved their epistemology of science. Figure 4 illustrates a design model we propose to foster students' scientific epistemology. It is an insight generated from the current study, and further studies are still needed to validate it.

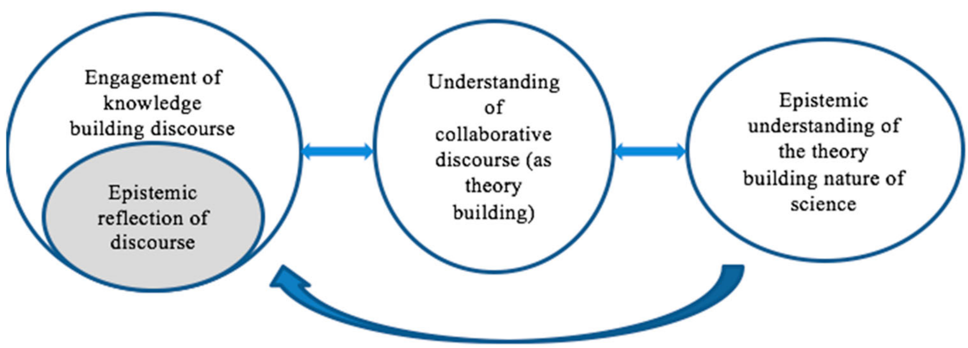

Figure 4. A proposed design model for fostering students' science epistemology.

The study has several implications for educational practice. First, teachers and students need a broader understanding of authentic science. Teachers need to move from emphasising methodological scientific skills to helping students see the role of ideas and theory building in science. Second, teachers can engage students in epistemic reflection, particularly reflection on their discourse. To help students understand the social constructive and theory-building nature of science, teachers may help students discuss and reflect on the quality of discourse and the epistemic features of productive discourse. Comparing their own and more productive discourse writing may be a good way to open up the discussion. Often, the epistemic features of students' inquiry and discourse are implicit to students; teachers can let students think about the epistemic nature of their inquiry and have them discuss how their inquiry process resembles mature science.

This study also has a few limitations. The intervention is relatively short, lasting three weeks. There may be concerns about the possibility of change in short interventions and whether these changes would be sustainable. Even though some researchers have noted that epistemic change is possible in well-crafted short interventions directed at student epistemology (Sinatra, 2016), further research is needed to validate these findings. Moreover, delayed post-tests would have been helpful to examine the sustainability of such epistemic change. The scale of measuring scientific epistemology was found to be related to students' conceptual understanding, which suggested good validity. However, this is an initial attempt at examining young students' understanding of theory building in science, ongoing work is now being conducted to further validate the scale.

There were also challenges while we implemented this study. The major one was related to the teachers' epistemology. In the beginning, the teacher we worked with had a limited understanding about the theory-building nature of science. He had been teaching students to test their hypothesis with experiments. Though discussion was also common in his classroom, he did not understand how to facilitate good discussion, nor understand the role of KF in supporting students' discussion and theory building. It would be hard to promote students' scientific epistemology if the teacher did not have a sophisticated scientific epistemology. To overcome this challenge, we had several meetings with this teacher to help him understand the theory-building nature of science, and all the rationales and principles of the design were discussed. We also followed the teacher's implementation of the design very closely, and timely feedback was communicated. We believe that this process helped improve teachers' scientific epistemology and facilitated the success of the intervention. Future research may also need to take the teachers' epistemology into consideration while they try to develop students' scientific epistemology.

Conclusions

This study focused on the role of discourse and epistemic reflection in developing students' scientific epistemology. It employed a theory-building perspective and demonstrated that even elementary-school students could hold the view that science is progressive and involves continual pursuit of ever-deepening explanations, and could recognise the importance of social process in knowledge generation. Our findings showed that students in the knowledge-building class outperformed their counterparts on both scientific epistemology and science learning; students' engagement in idea-driven theory-building discourse and epistemic reflection of discourse brought about more mature conceptions of discourse that predicted their conceptual and epistemic scores. Theoretically, the study contributes to the notion of conceptualising epistemic reflection as a possible mechanism to help students to develop their epistemic view of science. The study also has pedagogical implications suggesting the need for young students to explicitly talk about the epistemic nature of their discourse and to compare their inquiry process with those of scientists. Further investigations on designing interventions on explicit epistemic reflection supported by knowledge-building dynamics are needed.

Disclosure statement

No potential conflict of interest was reported by the authors.

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