Collaborative Scientific Conceptual Change in Simulation-Supported Learning Environment

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Abstract: The purpose of our study is to: 1) propose a new model of conceptual change called collaborative scientific conceptual change model; 2) examine student collaborative scientific conceptual change process while using computer simulations to understand aquarium ecosystem through three perspectives (i.e., cognitive, social, and epistemic) included in the new conceptual change model. We propose that collaborative scientific conceptual change occurs when learners co-construct new knowledge and make a shift from their previous ways of thinking towards the scientific ways of thinking that scientists use to explain phenomena. We report preliminary results of a classroom study exploring how students used the simulations to develop collaborative discourse and applied epistemic practices to achieve conceptual change. The results imply that this new theoretical framework is effective to study conceptual change and the simulation environment may mediate the development of successful collaborative interactions (including collaborative discourse and epistemic practices) that lead to conceptual change.

Introduction

One problem in science education is that students often do not possess an in-depth conceptual understanding of science and demonstrate an inability to analyze and apply scientific thinking processes (National Research Center, 1996). The field of research in conceptual change has proliferated studies to investigate the nature and process of conceptual change and to search for theoretical underpinnings and pedagogical strategies to foster student conceptual change and improve higher-level thinking and conceptual understanding. One of the common instructional strategies is to confront students with discrepant events to help students realize the cognitive conflicts, which is widely accepted to be essential to radical conceptual change (Posner, Strike, Hewson, & Gertzog, 1982). However other researchers propose that conceptual change is a gradual process and argue that adults, children and even trained scientists failed to make a change in their theories when they face conflicting evidence (Chinn & Brewer, 2002; Mason, 2003). Other facilitating factors may be required to develop deep conceptual understanding, such as peer interactions and sophisticated scientific epistemic practices. The purpose of the reported study is to: 1) propose a new model of conceptual change called collaborative scientific conceptual change model; 2) examine student collaborative scientific conceptual change process while using computer simulations to understand aquarium ecosystem through three perspectives (i.e., cognitive, social, and epistemic) included in the new conceptual change model.

Theoretical Framework

In our study, we employ a new theoretical framework to interpret the conceptual change process – the collaborative conceptual change model. Instead of focusing on the cognitive conflict, we use a new theoretical framework, the collaborative scientific conceptual change model, to explain conceptual change processes. This model stresses cognitive factors as well as the effect of social interactions and role of epistemic practices of science. We propose that collaborative scientific conceptual change occurs when learners co-construct new knowledge and make a shift from their previous ways of thinking towards the scientific ways of thinking that scientists use to explain phenomena. Collaborative discourse may help students discover knowledge discrepancies and insufficiency through knowledge sharing thus stimulating convergent conceptual change. In addition, the sociocultural views suggest that collaborative discourse may allow students to engage in scientific practices that encourage deep processing while engaging in observation, collaborative argumentation, and experimentation.

This framework echoes with Sinatra's urges to use multiple theoretical spotlights to understand student conceptual change process. Sinatra (2002) suggested the pursuit of both internal (cognitive and motivational) and external (social and contextual) aspects of conceptual change. Using the framework of collaborative scientific conceptual change, we integrate three major perspectives (i.e., cognitive, social, epistemic) to explore the conceptual change process with a particular stress on social and epistemic aspects. Conceptual change is not easy to achieve because students tend to use their intuition to explain science concepts, which leads to superficial understanding that may be resistant to change despite instruction (Chi, 2005). The distributed nature of cognition suggests that conceptual change requires communication among people (Pea, 1993). Peer discourse may create an awareness of the need for knowledge revision and encourage deep processing, thus is a powerful tool for conceptual change (Roschelle, 1992). In addition, the intersubjective meaning making in peer discourse helps create joint interpretations through phases of negotiation focused on shared information (Suthers, 2006). However, collaborative learning is not always productive as few students see science as a process of formulating researchable questions, conducting experiments to test ideas, and formulating evidence-based argumentation (Carey & Smith, 1993; Dillenbourg, 1999; Sandoval & Reiser, 2004). Students need more opportunities to develop sophisticated epistemic practices such as testing and modifying ideas through experimentation and evidence-based argumentation. Both diSessa (2006) and Linn (2006) question the coherence of the criteria students use for their epistemic practices and advocate epistemic practices entailing systematic observation, argumentation, and experimentation. In our framework, we argue that on one hand, collaborative discourse makes students' epistemic practices visible and available for comparison. On the other hand, the epistemic practices of science require that students use evidence to support their claims thus producing productive discourse. Such reciprocal relations between collaborative discourse and epistemic practices seem likely to foster collaborative scientific conceptual change.

We report here on a classroom study using the collaborative scientific conceptual change framework to investigate trajectories of conceptual change in a simulation-supported collaborative learning context. In our study, we use computer simulations as a media to provide opportunities for students to conduct science observation, collaborative argumentation, and experimentation. The computer simulations can mediate students' collaborative discourse and their epistemic practices. First of all, computer tools shape the way students interact with each other, such as how they propose an argumentation or solve a problem. Second, running computer simulations immediately reflect the results of students' epistemic practices of problem solving and such visual feedback help learners develop and adopt sophisticated epistemic practices such as designing experiment, collecting data, coordinating theory and evidence, and testing and modifying hypothesis.

Methods

We designed two computer simulations and conducted a classroom study address the following research questions: 1) What patterns of collaborative discourse occur during students' collaborative use of computer simulations? How do these patterns relate to students conceptual change process? 2) What patterns of epistemic practices occur during students' collaborative use of the computer simulations? How do these patterns relate to students conceptual change process? 3) What are the relationships between the patterns of students' collaborative discourse and epistemic practices?

Participants

The participants in this study were 145 middle school students from two public schools who volunteered to participate in this study. Seventy were seventh graders taught by Ms. W. Seventy five were eighth graders taught by Mr. K. Both teachers were experienced middle school science teachers and taught five classes. The study was conducted in both classrooms as part of students' science instruction. Twenty focal groups' collaborative activities were video and audio taped. In this paper, we report the preliminary results of four case studies. Group 1 and 2 were from Ms. W's classes and group 3 and 4 from Mr. K's classes.

The Domain of Study

The aquarium ecosystem, an example of a complex system, was the science domain for this study. It includes both macro and micro levels components. The macro level components include fish, food, plants, filters, air pump, light; micro level components include bacteria and other micro-organisms, the chemicals involved in the nitrification process (ammonia, nitrite, nitrate), oxygen, and carbon dioxide. It is difficult for students to develop a systematic understanding of such a complex system because the macro and micro level components are interrelated with each other to maintain a balance in the system. For instance, the fish produce waste composed of toxic chemical, ammonia. The gravel provides a place for the colonies of beneficial bacteria to survive and reproduce, ensuring that the aquarium remains healthy by converting the ammonia into less harmful chemicals, such as nitrite and nitrate. As a closed system, some designed components are needed to maintain the equilibrium in aquarium, such as the filter, heater, and light. Part of the filter is the biological filter, which is composed of bacteria that convert ammonia to less toxic chemicals. The primary source of ammonia is from the fish waste. Bacteria in the water first convert the ammonia into less toxic nitrite and finally non-toxic nitrate, which can be used by plants as fertilizers.

Computer Simulations

To facilitate students' understanding of the system, we programmed two simulation models using NetLogo (Wilensky & Reisman, 2006). Students could run and observe the simulations, generate and test hypotheses, and modify ideas based on observed results. The two simulations (the fish spawn model and the nitrification process model) present the system knowledge at different scales. The fish spawn model is a macro level simulation, simulating how fish spawn in a natural environment. We used pink and blue fish-shaped representations to embody the fish gender and yellow dots to represent the fish food. The purpose of this simulation model is to help students learn about the relationships among different aspects of an aquarium ecosystem, such as the amount of food, initial gender ratio, filtration, water quality, reproduction, and fish population. The nitrification process model presents a micro level simulation of how chemicals reach a balance to maintain a healthy aquarium. We used red, white, and yellow dots to represent the chemicals (ammonia, nitrite, nitrate respectively) in the water and blue and purple patches as two different types of bacteria. The symbolic representations in both simulation models initiated students' collaborative discussion by providing shared references that was initially puzzling. Both simulations allow students to adjust the values of variables and observe the results. The manipulable representations guided students to useful learning interactions as they designed experiments to test ideas.

Procedures

The goal of the designed study was to support middle school science curriculum instruction and to promote deep scientific understanding of the aquarium ecosystem through the use of computer simulations. We collaborated with two public middle school science teachers to develop specific curriculum units. Prior to enacting instruction, the teachers participated in a two-week professional development on the content and tools.

In both classroom settings, teachers instructed to facilitate students to use the computer simulations to learn about the aquarium ecosystem. Before the classroom study, both classrooms had a physical aquarium model installed and maintained for about two months. All learning activities were completed in small groups, the size of which varied from 2 to 6 students.

The two teachers used different teaching approaches due to existing differences in curriculum focus of the school districts and their previous teaching experiences. Ms. W designed worksheets with open-ended questions for groups while they explored the computer tools, and expected homogeneous progress for the whole class thus provided direct instructions to frame group activities. Mr. K was more inquiry-oriented and tended to scaffold groups' progress with explanatory questions and prompted students to explain their observations. In addition, Mr. K encouraged heterogeneous progress among the groups and facilitated student learning by using open-ended questioning. Both teachers used the unit for approximately two school weeks and succeeded in getting students engaged in most of the learning events. In both classrooms, before using the computer simulations, both teachers started with a class discussion on the aquarium ecosystem to activate students' prior knowledge and make connections to the physical fish tank in the classrooms. Then the teachers introduced a hypermedia we designed to introduce some basic understanding of the aquarium ecosystem with a focus on the functions of the components in the system. The students explored the hypermedia software in groups followed by other activities such as class discussions and construction of concept maps that connected parts of the system to their function. Then the teachers conducted a demo class to introduce students to how to use the NetLogo simulations by demonstrating one sample model unrelated to the aquarium system. Then the students went to groups to collaboratively explored the fish spawn simulation and the nitrification process simulation. Students took an individual pre and posttest. Twenty focal groups' collaborative activities were video and audio taped. This paper reports the results of a case study of four focal groups' exploration of the computer simulations (a four-day intervention of pure group exploration and discussion).

Data Coding and Analysis

The video and audiotapes of the groups' discourse throughout their exploration of the computer simulations were transcribed verbatim. The discourse was segmented by turns. Three sets of codes were developed and applied to investigate students' collaborative learning through different lenses. Both the collaborative discourse coding and the epistemic practice coding were conducted at the level of conversational turns. A conceptual change code was given when a new level of understanding occurred. Both the transcripts and the codes were imported into the Multiple Episode Protocol Analysis (MEPA) software (Erkens, 2005), for frequency calculation, pattern identifications by inductive possibility calculation, and sequential data analysis. Besides, qualitative analyses will be applied to investigate how students scaffold each other and how computer tools are used as part of discourse.

The *collaborative discourse* coding scheme was designed to uncover cognitive and metacognitive processes underlying the groups' discourse as well as the facilitators' roles (see definitions in Table 1). The second coding scheme was developed to capture the characteristics of *epistemic practices* (i.e., the practices embodying ways of scientific thinking, see in Duschl & Osborne, 2002) to build understanding (defined in Table 2). The third coding scheme identified hierarchical levels of *conceptual understanding*. At the lowest level, the recognizing level, students engage in a low level of cognitive processing, such as proposing ungrounded hypotheses of what symbols (e.g., the dots and patches) represent in the simulation models or identifying the patterns of observed phenomena. At the explanatory level, students either build upon their initial hypotheses with elaborated explanations or propose a grounded hypothesis that includes causal relationships between representations. At the critiquing level, students criticize the stated understanding by checking knowledge validity and identifying the gap between the evidence and previous hypotheses. Finally, the examined level represents the greatest depth of conceptual understanding. At this level, students have checked the validity of their understanding, which they believe is supported by the collected evidence.

Table 1. Definitions for collaborative coding categories.

Categories	Definitions
Cognitive Process	
Fact Question	Questions asked with a purpose to obtain factual information
Explanation Question	Questions asked with a purpose to obtain cause-effect information
Confirm Question	Questions asked to make sure one gets the shared information
Directing Statement	Demanding statement for an ongoing activities
Agree	Explicit express of acceptance of other's ideas
Disagree	Expressing express of rejection of other's ideas
Share Knowledge	Share information with other members in the group
Describe Observation	Descriptions on what is observed in the simulations
Retrieve Prior Knowledge	Making connections to one's previously perceived knowledge or experiences
Generate Theory	Statement of a hypothetical proposal
Paraphrase	Rewording other's statements
Warranting Claim	Statements to provide ground for an idea
Identify Cognitive Conflict	Realizing the discrepancies in one's or the group's reasoning
Off-topic Talking	Statement unrelated to the learning target
Metacognitive Process	
Plan	Defining the learning goals
Monitor	Reflecting on the learning process to keep track of the conceptual understanding
Review	Looking back on the strategies (e.g., designing experiments, running simulations) that lead to knowledge construction
Evaluate	Judging the effectiveness of learning strategies
Facilitators' Roles	
Educational Statement	Statements related to the learning content and strategies
Performance Statement	Statements related to class management and students' performance
Open Question	Questions seeking an elaborated answer or explanation
Closed Questions	Questions seeking a short and factual answer

Table 2. Definitions for epistemic practice coding categories.

Categories	Definitions
Basic Knowledge Construction	Superficial meaning making practice without reasoning or supporting evidences
Observe	Practices of observing phenomena on the computer screen
Predict	Practices aiming to propose predicting result of a simulation
Design Experiment	Designing a simulating experiment to test hypotheses
Check Knowledge Validity	Examine the consistency or accountability of constructed knowledge
Coordinate Theory-Evidence	Practices entailing using theories to explain data and using data to evaluate theories
Modify Knowledge	Making a change in previously constructed knowledge
Exchange Knowledge	Explicit articulation of one's knowledge
Scaffold	Applying purposeful strategies to support other's understanding
Give Feedback	Providing evaluative responses to other's statements or actions

Quantitative Results

Our previous analysis of pre and posttests data showed that students from both classroom settings gained similar learning outcomes and indicated successful conceptual change by shifting a superficial understanding of the structural knowledge about components to a deeper understanding of the functional knowledge of the system (see details in Author, 2007). This paper reports the analyses of results of four focal groups' video data focusing on investigating the trajectories of students' collaborative scientific conceptual change from the cognitive, social, and epistemic aspects. In this section, we first report the quantitative findings derived from the calculated descriptive frequencies of the categories in the three types of coding (see Table 3).

Second, we report the patterns of collaborative discourses, epistemic practices, and trajectories of conceptual understanding (produced by MEPA software through calculation of inductive possibilities) as well as the relations among the patterns with the support of qualitative evidence.

Table 3. Percentages of total statements in coding categories and total turns.

		Ms. W		Mr. K	
		Group 1	Group 2	Group 3	Group 4
1. Collaborative Discourse %	- Describe Observation	23.34	19.18	5.12	17.08
	- Warrant Claims	7.07	5.82	10.24	5.17
	- Generate Theory	5.35	5.39	6.20	6.07
	- Identify Cognitive Conflict	1.50	0.86	1.89	0.67
	- Other Categories	40.25	43.53	30.73	32.58
	Total Cognitive Process %	*77.51*	*74.78*	*54.18*	*61.57*
	- Plan	5.57	5.60	2.96	5.84
	- Monitor	1.93	3.88	5.66	2.47
	- Review	4.07	4.09	7.55	5.62
	- Evaluate	0.21	0.65	0.81	0.90
	Total Metacognitive Process %	*11.78*	*14.22*	*16.98*	*14.83*
	- Open Questions	2.36	1.94	12.67	3.82
	- Closed Questions	5.14	3.02	3.23	6.74
	- Educational Statement	2.14	3.02	10.51	10.79
	- Performance Statement	1.07	3.02	2.43	2.25
	Total Teacher Facilitation %	*10.71*	*11.00*	*28.84*	*23.60*
2. Epistemic Practice %	Design Experiment	19.70	9.05	2.16	9.21
	Observe	28.91	24.78	5.39	22.25
	Predict	5.35	1.72	6.20	2.02
	Coordinate Theory and Evidence	4.93	6.47	10.24	6.29
	Check Validity	1.07	1.51	4.85	1.57
	Scaffold	9.42	8.19	19.14	19.33
	Modify Knowledge	0.43	1.08	7.01	0.67
	Other Categories	30.19	47.20	45.01	38.66
3. Conceptual Understanding	Level 1: Recognizing Level	25	12	23	24
	Level 2: Explanatory Level	28	25	33	15
	Level 3: Critiquing Level	8	3	10	2
	Level 4: Examined Level	4	4	8	5
	Total Turns with Conceptual Understanding Codes	*65*	*44*	*74*	*46*
Total Turns		*463*	*462*	*370*	*443*

Results showed that most of students' discourse stayed at the first two levels of understanding focused on identifying representations in the simulation models and developing explanations of the representations. To some extent, the groups' discourse did show that sometimes students questioned their previous understanding (Level 3) and reached the level of evidence-based understanding (Level 4). Interestingly, there was obvious percentage difference at critiquing level across groups. Particularly, group 1 and 3 did more critiquing in their understanding process than group 2 and 4.

The distribution of collaborative discourse percentages showed that all the four groups were very engaged in the cognitive process, based on indicators such as different types of questions, describing observations, retrieving prior knowledge, generating theories, proposing warrant claims, sharing knowledge, paraphrasing, and identifying cognitive conflict. However the results exhibited divergence across groups. Both groups from Ms. W's classes spent a good amount of time describing their observations (23.34% for group 1 and 19.18% for group 2). However, group 3 from Mr. K's classes did not show this tendency (5.12%). In addition, group 3 also provided the highest percentage of warranting claims (10.24%) among all the four groups even though all the four groups provided similar percentages of discourse to propose hypotheses. It is interesting to notice that the there a very low percentage of the discourse was used to identify cognitive conflict, which has been regarded as the most important factor in radical conceptual change theories. The data also showed that all groups focused their metacognitive process on planning learning strategies and reviewing what activities they conducted and that they rarely evaluated their learning strategies.

Furthermore, we found there were differences in teachers' approaches to facilitating students' simulation-based learning activities. Mr. K provided more facilitation for groups' collaborative activities than

Ms. W did. Mr. K tended to ask more open questions than Ms. W to scaffold students' knowledge co-construction. The data also demonstrated that Mr. K adopted different strategies to different groups. For group 3, he asked more open questions than closed questions but vice versa when he facilitated group 4. In contrast, Ms. W seemed to use the same strategy in questioning and tended to ask more closed questions than open questions.

The frequency distribution of the epistemic practice coding showed that all groups were engaged in designing experiments and observing the simulations but they did not often modify previously constructed knowledge except for group 3. Instead, group 3's discourse demonstrated fairly large percentages of talk devoted to sophisticated epistemic practices such as predictions, coordinating evidence and theory, and modifying knowledge, In addition, the transcripts showed different amount of scaffolding practices across the two classroom settings. This might be caused by the different amount of facilitation across the teachers.

Qualitative Results

Although the quantitative results provide a description at a gross level of collaboration, they say little about the patterns of collaboration and the relationships among collaborative discourse, epistemic practices, and conceptual change. We found several interesting patterns in students' collaborative discourse, epistemic practices, and conceptual understanding process resulting from the sequential analysis using MEPA software. Two major findings were derived from a synthesis of the sequential patterns and the qualitative evidences: first, the process of students' conceptual understanding is nonlinear; second, the sequential patterns in students' collaborative discourse and their epistemic practices were associated with their conceptual understanding.

In general, when students explored the computer simulations, their understanding often started at the recognizing level, and then moved to the explanatory level (shown in Figure 1). Sometimes, the students went through the critiquing phase and went back to the explanatory phase and finally reached the examined level. However it is interesting to notice that the students' conceptual understanding frequently vacillated among different levels. That is their conceptual understanding was not always progressing to higher levels and it very often regressed to lower levels. For example, group 1 once was trying to figure out what the blue patches were in the nitrification process simulation when they observed that "the red dots disappear once they get into the blues". Then they came up with an explanation that "that's the bacteria that influences the ammonia. Cause every time the red dots go into the blue squares, the ammonia disappear. And then, the purple squares." Then they restarted the simulation again to test their ideas. Finally they reached a conclusion that the blue patch represented bacteria in the model. However, in their later discussion about another topic of "what will happen if the number of plants increase", their understanding about the blue patches went back to the recognizing level and restarted a reasoning cycle. The dashed link between the critiquing level and the examined level (see in Figure 1) indicates that sometimes students' inquiry-based reasoning stopped at critiquing and failed to reach the examined level.

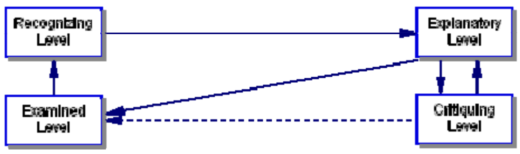

Figure 1. Conceptual Understanding Process.

Due to the numerous categories for collaborative discourse and epistemic practice it was difficult to identify patterns of multiple codes. Instead, we ran two-codes sequential analyses, which calculated the inductive probabilities of two successive codes in the transcripts. The results identified many patterns associated with students' conceptual understanding. For example, for the collaborative discourse process, students' observation descriptions were frequently followed by warranting claims that were often followed by prior knowledge retrieval; students' identification of cognitive conflict often followed warranting claims. For the epistemic practice process, students tended to check knowledge validity after observing; they began coordinating theory and evidence after either building basic knowledge construction or knowledge exchange; they engaged in predictions often followed by experiment design. The types of collaborative discourse functions and epistemic practices involved in the above patterns are widely accepted as sophisticated ways that scientists tend to use in their scientific reasoning.

In-depth qualitative analysis found that, in the simulation-supported learning context, there were mutual relations between the patterns of collaborative discourse and epistemic practices, which are important for students' conceptual co-construction. Specifically, the simulation provided opportunities for students to engage in epistemic practices (e.g., generating hypothesis, designing experiments to collect data during observation, coordinating theory and evidence, checking validity, and modifying knowledge). The computer simulations also provided opportunities for students to engage collaborative discourse that included high-level cognitive and metacognitive processing (e.g., presenting warranting claims, monitoring learning process, identifying cognitive conflict). The combination of various collaborative discourse functions (e.g., questioning, sharing knowledge, retrieving prior knowledge) stimulated students to further engage in epistemic practices to develop and test ideas. The following excerpt showed how the students in Group 2 figured out what the purple and blue patches represented in the model through patterns of collaborative discourse and epistemic practices:

Chris: get more plants. let's do 10 and 10 and see what happens … okay now is just all ammonia
Gabby: see at least is going up, 129
Chris: now there is low 50, now there is little nitrite
……
Chris: ammonia turns into nitrate and nitrate turns into nitrite, and plants eat the nitrite
Gabby: but it's all ammonia there is like no nitrate. So if ammonia turns into nitrate, and then nitrate turns into nitrite. Then would it most of the ammonia have be gone if the plants eat it?
Chris: no cause something else eats the ammonia, and the plants eat
Gabby: doesn't the bacteria or something…bacteria creates nitrite or nitrate right?
Chris: right. Wait let's see now is going up like crazy, nitrate is too high
Chris: what's the blue?
Gabby: That’s the …
……
Gabby: yea, what's the purple and the blue? What's that supposed to be?
Chris: maybe that's..that's nitrite or something …
Gabby: see what happens if it like hum..there is a lot of plants then if the nitrite goes down.
Chris: is the number of ammonia going down, now is going up. It goes down like every couple things but mostly it's going up. And the nitrite is going up too
……
Chris: wait the purple is the bacteria and it's eating all of the stuff.
Gabby: and then the blue is the bacteria too, but the blue is the bacteria from the…
……
Chris: Let’s try again.

The observation of the simulation dynamics stimulated the students’ conversation as they described what they saw in the model. When Chris started making meaning by retrieving knowledge achieved from previous hypermedia exploration saying that “ammonia turns into nitrate and nitrate turns into nitrite, and plants eat the nitrite,” Gabby identified the conflict that there was no nitrate appearing in the model. This conflict prompted the group to continue their reasoning and Gabby retrieved that “bacteria creates nitrite or nitrate”. Then the appearance of the blue and purple patches on the screen triggered the question “what's the purple and the blue?” which led to the experiment design to see what if there are a lot of plants then if the nitrite goes down. During the following observation, Chris realized that “the purple is the bacteria” because “it's eating all of the stuff”. Inspired by Chris, Gabby figured out that “the blue is the bacteria too”. Then they started another experiment to testify their theories. This example showed that the collaborative discourse and epistemic practices were mutually supporting each other to a more profound depth.

Discussion

This study applied a new framework to investigate students’ collaborative scientific conceptual change process in a simulation-supported learning environment through the lenses of cognitive, social and epistemic practices. We draw two major conclusions from these preliminary results. First, the descriptive frequencies showed that students were highly motivated and engaged in their collaborative learning activities and successfully achieved high-level conceptual understanding in the simulation-based learning context, even though differences in learning processes existed due to differences in individuals and facilitation provided. The results of the sequential analyses demonstrated that students went through a gradual and nonlinear process to achieve conceptual change. The groups went through multiple cycles of testing and modifying hypothetical theories via experimentation and evidence-based reasoning to reach the highest level of conceptual understanding – the examined level. Consistent with what Chinn (2001) found in their study, we also found that students sometimes identified but ignored the cognitive conflicts. This might result from the fact that they did not possess the sophisticated epistemic practices needed to solve the conflicts. Our second major conclusion was that computer simulations provided opportunities for students to produce productive collaborative discourse that engaged high-level cognitive and metacognitive process, and they mediated students’ epistemic practices. The sequential analyses identified significant collaborative discourse patterns and epistemic practice patterns that were mutually related and contributed to students' conceptual change. Consistent with the findings of other research on conceptual change (e.g., Linn, 2006; diSessa, 2006), the results indicate that there are other factors (i.e., the convergent knowledge co-construction and sophisticated epistemic practices) besides cognitive conflict that are needed to foster scientific conceptual change, a change not only in knowledge content but also in scientific ways of thinking and knowledge construction. As mentioned before, this may explain why students sometimes failed to solve cognitive conflicts. In summary, the results of the study imply that the collaborative scientific conceptual change model is an effective framework to study conceptual change and the simulation environment may mediate the development of successful collaborative interactions (including collaborative discourse and epistemic practices) that lead to collaborative scientific conceptual change.

References

Carey, S. & Smith, C. (1993). On understanding the nature of scientific knowledge. *Educational Psychologist, 28*, 235-251.

Chi, M. T. H. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *Journal of the Learning Sciences, 14,* 161-199.

Chinn, C. A., & Brewer, W. F. (2001). Models of data: A theory of how people evaluate data. *Cognition and Instruction, 19*, 323-393.

Dillenbourg, P. (1999). What do you mean by collaborative learning? In P. Dillenbourg (Ed). *Collaborative-learning: Cognitive and Computational Approaches* (pp. 1-19). Oxford: Elsevier.

Duschl, R., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education, 38*, 39-72.

diSessa, A. (2006). A history of conceptual change research: Threads and fault lines. In R. K. Sawyer (Ed), *The Cambridge handbook of the learning Science (*pp. 265-281), Cambridge, NY.

Erkens, G. (2005). MEPA, Multiple Episode Protocol Analysis (Version 4.10). [Computer software]. Retrieved October 24, 2005, from http://edugate.fss.uu.nl/mepa/

Linn, M. (2006). The knowledge integration perspective on learning and instruction. In R. K. Sawyer (Ed), *The Cambridge handbook of the learning Science* (pp. 243-264), Cambridge, NY.

Mason, L. (2003). Personal epistemologies and intentional conceptual change. In G. M. Sinatra, & P. R. Pintrich (Eds.), *Intentional Conceptual Change.* (pp. 199-237) Mahwah, NJ: Lawrence Erlbaum.

National Research Center. (1996). Third International Mathematics and Science Study. Lansing, MI: U.S. National Research Center.

Pea, R. D. (1993). Learning scientific concepts through material and social activities: Conversational analysis meets conceptual change. Educational Psychology, 28, 265-277.

Posner, G., Strike, K., Hewson, P., & Gertzog, W. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*, 211-227.

Roschelle, J. (1992). Learning by collaborating: Convergent conceptual change. *Journal of the Learning Sciences, 2*, 235-276.

Sandoval, W. A. & Reiser, B. J. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. Science Education, 88, 345-372.

Sinatra, G. M. (2002). Motivational, social, and contextual aspects of conceptual change: A commentary. In M. Limon and L. Mason (Eds.), *Reconsidering conceptual change: Issues in theory and practice* (pp. 187-197). Dordrecht, The Netherlands: Kluwer.

Suthers, D. D. (2006). Technology affordance for intersubjective meaning making: A research agenda for CSCL. International Journal of Computer-Supported Collaborative Learning, 1, 317-335.

Wilensky, U., & Reisement, K. (2006). Thinking like a wolf, a sheep, or a firefly: Learning biology through constructing and testing computational theories – An embodied modeling approach. *Cognition and Instruction, 24*, 171-209.