# Knowledge Building Inquiry and Reflection in Developing Children's Epistemology of Science

Carol K. K. Chan, The University of Hong Kong, ckkchan@hku.hk
Guangxin Xu, The University of Hong Kong, xgx0625@163.com
Feng Lin, University of Wisconsin-Madison, irisfeng83@gmail.com

**Abstract:** This study examined how elementary-school students developed their epistemology of science in a knowledge-building environment that involves idea-driven discourse and reflective inquiry. Twenty-two grade-4 students participated inquiring into a topic in earth science; they worked collectively on knowledge-building inquiry supported by Knowledge Forum®, a computer-supported collaborative learning environment. The key designs included students engaging in idea-driven discourse on Knowledge Forum augmented with epistemic talk and reflection, and linking the understanding of their own inquiry process with scientists' inquiry. Results indicated that students changed towards more sophisticated views of science from concrete-absolutist to evolving views of science. Analysis of classroom events illustrated how students reflected on their inquiry and KF discourse in relation to epistemic features of scientific practice, and developing the notions that they can be little scientists emulating the practice of scientists. Implications of designing knowledge building enriched with explicit and collective reflection to promote epistemic change are discussed.

## Introduction

It is widely recognized that students' epistemology of science, what they understand about the nature of science and scientific inquiry, is important both as an educational goal and for its role in scientific understanding (Elby, Macrander, & Hammer, 2016). Current reforms in science education emphasize scientific practices as ways students develop and use scientific ideas (NRC, 2012, and the Next Generation Science Standards, NGSS). These changes indicate the need to shift from hands-on and activity-based science to helping students engage in authentic inquiry working together to build knowledge. For students to develop scientific practice, they also need to think like scientists and develop ways to think about what science is about, what it means to develop scientific ideas, and how scientists go about creating knowledge; scientific practice involves epistemic understandings of science. The emphasis of scientific epistemology and science practice can also be related to the social-situated perspective of learning in which students learn through participating in a community of practice -- Scientific practice involves collective inquiry to construct explanations and scientific discourse.

There is increasing interest in examining students' science practices related to epistemological development (Elby et al., 2016) but relatively less attention has been given to examining scientific epistemology from a community of learning perspective supported by technology. This study uses the knowledge building approach (Scardamalia & Bereiter, 2014) premised on the idea that participants, even as school-aged children, can be a community of scientists working creatively with ideas and, adding value to the community. While knowledge-building research has made substantial progress in scientific inquiry, there is still limited systematic investigation of how knowledge-building works to help young students develop more sophisticated scientific epistemology (Lin & Chan, 2018). A key theme in science education examines explicit reflection in promoting students' understanding of nature of science (NOS) (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002) and there are diverse approaches for developing explicit reflection. This study investigated how knowledge building inquiry and practice enriched with reflective discourse can promote students' scientific epistemology.

## Epistemology of science

Different research strands have examined students' understandings of the nature of science (Elby et al., 2016). Researchers have adopted psychometric and multi-dimensional approaches (Hofer & Pintrich, 1997), such as exploring certainty, source, justification, and development of knowledge to examine epistemic beliefs in science; intervention studies have examined changes in epistemology based on these dimensions (Conley et al., 2004). Research in science education (Lederman et al., 2002) focused on examining the nature of science (NOS), including its empirical, tentative, creative and inferential aspects. Another tradition has examined how students understand the nature of science as constructive and evolving (Carey et al., 1989) involving idea-driven and theory-building processes (Scardamalia & Bereiter, 2014). Carey et al. (1989) examined children's scientific epistemology and identified three general patterns: science as simply carrying out activities; science as tentative and uncertain; science as a constructive process for generating deeper explanations of natural phenomena. Smith et al. (2000) examined children's scientific epistemology in terms of how students understand the goals of science, the nature of scientific questions, purpose of experiments, and the nature of the idea-change process. Chuy et al. (2010) identified four aspects of fourth graders' understanding of science: the nature of theoretical progress; theory-fact understanding; the role of ideas in scientific inquiry; and, invention.

Chinn, Buckland and Samarapungavan (2011) developed an epistemic cognition model for examining epistemic goals, the structure of knowledge, and justification involving epistemic aims, ideals, and reliability of knowledge; epistemic cognition needs to be examined in situated and complex learning environments. Sinatra (2016) argued for the importance of examining both what students say what they believe about science, and how they engage in scientific process and practices. Sandoval (2005) postulated two kinds of epistemology, the *formal* epistemology of what students understand about the nature of science and scientists' work, and the *practical* epistemology pertaining to students' understandings of their own inquiry. These studies indicate the need to examine the intertwined relations of students' epistemic understandings of science and their epistemic practices of building knowledge in science.

### Knowledge building for epistemic development

Knowledge building is an educational model that postulates students taking *collective cognitive responsibility* for community knowledge advancement (Scardamalia & Bereiter, 2014). In knowledge building classrooms, a community or class of students posted problems, co-constructed explanations, and refined their theories on Knowledge Forum® (KF) in ways that emulate what scientists do in advancing the frontier of knowledge. Knowledge building is premised on the idea of students creating and improving new knowledge working as a community of scientists; focus is placed on how science knowledge is generated involving explanation and theory building. Researchers have investigated knowledge building from the vantage point of epistemic development. Hakkarainen (2003) analyzed the discourse on CSILE (an earlier version of KF), and showed school-aged children were engaged in explanatory-driven epistemological inquiry *like* scientists. Chuy et al. (2010) examined how students experiencing knowledge building had more sophisticated views about science compared to those using project learning. We have also examined the role of knowledge-building designs using explicit reflection to promote grade 5/6 students' epistemology of science (Lin & Chan, 2018; in press).

In this study, we followed our previous work and designed a KB environment focusing on collective inquiry, discourse and reflection, extending the design incorporating model building in earth sciences, a different curricula area. There are two design themes: First, we emphasize students' idea-driven *inquiry* and discourse both online and offline, when they worked together for idea improvement and to advance collective knowledge. In doing so, students would better understand nature of progressive science and theory building. A second theme is explicit epistemic *reflection* in a community KB context - There are diverse meanings of explicit reflection, and in this study "explicit" refers to an intentional design and not didactic or "telling." "reflection" involves students reflecting on their inquiry/ discourse in a collective space; and "epistemic" involves the notion that reflection is conducted in relation to epistemic criteria/standards. Specifically, we examined how young students develop an understanding of science, focusing on linking their practical epistemology (what they experience in their knowledge-building inquiry) and formal epistemology (what they understand about scientists' inquiry) (Lin & Chan, 2018). *In sum*, this study aimed to examine how a KB environment facilitates scientific epistemology through knowledge-building inquiry and reflection. We examined the following questions: (1) What characterized students' views of science and how were they related to domain understanding and KF engagement? (2) How did knowledge-building classroom processes and epistemic talk/reflection support students' scientific epistemology and practice? And (3) How did students link their inquiry processes with scientists' inquiry processes in developing their understanding of nature of science?

## Methods

### Participants and context

Twenty-Two Grade-4 students aged between 9 and 10 participated in a Hong Kong classroom and they came from an average to below average academic class. The teacher had previously conducted knowledge building pedagogy for several years and welcomed the opportunity to extend to diverse students. During 10 weeks' study, students worked on an earth sciences unit (volcanoes, earthquakes, and tsunamis).

### Designing the knowledge-building environment

Students were encouraged to engage in scientific practice and build knowledge together in a KB environment. The specific designs included: (1) Initiating collective inquiry with authentic problems: To stimulate thinking, the teacher showed video clips about an earthquake/tsunami in Japan. Students posed questions after watching, then worked collaboratively to identify good questions through discussion, and started inquiry on the knowledge-building wall. (2) Classroom inquiry was followed with collaborative online discussions on KF and deepening inquiry through knowledge building talk related to principles (3) Students drew diagrams as models to explain the mechanism of different earth sciences phenomena and reflected on such practice related to explanation. (4) Students engaged in epistemic talk and reflection examining how their classroom and online work reflected knowledge building and good scientific practice; they wrote reflection portfolio with the support of designed scaffolds in KF.

### Data sources

The following data sources were included: (1) *Epistemology of science.* A set of five open-ended questions adapted from Lin and Chan (2018) was administered to students at pre-posttests to explore their understandings of nature of science. A Likert-scale questionnaire was administered to assess their epistemic beliefs of science learning. It contained 26 items with 4 dimensions of epistemic beliefs (source, certainty, development, and justification) adapted from Conley et al. (2003). (2) *Domain understanding*. Pre- and post-test domain knowledge (e.g., causes of earthquake) were examined using a set of written questions. Students were encouraged to draw diagrams to help express their understanding. (3) *KF participation and writing:* (a) Data logs based on Analytic Toolkit, an assessment tool within KF, was used to measure students' participation in online KF discourse. (b) Depth of explanation. Students' notes were coded on a 4-point scale for level of explanation adapted from the epistemology of inquiry scale (Hakkarainen, 2003), and (c) KF portfolio notes were analyzed qualitatively to gauge students' reflection in relation to knowledge building inquiry. (4) *Classroom process* and discourse of students' scientific practice and understanding supported by knowledge-building dynamics were examined. (5) Students' understanding of knowledge building process was examined using focus group interviews.

## Results and analysis

### Characterization of students' scientific epistemology and change over time

Different patterns of students' views about science were identified using a theory-building perspective (Lin & Chan, 2018; in press; Chuy et al., 2010). Key dimensions included role of ideas, theory change, and social process. For the question on what scientists do (i.e., what do scientists want to achieve?) one student wrote that "scientists invent things to help people" [NJC]; another wrote that scientists want to find out the right answers (WYT); for higher-level responses, a student wrote that "scientists work to think about new theory. They are involved in observation, conducting experiments, and inquiry (TYX). In response to another question on whether they think theory will change, one student wrote that "theory will not change. We always have gravity on our earth." (TYX); another student said that "every theory will change once in a while for example in every five years" (WSY); for more sophisticated responses, the student wrote that "scientists will continue their inquiry to make science better; they will not only do experiments once; they will do different experiments; and if the results are different, they will think about the problems and make changes; they may change their original theory to some different theories" (WZY).

Students' responses to the five open-ended questions were coded on a 4-point scale ranging from naïve to sophisticated responses (Cohen Kappa, 0.91). Analysis of open-ended responses showed significant changes on students' scores between pretest 1.68 (.58) and posttest 2.54 (.80), $t$=3.65, $p$<.001. Overall, students seemed to exhibit better understandings of the purpose and development of science for explaining or creating new theory; students also had a general sense of some key elements in scientific inquiry including data, experiments, and theory. Findings from questionnaires on epistemic beliefs (Conley et al. 2004) (source, certainty, development, and justification) showed pre-posttest differences on the dimension of "development" (3.65 (.69) to 4.06 (.54), $t$ =-.23, $p$<.007). Students seemed to be most influenced after instruction in viewing knowledge as evolving and changing, and not static; such results also align more with the knowledge-building perspective.

### Scientific epistemology, domain understanding and KF engagement

Student engagement in KF discourse was examined using data logs information in KF notes. The mean number of notes written was 6.6 (3.4); 20.6% (9.7) of notes were read; keyword use totals were 55.3 (31.47); and the mean number of notes revision was 3.73 (3.61). Correlation analysis indicated that the number of notes written (productivity) showed no association with explanatory notes; however, the number of notes read (collaboration) was significantly correlated with the explanatory quality of notes (r=.66, $p$<.01). These results suggest that the more students read others' notes and as they were aware of community work, the more they wrote high-quality explanatory notes. Students showing low levels of epistemological understanding also wrote notes with lower explanatory value ($r=-.425$, $p<.05$). Quantitative analysis also showed pre/post-test changes on students' domain understandings. Post-test domain scores were also shown to be correlated with the scientific epistemology scores. These quantitative findings were generally consistent with other studies in knowledge-building research and provided some validation that the identified science epistemology scores are meaningful.

## Knowledge building inquiry, discourse and reflection

We analyzed key themes emerging in the knowledge building classroom reflecting students' epistemic inquiry and reflection; online and offline discourse were integrated. These selected themes were guided by our framework emphasizing knowledge building inquiry and epistemic reflection.

### Theme 1: Formulating problems for inquiry and selection of productive questions

Generating productive questions and formulating problems is key to scientific practice and progress. In the knowledge building classroom, from the start, the focus is about helping students develop the practice of asking questions and formulating these questions into more specific problems. The knowledge-building wall (Fig 1) provided a public space where students posted ideas and questions and made their ideas public and visible for improvement. A developing epistemic culture is that ideas are out there to be improved as in the classroom talk.

| | |
|---|---|
| T | Please look at the knowledge-building wall. What are some questions you are interested in? |
| S24 | How do computers or earthquake warning systems predict earthquakes? |
| T | Could you share what you wrote? |
| S22 | There is vibration in the mantle when earthquakes happen; after ten seconds, the warning system can detect the earthquake. |
| S21 | I think the detector is put in the mantle but the detecting time is different… um… I think it should be longer than 10 seconds. |
| T | Do you have questions about these responses? Do you want to build on these ideas? |
| S25 | How could the warning system detect the vibration in the mantle? |
| S8 | Why must the detector be placed in the mantle but not other parts [crust]? |
| S24 | Why must we use a detector or electromagnetic wave to detect the P wave? |

This excerpt illustrated how the teacher helped students to make ideas visible using KF wall; how they began to engage in the scientific practice of asking questions; different ideas were put forward and considered as students worked together to deepen the inquiry problem.

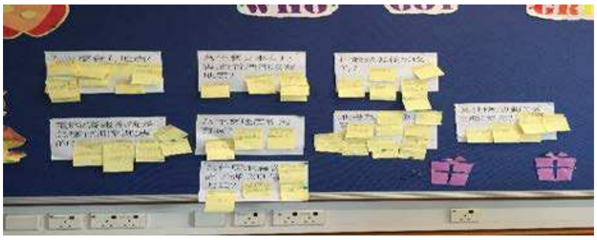

Figure 1. Student posting ideas on the knowledge-building wall.

In addition to the scientific practice of asking questions, students were also encouraged to explicitly reflect on their practice of formulating problems; they discussed how they chose the questions for inquiry.

| | |
|---|---|
| T | All groups have written several questions and you chose two each. What are the questions you did not use? |
| S4 | How big is the mantle? |
| T | And why? |
| S12 | This question has a definite answer. |
| S14 | Some questions you can find in the textbook. |
| T | How do you choose your questions then? |

| | |
|---|---|
| S15 | My other questions are broader with more to find out. |
| S18 | We can talk more about these questions, we can all discuss more. |
| T | Let's go to the KF wall and put more ideas there, and keep building on them. |

As they discussed their selection of questions alluding to features such as certainty [S12], scope for inquiry [S15], community interest [S18], the teacher engaged students in reflection relating to epistemic aspects – he was helping students to develop the epistemic criteria for problem formulation, analogous to scientists choosing productive questions for inquiry. In this process, students would gradually develop the epistemic habits of generating questions, sharing ideas, choosing productive questions, and building on each other's ideas to advance collective understanding.

### Theme 2: Co-construction of explanation and criteria of good discourse

Explanatory inquiry and co-construction of ideas is important in scientific practice. After posting questions and ideas on the KF wall, they continued their inquiry in KF. Here are some examples of KF notes that show how students co-constructed explanation on a problem they posted on the KF wall.

| | |
|---|---|
| [INTU] | Why are there earthquakes in Japan but not in Hong Kong? [YHH] |
| [My theory] | I think Japan is in between two plates. [LCH] |
| [My theory] | The plate is near Japan but far from Hong Kong [WTL] |
| [My theory] | Near Japan there are different plates…Pacific, Eurasia…the Japanese islands are there near these 4 plates.. so there are more earthquakes and volcano in Japan. [WCY] |
| [My theory] | Most strong earthquakes in our world occur at the edge of the tectonic plates. Hong Kong is located within the Eurasian plate and not at the edge. The famous Pacific earthquake belt is found at the edge of the Eurasia and Pacific plates that go through Japan and Taiwan... Hong Kong is far from this active belt so I think the chance of major earthquake is smaller. [LHY] |

Although student understanding is still rudimentary, they are moving from general responses to more specific ones and progressively improving their explanations together using information and evidence. The last response suggested that the student [LHY], in comparing earthquakes in Hong Kong and Japan, has moved up to a general principle and using the location of plates to explain the occurrences of earthquake. Following their KF writing, the teacher conducted a knowledge-building talk, to help students reflect explicitly on their inquiry.

| | |
|---|---|
| T | What do you think are the good notes on Knowledge Forum? |
| S6 | They provided detailed information.... |
| T | yes…details. and what others? |
| S5 | not just something else. Good notes add on.. it is about our original problem. |
| S12 | I like the notes that answer my question. |
| S21 | Not just answer one question… the good notes follow on. *We can continue the inquiry* |
| T | Which are some notes you like? |
| S18 | I like CX's note because he provided explanation about the volcano eruption; he also had some source information. |

As the excerpt showed, these young students, in their intuitive and simple language, seemed to be developing some notions that it is important to address the key conceptual problem; they need to continue the inquiry; and ideas need to be explanatory. In this classroom, student engaging in KF writing and discourse was enhanced with explicit reflection on epistemic standards of good discourse moves; discussion on reflection was enhanced with the collaborative space of knowledge forum.

### Theme 3: Drawing models and evaluating quality relating to processes and mechanisms

Another aspect of scientific practice is the use of model for explaining scientific phenomena. Students drew diagrams as a model to explain their understanding of volcanic eruption; they shared their artifacts with the class and refined their diagrams through collaborative discussion, as they continued their discussion on KF, then they repeated the drawing of the model and they explained the change in classroom discourse (Figure 2).

T Could you share with us your diagrams? Can you explain them?

S5 This is only a diagram without words or explanation [refers to the first one]. My second one explains the reasons and mechanism and I included words.

S11 Both diagrams explained that volcanic eruption is caused by the movement of the plate. However, the first one is not as detailed as the second. I have drawn the whole process of the volcano eruption in the second diagram.

S2 When I drew the second diagram, I referred to the movement of magma and three types of plate movement. I also referred to my first diagram, and discussed with WZL about what other reasons could cause volcanic eruption. And here I also drew the harmful effects of volcano eruption.

Students through drawing these diagrams depicted their model of how volcanic eruption took place. The discussion suggested that these students seemed to have recognized the important role of process and mechanism in explaining scientific phenomena. They were not just describing how volcanic eruption took place; they were evaluating the quality of the diagrams and alluded to epistemic features and role of explanation. Students also noted the positive effects of working together and social interaction in improving ideas.

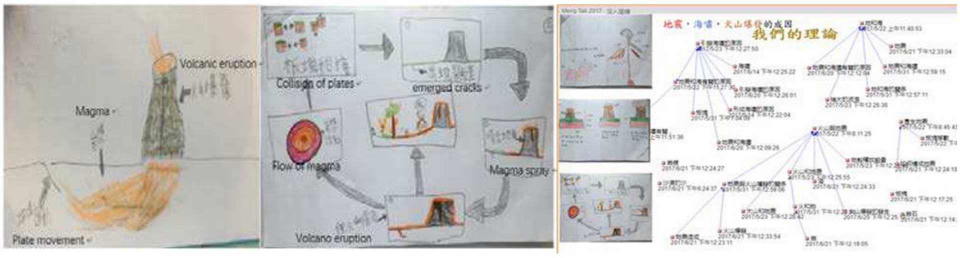


Figure 2. A student's first and second drawings on volcano eruption (left and center) and a KF view on formation of volcanos and student drawings (right).

Knowledge Forum provides the environment that emerging ideas and different models can be made public for continuing inquiry; selected diagrams and models were posted on KF for students' further inquiry in a deepening view when students continued their discourse (Figure 2).

### Theme 4: Epistemic talk and epistemic reflection

The teacher also helped students to engage in epistemic talk and reflection to develop ways of thinking in line with what scientist do and how they think.

T What do you think about geologists and scientists' work?

S1 They also learn things.

S5 They search information from the internet?

T *What* are the differences between our inquiry and scientist inquiry?

S9 They do many experiments.

S6 ….um…We also search information like the scientists..

T Do scientists trust the information?

S8 No... not all information is true. They would do some investigation; then test again to find out about the information

T How then do they test the information?

S9 Do some research…

S10 they also do experiments… they go to places with earthquake for field work

T So scientists know a lot?...more than we do......

S12 they will always continue their work …and improve the knowledge.

The excerpt suggested that some students began with intuitive ideas, but through dialogue, diverse ideas emerged suggesting some understanding about science as involving experiments and source of information; how scientists go about doing experiments and field inquiry in testing external information; and the continual work of scientists for progress.

Students were engaged in reflection on their inquiry related to the epistemic processes of knowledge building. A set of KB principles have been used to inform knowledge-building design (Scardamalia & Bereiter, 2014) that reflect the epistemic standards of knowledge work. Throughout the program, the teacher helped students to talk about selected key principles using simple language including “all ideas can be better” (idea improvement), “questions start us thinking” (epistemic agency) and “we work together to move forward” (community knowledge). Towards the latter part of the program, students were provided with a diagram that illustrated the epistemic criteria of knowledge building as related to scientific practice (Figure 3); they reflected and provided examples from their own experience in relation to these features. Their epistemic reflection on their own inquiry and scientist’s inquiry was extended in their writing of portfolio notes on KF (next section).


Figure 3. Knowledge-building principles as epistemic prompts for reflective inquriy.

## Students linking their own inquiry with scientific inquiry

We included examples from KF reflective portfolio notes and interviews to illustrate how students link their inquiry processes with scientists’ inquiry processes as they discussed their understanding of nature of science.

> Scientists use their observation to help them pose questions…Before they do the experiments they would predict… and after that, they would analyze the data and information, they would also work together to ask more questions... they would continue with their inquiry…
>
> For us, we also construct knowledge together. Using KF we read others’ ideas... to help enrich our ideas... we also go and research and look for information so we can have better ideas... We also have changed our ideas... [about volcanic eruption]. When we worked on that first... we don’t know much…we find more information and improve the explanation [TWT].

This response suggested how this student drew upon her KF inquiry and connected the similarities with scientists considering the need to search for information, to test and improve these ideas; and these ideas can be changed to provide better explanation. The interview excerpt shows some similar patterns.

| | |
|---|---|
| S5 | um...it seems yes. .. we are somewhat like scientists.. |
| I | Do you want to tell us more.. |
| S5 | We are now finding out more about volcano... these are things that experts do research on…but we are also trying to inquire about volcano; somehow we are beginning to follow.. model after scientists |
| S5 | Yes.. We can do that.. |
| S9 | I think we are also like scientists looking for information and doing research; um we are also working to find out *why* volcano erupt. |
| S16 | We are not like scientists.. they know a lot more than we do… |
| I | So you think scientists have a lot more knowledge than us?… |
| S5 | um. I still think we are like scientists.. we also know something about volcano eruption ..something [in the area of scientists] We are like little scientists.. um following the examples of what scientists do.. |
| S9 | um…we are also working together like a community.and scientists do that. |

In this excerpt, these students indicate how they could be like scientists working on research Interestingly, one student disagreed and noted that scientists have more knowledge [S16]. This brought about further explanations that they can be like little scientists, working in the same inquiry area, emulating the scientists [S5]and how they can work collectively just as scientists do [S9]. These data suggested for these young children, even in their simple language, had some intuitive sense that while they do not know as much as scientists, they can follow the scientists' practice on developing knowledge.

## Implications and significance

This study contributed to the knowledge building literature and investigated how school-aged students developed epistemologies of science supported by knowledge building inquiry and reflection. The findings supported our earlier work and extended to a younger group in a different curricula area, including both what students said about their epistemic understanding of science as well as how they approached the epistemic work of building knowledge. This study illuminates the ideas that if students are to understand certain aspects of nature of science, they must experience those aspects and make reflection on such experience. Our findings show that knowledge-building supported by KF provides opportunities for students to experience scientific inquiry and practice involving formulating questions, construction of ideas, model building and explanation, and community processes. The findings also show how epistemic talk and reflection on collective work, relating to why and how and criteria, help students to link their practice with their understandings -- they are linking their practical epistemology of knowledge-building experience with the formal epistemology of how scientists build knowledge. Theoretically, this line of research in knowledge building may enrich the notion of explicit reflection examining how it may be enhanced as collective reflection in a community context. There are also design implications of scaffolding young students in idea-driven inquiry and discourse and engaging them in epistemic talks to help them to reflect on their practice as little scientists and knowledge builders.

## References


Carey, S., Evans, R., Honda, M., Jay, E., & Unger, C. (1989). An experiment is when you try it and see if it works: a study of grade 7 students' understanding of the construction of scientific knowledge. *International Journal of Science Education, 11*(5), 514-529.

Chinn, C. A., Buckland, L. A., & Samarapungavan, A. L. A. (2011). Expanding the Dimensions of Epistemic Cognition: Arguments From Philosophy and Psychology. *Educational Psychologist, 46*(3), 141-167.

Chuy, M., Scardamalia, M., Bereiter, C., Prinsen, F., Resendes, M., Messina, R., Angela Chow, T. C. Y. (2010). Understanding the nature of science and scientific progress: A theory-building approach. *Canadian Journal of Learning and Technology, 36*(1).

Conley, A. M., Pintrich, P. R., Vekiri, I., & Harrison, D. (2004). Changes in epistemological beliefs in elementary science students. *Contemporary Educational Psychology, 29*(2), 186-204.

Elby, A., Macrander, C., & Hammer, D. (2016). Epistemic cognition in Science. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 113-127). New York: Routledge.

Hakkarinen, K. (2003).Emergence of progressive inquiry culture in computer-supported collaborative learning. *Learning Environment Research*, *6*,199-220.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. e. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching, 39*(6), 497-521.

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching, 39*(7), 551-578.

Lin, F. & Chan, C.K.K. (2018). Promoting elementary-school students' epistemology of science through computer-supported knowledge building discourse and epistemic reflection. *International Journal of Science Education*.

Lin, F. and Chan, C.K.K. (in press). Examining the role of computer-supported knowledge-building discourse in epistemic and conceptual understanding. *Journal of Computer Assisted Learning.*

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education, 89*(4), 634-656.

Scardamalia, M. & Bereiter, C. (2014). Knowledge building and knowledge cration: Theory, pedagogy and technology. In K. Sawyer (Ed*.), Cambridge Handbook of the Learning Scences* (pp. 397-417).

Sinatra, G. (2016). Thoughts on knowledge about thinking about knowledge. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 479-491). New York: Routledge.

Smith, C. L., Maclin, D., Houghton, C., & Hennessey, M. G. (2000). Sixth-Grade Students' Epistemologies of Science: The Impact of School Science Experiences on Epistemological Development. *Cognition and Instruction, 18*(3), 349-422.