Conceptual Change and Epistemic Growth through Reflective Assessment in Computer-Supported Knowledge Building

Carol K.K. Chan, Ivan C.K. Lam, University of Hong Kong, Pokfulam, Hong Kong
Email: ckkchan@hku.hk; ivanlmhk@gmail.com

Abstract: This study examined the design and process of how students' reflective assessment promoted collaborative metacognition for conceptual and epistemic changes, mediated by Knowledge Forum, a computer-supported environment. The design involved augmenting knowledge-building inquiry with reflective assessment – Students wrote reflective summaries to track their initial understanding and trajectories of growth toward scientific understanding in the domain of electrochemistry. Two classes of 10th grade students in Hong Kong participated in Reflective Assessment (RA) and Reflective Assessment with Scaffolds (RAS) conditions. Results indicated that both classes improved on conceptual-change and epistemic-beliefs measures; the effects were stronger for the class with scaffolds. Qualitative analyses showed how students' reflective assessment and collaboration helped them to develop metaconceptual and epistemic awareness as they examined their own and others' understanding. A path analysis indicated that students' engagement on Knowledge Forum predicted reflective collaboration that in turn exerted effects on their changes in conceptual understanding and epistemic beliefs.

Theoretical Perspectives

Across science education and learning sciences, there are now major shifts towards theories of learning that emphasize both individual and social aspects of science learning (Duit & Treagust, 2003; Vosniadou, 2008). It is now widely accepted that science learning can be facilitated when students articulate their prior ideas and explain their understanding to each other. Conceptual change is examined emphasizing the social construction of knowledge and discursive interactions in classroom (Scott, Asoko & Leach, 2007). Furthermore, researchers now question conceptual change as a sudden change or a replacement of misconceptions with scientific ones through externally-driven conceptual conflict (Chan, Burtis & Bereiter, 1997). Instead, conceptual change involves a gradual process where science concepts are gradually restructured mediated by students' intentional-learning strategies (Sinatra & Pintrich, 2003). From a learning sciences perspective, there is a need to capture processes of conceptual change supported by collaborative discourse and to design learning environments to foster intentional conceptual change.

Intentional Conceptual Change

Current research on intentional conceptual change emphasizes the role of learners' metacognitive strategies, epistemic beliefs and agency in knowledge restructuring (Sinatra & Pintrich, 2003). It also points to the need to designing learning environments that encourage learners to employ goal-directed, reflective strategies and to develop metaconceptual awareness. Cognitive research has shown that students' epistemic beliefs can constrain or facilitate student thinking, reasoning, and science learning (Stathopoulou, & Vosniadou, 2007). Researchers have argued that conceptual change involves not only changes in concepts; there needs to be changes in students' views about the nature of science (Duit & Treagust, 2003). Vosniadou (2008) noted that conceptual change involves metaconceptual awareness – Students will be able to learn science concepts and principles only if they are aware of their prior understanding and the shift of their initial views toward science knowledge. Increasingly the emphasis is to examine conceptual change that includes not only individual cognitive development but also social and collective aspects; socio-cognitive discourse plays a key role in facilitating conceptual change. Although there has been much progress indicating the role of metacognition and epistemic beliefs on students' conceptual change, most of the research are correlation studies. Fewer studies have examined designing for intentional conceptual change that brings about metaconceptual awareness with epistemic changes supported by social and collective discourse.

Computer-Supported Collaborative Knowledge Building

How can current views of intentional conceptual change be integrated in instruction emphasizing collaborative discourse? Researchers have suggested how computer-supported collaborative learning (CSCL) can make important contribution to conceptual-change research (Miyake, 2007). Relating to the roles of interaction and discourse in science classroom, technological affordances can further provide a medium whereby students can articulate, communicate, represent and reconstruct their ideas for sustained inquiry. This study adopts an educational approach,

knowledge building, a forerunner of CSCL, that emphasizes knowledge creation as a collective work of the community; and that knowledge is improvable by means of a discourse (Scardamalia & Bereiter, 2006). To support student discourse, knowledge Forum (KF), a multi-media database constructed by students, was designed to support collaborative knowledge building discourse. In a knowledge-building community (both face-to-face and online), students engage in scientific discourse that involves posing cutting-edge problems, generating theories and conjectures, searching for scientific information, elaborating on others' ideas, co-constructing explanations, and revising their theories. Students' pre-instructional ideas and learning pathways can be represented on the computer forum and thus become objects of inquiry for conceptual change. There is now substantial evidence on the roles of knowledge building on students' collective inquiry and scientific understanding (e.g., Zhang et al., 2007)

Knowledge Building, Reflective Assessment and Conceptual Change

A question may then arise as to why another study is needed on knowledge building and scientific understanding. Despite major progress in two decades of research, there have been no systematic studies using this knowledge-building approach to examine conceptual change. Various principles advocated by researchers in conceptual change such as intentional goal-directed strategies, metaconceptual awareness, epistemic beliefs (Vosniadou, 2008) are well aligned with knowledge-building. However, how collaborative knowledge-building dynamics can bring about metaconceptual awareness and epistemic changes has not been examined. Further, we argue that knowledge building can enrich conceptual change studies that often emphasize small-group collaboration. There is a need to understand how conceptual change can take place in communities of learners and knowledge-builders. Knowledge building is not just a pedagogical approach but a theory of epistemology; so how students working with knowledge might change their epistemic views are fruitful lines of inquiry. Finally, knowledge-building research on science learning has mostly been conducted with elementary-school children. It would be useful to extend the scope of inquiry to investigating knowledge building for high-school science.

This study employed a design developed in research on assessment of knowledge building with students assessing their own collaboration (Lee, Chan, & van Aalst, 2006; van Aalst & Chan, 2007). Research has shown that students assessing their own scientific inquiry promoted metacognition (White & Fredericksen, 1998). Similarly, student-directed e-portfolio assessment with students documenting how they collaborated in knowledge-building discourse fostered their domain understanding (van Aalst & Chan, 2007). This study extends this line of inquiry: We designed knowledge building for conceptual change focusing on promoting metacognition in a collaborative context. Extending our earlier study (xx), we asked students to reflect on their prior conceptions and to track how they moved towards scientific understanding as they considered others' contributions and revised their ideas.

To iterate, this study aimed to design and examine how reflective assessment with collaborative dynamics would promote metaconceptual and epistemic awareness for conceptual change. Three research questions were included: (1) What was the role of the knowledge-building environment on students' conceptual and epistemic changes? (2) How did students' reflection contribute to their changes in conceptual and epistemic understanding? and (3) what were the relations among knowledge-building dynamics, conceptual change and epistemic growth?

Methods
Participants
Eighty 10th graders (Age ranging 15-16) in two chemistry classes in Hong Kong participated in this study. The lessons were conducted in English and students wrote notes in English on Knowledge Forum (KF). Both classes engaged in knowledge-building inquiry with reflective assessment. The first class is called Reflective Assessment (RA, n = 40) and the second Reflective Assessment with Scaffolds (RAS, n = 40). Both classes were taught by the same teacher, who had taught high-school chemistry for more than twelve years and had used knowledge-building pedagogy for over 6 years.
Procedure
This study was conducted in the second semester of 2008-09 lasting from Feb-June (16-18 weeks). There were five chemistry lessons each week; each lesson was of 35 minute duration. In both classes, students learned electrochemistry using knowledge-building inquiry approaches and they wrote computer notes on Knowledge Forum. Due to school policy for comparable curriculum, students had similar inquiry experiences (see later section, 1-4) and both used the same instructional topics, textbooks and reference materials and conducting the same experiments. However, there were also some key differences: Primarily students in the "Reflective Assessment with Scaffolds" class (RAS) wrote reflective summaries on KF using a set of pre-designed conceptual-change "scaffolds" (e.g., *My initial ideas, What we think, What I think now).* Alternatively, students in the "Reflective Assessment" class (RA) wrote reflective summaries without the scaffolds (RA). "Scaffolds" are prompts or sentence openers on

KF; different scaffolds can be designed depending on subjects and contexts. The use of conceptual-change scaffolds were to examine further whether the use of scaffolds would enhance further students' collaborative reflection.

Designing a Knowledge-Building Environment for Conceptual Change

We designed the learning environment based on knowledge building pedagogy aligning that with conceptual change principles (Vosniadou & Kollias, 2003). The principles and activities of the design are briefly described:

(1) *Activate prior knowledge through classroom discourse*. Students need to activate and reflect on prior knowledge and to articulate their ideas for science learning. Students worked in groups discussing science topics/problems in classroom. Students were scaffolded to present their ideas, make observations of experiments; raise questions they did not understand, elaborate and comment on others' views. Students' ideas were shared and made public using concept-maps, posters and knowledge-building walls (boards for posting ideas). When students became familiar with articulating their thinking, they then continued their inquiry and contributed their ideas and questions onto KF.

(2) *Foster metacognition through KF scaffolds and problem-centered inquiry*. Students were encouraged to raise authentic problems from prior ideas and daily life on electrochemistry that puzzled them. Extending the classroom inquiry, students wrote their ideas on the discussion views on KF (Figure 1 left): Students engaged in goal-directed inquiry- they posed problems, made conjectures/hypotheses, co-constructed explanations, compared different explanations and revised their understanding. KF scaffolds including '*I need to understand*', '*my theory*', '*new information*', and '*a better theory*' prompted metacognitive thinking and theory revision. Teacher facilitation involved helping students integrate KF and classroom discourse and to notice conflicts, discrepancies and identifying gaps for further inquiry.

(3) *Develop deep understanding through model-based explanatory inquiry*. Students were involved in constructing models of chemical cells using everyday materials and explaining to each other how their chemical cells work.

(4) *Integrate fragmented ideas and use 'rise-above' explanation*. To tackle the problem of fragmented ideas, a common barrier to conceptual change, students deepened their understanding using KF functions of 'rise above' and 'references' to synthesize diverse and fragmented ideas from classmates as they worked towards more *coherent explanations*. Teachers integrated online discussion with classroom talk to help students deepen their inquiry.
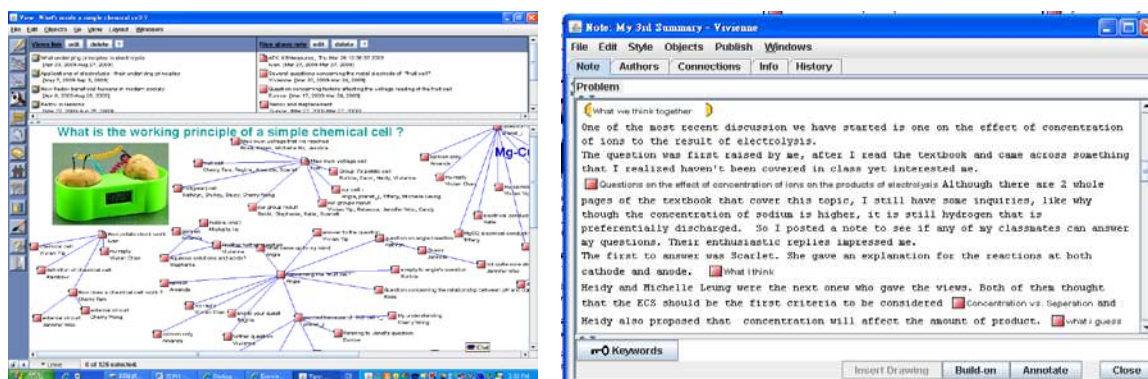

Figure 1. A Discussion View on Knowledge Forum (left) and an Example of a Reflective Summary Note (right).

(5) *Develop metaconceptual awareness through reflective assessment*. In both classes, students were asked to review the notes on KF, to reflect on their initial beliefs, and to track their changing ideas incorporating classmates' ideas (Figure 1, right): The teacher prompt written on KF included: You are encouraged to review the computer notes written by you and your classmates in the database. Write a summary note to reflect and to consolidate what you have learnt from the views of '*Batteries*' & '*Simple chemical cell*'…In writing the summary, you may select relevant computer notes (references) as evidence that support your understanding. Think about how your chemical knowledge has developed or changed. As noted above, in the Reflective Assessment with Scaffolds (RAS) class, students were further provided with conceptual-change scaffolds (e.g., "My initial idea"). Students could also use other KF scaffolds such as "a better theory" and "this theory cannot explain" and "putting our knowledge together".

To help students with their reflection, in both classroom and online discourse, the teacher would scaffold students to reflect more deeply in discussing their notes. As well, the teacher also wrote on KF making some observation: "So far I have observed some benefits of chemistry gains from your summaries: (i) You are

encouraged to give more evidence (chemical knowledge) to reflect on your understanding or knowledge gains (not just say KF is good). (ii). It may be useful to tell us more of your initial thoughts and final thoughts on a particular chemistry concept. (iii) Continue to build on others' notes to deepen your ideas after reviewing these previous notes. Of course you can continue to raise other (emerging) questions or observations in everyday life."

Analyses and Results

We first assessed student changes in conceptual and epistemic changes after the instruction; we then examined why and how such changes might take place relating to knowledge-building inquiry and reflection, and finally we investigated the relations among knowledge building activities, conceptual-change learning and epistemic changes.

Conceptual-Change Learning in Electrochemistry

Conceptual-Change Written Tests and Explanation   Written questions were designed to tap into students' understanding of electrochemistry probing into students' alternative conceptions. The written questions were designed based on studies on conceptual-change in electrochemistry in science education research. Questions included open-ended ones asking students to explain their understanding of key concepts to probe their conceptions (what is oxidation?). Responses to forced-choice questions were coded on students' explanations of their choice. The pretest and posttest percentage scores were 13.8 (7.1) and 57.3 (12.3), and 14.1 (6.4) and 49.1 (15.4) for Reflective Assessment with Scaffolds (RAS) and Reflective Assessment (RA) classes, respectively. Analyses of pre-posttests using paired t-tests showed that both classes improved on the conceptual-change tests with RAS, t (39), = 20.14, $p<.001$, and RA, t (39), = 14.21, $p<.001$. Analyses using ANCOVA controlling for pre-test differences indicated that higher scores were obtained for students in Reflective Assessment with Scaffolds (RAS).

Changes in Alternative Conceptions in Written Tests   The number of alternative conceptions (misconceptions) for each student was identified from their responses to the written tests. The means of alternative conceptions were 6.4 (1.7) and 5.7(1.2) at pretests and 1.9 (1.5) and 3.0 (1.9) at posttests for RAS and RA classes respectively. Students in both classes decreased in the number of alternative conceptions after instruction. ANCOVA on posttest results using pretest scores as covariates indicated that there were more decreases in the number of alternative conceptions for students in the class of Reflective Assessment with scaffolds (RAS), F (1, 78) = 10.08, $p<.003$.

Changes in Epistemic Beliefs

Students were administered a questionnaire on epistemic beliefs (adapted from Conley et al., 2004) to examine the ways students think about the nature of knowledge. The questionnaire was pilot tested with over 300 students and validated in our earlier study (xx). Consistent with the earlier study, three factors were identified (1) "Certainty-Source", (2) "Development" and (3) "Justification" with scale reliabilities ranging from 0.64 to 0.83. An example of an item on Certainty is "Most questions in science have one right answer"; an example of an item on Development is "Scientific knowledge will not change over time", and an example of an item on Justification is "Ideas in science can come from your own question". Interviews were also conducted to provide more information on what students thought about these items; qualitative analyses are currently undertaken. Paired t-tests showed that students in both classes made changes towards more sophisticated epistemic beliefs based on the combined scores, for RAS, t (38) = 4.73, $p<.001$ and for RA, t (38) =2.27, $p<.03$. Separate analyses showed that students in RAS improved more on the subscales of "certainty-source" and "development" and students in RA improved more on "justification".

Students' Knowledge Forum Engagement and Collaborative Reflection

Knowledge Forum Engagement (ATK) We examined students' overall participation and engagement in Knowledge Forum (KF) using a software called the Analytic Toolkit (ATK, Burtis, 1998) that uses log files to show students' participation and activity on KF. We included several ATK indices commonly used in knowledge-building research : (1) number of KF note written, (2) % of notes read, (3) % of linked notes, (4) scaffolds (thinking prompts) (5) keywords and (6) revision. Some of these indices show student collaboration (e.g., notes read/linked) and others reflect metacognition such as the use of scaffolds" and "revision" of notes for purposeful activities.

We now report results of ATK indices for RAS and RA classes: number of notes written, 21.5 and 22.60 notes; percentage of notes read, 55% & 47%; note-linked, 80% and 68%; and scaffolds, 21 and 9.0, respectively. Although there were no norms for ATK, comparison with other studies indicated that these students were engaged actively participating and collaborating on KF. Compared to the literature on online learning with fragmented contribution (Hewitt, 2003), these number indicate high level of contribution; they are also comparable to those identified in mature knowledge building communities (Zhang et al., 2007). Comparison of ATK indices also showed some advantages for the RAS class over the RA class.

<u>Reflective Assessment and Collaborative Reflection</u>   As described above, students wrote three reflective summaries to reflect on their initial and new ideas in electrochemistry based on their discourse. These reflective summaries were scored on a 6-point scale. At the lower levels (1-2), the reflection depicts that students were just describing new information with limited reflection on what it meant for their conceptions. At the mid-levels (3-4), students demonstrated some personal thinking for identifying misconceptions or knowledge gaps in their understanding. At the highest levels (5-6), student reflected on their prior knowledge, identified gaps, considered how others' ideas supported their reflection; they demonstrated metaconceptual awareness of initial and new ideas and noted how they changed in their understanding of some concepts The summaries were coded and currently inter-rater reliability checks were being conducted. In the following, two contrastive examples of reflective summaries are provided to suggest how collaborative reflection may foster metaconceptual awareness for conceptual and epistemic growth..

Table 1: An example of a reflective summary note (low-level response).

Restating Information	Excerpts from the Reflective Summary Note
States impartial information	In the simple chemical cell, I found out that a potato cell can actually conduct electricity and drive the calculator to work. …
Makes reference to one note; no reference to one's own thinking	Through Florence's note, I knew that the electromotive force within each potato makes to move electric current. And the copper wire makes the electrons move in the potato, causing energy to move into the clock. This let me know more about how a potato cell conducts electricity
Describes factual information and formulae; no reflection	In the redox reaction of copper, I knew that …when the copper reacts with oxygen, copper acts as the reducing agent and causes oxidation, while oxygen acts as the oxidizing agent, causes reduction : $2Cu(s) + O_2 (g) \rightarrow 2CuO (s)$ And when hydrogen reacts with the copper oxide, hydrogen acts as the reducing agent, reduce the copper oxide : $CuO(s) + H_2(g) \rightarrow Cu(s) + H_2O(l)$…

Table 2: An example of a reflective summary note (high-level response).

Reflective Metacognition	Excerpts from the Reflective Summary Note
The student reflected on her understanding on state of matter and electrolysis	
- Identifies her prior conception; reflects on the source of difficulty -Considers role of textbook information	What I think before The products of electrolysis are always the same as long as the chemical salt is the same, disregarding its state. -*Because in many previous textbook chapters such as molarity, water plays no role* in the sense that it does not react [1] What I think I thought we do not melt the salt in electrolysis just because it is too troublesome.
-Considers other ideas and explanations -Selects relevant ideas and organizes them to show some learning pathways (e.g., further)	What we think together Jennifer provides detailed chemical equations to explain the difference [2] Agree. Candy *further* provides the significance of the difference [3] *molten and aqueous*, that metals like sodium could never be formed in electrolysis if there were no molten sodium salts…She also mentioned an interesting fact that mercury electrode can be used to extract pure sodium. This thought is *further worked* on. [4] Mercury electrode
-Reflects on new idea –Continues to query gap of understanding	When doing work regarding electrolysis, I have to look carefully whether the chemical is *molten or aqueous* as the results are very different. *However I still do not understand* the working principles of mercury electrodes.
The student noted another cycle examining factors influencing electrolysis	
-Reflects on prior beliefs; notes prior gaps in understanding; -Identifies source of confusion & difficulties -Refers to textbook as conveying information not in real science	What I think before As stated above, *I thought* the products of electrolysis are always the same if chemical salt is the same. *I didn't think a* higher voltage, except speeding up the process, will produce other results. For example, in aluminum anodization, *I thought only* the quality of the original aluminum will provide different results. Moreover, although I noticed that the metal deposited on the electrode is unevenly distributed, *I always thought* it was due to our poor skills or equipment. I have not considered it a natural occurrence, *mostly because textbooks often show the electrode fully and smoothly covered with the metal.*
-Considers others' ideas –Identifies puzzling info	What we think together …Rainbow suggested that temperature as well as acidity affects the results. *She also gave a curious suggestion that lower temperature gives*

and reflects on what she does not understand; - Examine various ideas and explanations to help her move toward better Understanding	*thicker layer of aluminum oxide, which I still can't understand* as I thought a higher temperature facilitates reaction, like what angie said ⬛[6] Answer.. ⬛[7] more information Cherry Wang further told us that an unsmooth layer is resulted as the metal plated is attracted to external corners and avoids internal ones. ⬛[8] Effects and Limitations of electrolysis. Besides, a higher current can lead to the formation of other substances in the solution, as mentioned in ⬛[9] 2 substances formed?
Reflects on new understanding	❲What I think now❳ The product of electrolysis could be affected by various [external] effects; the metal plated does not naturally spread out evenly.
The student included another scaffold and reflect on her beliefs and knowledge	
Reflects on beliefs about knowledge pointing to coherence (structure of knowledge) and evidence in justification	❲My belief on learning &knowledge❳ The most useful part is it broadens our thinking by *relating one topic to another*. For example I have never considered rusting from a redox or electrolysis point of view. *I believe we could learn more if we try to search for information before writing the notes instead of guessing without any evidence*

Note: 1. ❲ What I think❳ – Scaffolds in reflective summaries

2. ⬛[3] Reference notes in summaries with hyper-links to students' notes in the database

Table 1 shows an example of a reflective summary in which Student A was not actually engaged in reflection – She described some impartial information; referred to only one note from a classmate, described some factual information and formulae but did not reflect on her understanding or made attempts to describe changes. Table 2 shows another example with two related episodes – In the first one, Student B identified her prior understanding (state of matter & electrolysis); it is a key concept and a common alternative conception. She reflected on why she had the problem (prior knowledge & textbook); considered various classmates' explanations and organized them; and she noted her new understanding but continued to identify areas she did not understand (mercury electrode). In the second episode (factors influencing electrolysis), Student B continued to identify her prior ideas and gaps of understanding; noted others' ideas and she puzzled over her classmate's curious information. She tracked different ideas but focused on the original problem and reflected on her new understanding. Student B employed good use of the scaffolds and demonstrated metacognition noting what she knew and what she did not understand. As well, she showed metaconceptual awareness as she became more aware of her initial conceptions and how they differed from scientific ideas. There are various instances that showed how such reflection prompted Student B to examine nature and source of knowledge. For example, she noted textbook as unauthentic science and "imperfect" source of knowledge. Furthermore, she concluded using a scaffold ❲My belief on learning &knowledge❳ implying some thinking about the importance of coherence (structure of knowledge) and role of evidence.

Contribution of Knowledge Building Activity to Conceptual & Epistemic Changes

<u>Correlation Among Measures</u> Table 3 shows the correlation among various measures; we pooled the two classes because the key principles of reflective assessment are same. To improve the coherence for analyses, the various ATK KF indices were combined using factor analysis (see Lee et al., 2006). Two factors were extracted, Factor 1 is called **metacognition** (scaffold use, note revision and keyword) that explains 32.6% of the variance, and factor 2 is called **collaboration** (notes created, notes linked and read) that explains 30.1% of the variance. Table 3 indicates that KB reflection was significantly correlated with ATK metacognition, conceptual change and epistemic change scores. Furthermore, ATK collaboration scores were significantly correlated with conceptual-change scores.

Table 3: Correlations among ATK forum participation, KB reflection, conceptual and epistemic measures

	1	2	3	4	5	6
1.ATK Metacognition						
2 ATK Collaboration						
3. KB Reflection	.57***	.18				
4. Post-Epistemic Belief						
5. Epistemic Belief Change			.27*	.26*		
6. Post-Conceptual		.38**	.44**			
7. Conceptual-Test Change		.31*	.40**			.90***

Note: * $p<.05$; **$p<.01$; ***$p<.001$

<u>Regression and Path Analyses</u> We conducted hierarchical regression analyses on students' post-conceptual scores first using exam results and pre-conceptual scores (prior achievement) as predictors ($R^2 = .34$)   When KF engagement (ATK Collaboration) was added, additional 4.6% variance was explained ($R^2 = .38$). Further, when we added reflection scores (summaries), there were additional 7.4%variances explained ($R^2 = .46$); R2 changes were all significant. These results indicated that over and above science achievement and prior knowledge, student engagement in forum and metacognitive reflection further contributed to post-test conceptual scores (Table 4)..

Table 4: Regression on post-conceptual scores with achievement, ATK collaboration & reflection as predictors.

	R	R^2	R^2 Change	F Change
Mid-year exam & pre-conceptual scores	.58	.338	.338	39.82***
Forum – ATK collaboration	.62	.384	.046	5.63*
Collaborative Reflection	.68	.458	.074	10.3**

Note: *p<.05; **p<.01; ***p<.001.

We also employed a path analysis testing a causal model to provide a more coherent picture: Student engagement in Knowledge Forum including both ATK metacognition (e.g., scaffold use; notes revision) and ATK collaboration (e.g., notes read and linked) predicted KB collaborative reflection that further exerted effects on students' epistemic belief change scores and conceptual-change scores.
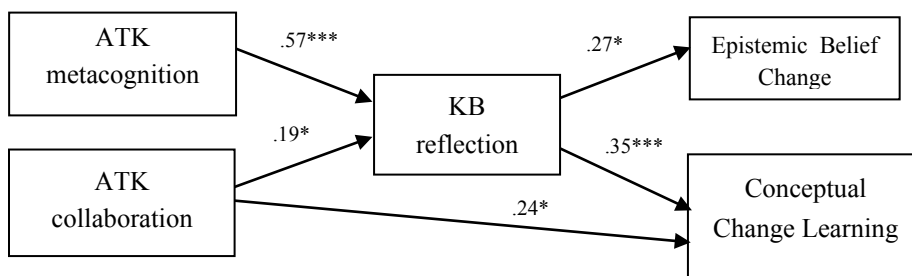

Figure 2. A Path Analysis Indicating Contributions of Knowledge-Building Activity
to Conceptual and Epistemic Changes.

Conclusions, Implications and Significance

This study developed a knowledge-building environment augmented with reflective assessment to examine and to foster conceptual change and epistemic growth. The environment was designed in ways that aligned with conceptual-change principles focusing on students' goal-directed strategies and agency elaborated with collaborative reflection. Results indicated that after the instruction, students in both classes changed towards more sophisticated scientific understanding measured by conceptual-change tests in electrochemistry. There is some evidence suggesting students also made some shifts in their epistemic beliefs. Comparing the two classes when students both had reflection, the effects were stronger for students supported with conceptual-change scaffolds for reflection.

A key question to address is to examine knowledge-building dynamics and to explain the pre-posttest gains, that is, how it may be possible for students to experience these changes. We demonstrated that asking students to engage in knowledge-building inquiry augmented with assessing their own scientific understanding in their discourse could help them activate prior knowledge, develop meta-conceptual awareness, and reconstruct fragmented views into more coherent explanations. As the excerpt shows, the student identified her prior conceptions; examined the nature of difficulties; considered others' views; puzzled over gaps of understanding; and integrated fragmented ideas into a more coherent account. The excerpt also suggests metacognitive reflection was facilitated because of the rich collaborative context with diverse ideas from classmates. Although ATK KF indices are quantitative, the extent to which students engaged in KF was a prerequisite for conceptual work – It supports the notion of how CSCL may provide the medium through which students can articulate, represent, interact and inquire into their ideas for sustained inquiry. Regression analyses provided support of this account indicating that students' engagement on KF and collective reflection predicted post-test conceptual scores *over and above* their academic achievement. A path analysis further showed that students' activity on Knowledge Forum predicted their collaborative reflection that in turn influenced students' posttest conceptual and epistemic changes.

Regarding epistemic shifts from questionnaire data, the excerpts provided some glimpses suggesting how changes were possible in collaborative inquiry and reflection. For example, Student B reflected upon the textbook as a source of 'imperfect" knowledge decontexualized from real-world science (i.e., textbook pictures always show smooth surface). She also pondered upon the importance of the connection among topics (structure of knowledge) and the need for justification using evidence. When students tackled authentic problems and reflected on their changes in understanding, they might be better able to see that knowledge is not certain and that it can be advanced.

To conclude, this study integrated two lines of research on intentional conceptual change and knowledge building examining how conceptual and epistemic changes could be fostered through collective inquiry and reflection. The study furthers research on knowledge building aligning with conceptual change augmented with student-directed assessment. Whereas many studies have demonstrated the role of metaconceptual awareness and epistemic beliefs, this is one of the few studies that illustrated how it might be possible to foster conceptual, metaconceptual and epistemic changes through collective reflection. Furthermore, the conceptual-change reflective assessment summaries provided a rich data source to examine students' alternative understanding of electrochemistry, as well as to track how students could move between individual and collective growth towards conceptual change. Instead of eradicating misconceptions, students' prior understandings could become objects of collective inquiry. Metacognition for conceptual change is not an individual accomplishment but one that can be examined and fostered in a community of knowledge builders. Turning over agency to students and asking them to reflect and to assess their own and collective understanding may help them develop conceptual and epistemic changes and provide insights into further research on collaborative conceptual change.

References

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

Burtis, P.J. (1996). Analytic Toolkit for Knowledge Forum. Ontario Institute for Studies in Education/U of Toronto.

Chan, C., Burtis, J., & Bereiter, C. (1997). Knowledge building as a mediator of conflict in conceptual change. *Cognition and Instruction, 15*, 1-40.

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

Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education, 25*, 671-688.

Hofer, B.K. and Pintrich, P.R. (Eds.) (2002), *Personal Epistemology: The Psychology of Beliefs about Knowledge and Knowing.* Mahwah, NJ: Lawrence Erlbaum Associates.

Lee, E.Y.C., Chan, C.K.K. and van Aalst, J. (2006). Students assessing their known collaborative knowledge building. *International Journal of Computer-Supported Collaborative Learning*, 1, 57-87

Miyake, N. (2008). Conceptual change through collaboration. In S. Vosniadou (Ed.). *International handbook of reesarch on conceptual change* (pp 453-478). New York: Routledge.

Sinatra, G.M. and Pintrich, P.R. (Eds.). (2003). *Intentional Conceptual Change.* Mahwah, NJ: LEA.

Scardamalia, M. and Bereiter, C. (1994). Computer support for knowledge-building communities. *Journal of Learning Sciences*, 3(3), 265-283.

Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 97-115). NY: Cambridge University Press.

Scott, P., Asoko, H. and Leach, J. (2007). Student conceptions and conceptual learning in science. In S.K. Abell and N.G. Lederman (Eds.) (pp. 31-56). *Handbook of research on science education.*

Stathopoulou, C. and Vosniadou, S. (2007). Exploring the relationship between physics-related epistemological beliefs and physics understanding. *Contemporary Educational Psychology*, **32**, 255-281.

van Aalst, J., & Chan, C. K. K. (2007). Student-directed assessment of knowledge building using electronic portfolios. *The Journal of the Learning Sciences, 16*, 175-220.

Vosniadou, S. (Ed.). (2008). *International handbook of research on conceptual change.* New York: Routledge.

Vosniadou, S. & V. Kollias (2003). Using collaborative, computer-supported model building to promote conceptual change in science. In E. De Corte, L. Verschaffel, N. Entwistle & J. Van Merrienboer (eds.), (pp. 181- 196), *Powerful learning environments: Unravelling basic components and dimensions.* Amsterdam: Pergamon.

White, B. & Frederiksen, J. R (1998). Inquiry, modeling and metacognition: Making science accessible to all students. *Cognition and Instruction, 16.* 3-118.

Zhang, J., Scardamalia, M., Lamon, M., Messina, R., & Reeve, R. (2007). Socio-cognitive dynamics of knowledge building in the work of 9- and 10-year olds. *Educational Technology Research and Development, 55*, 117-145.