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Abstract: One problem in science education is that students neither construct in-depth conceptual understanding nor are they able to apply scientific thinking processes. A myriad of studies on conceptual change have investigated the nature and process of conceptual change, pedagogical strategies to foster conceptual change and improve higher-level thinking. We propose a new framework - the collaborative scientific conceptual change model – to stresses the importance of high quality collaborative discourse and scientific epistemic practices in the process of conceptual change. To investigate how group interactions influence individual students’ learning gains, multilevel analysis was used to analyze the hierarchically nested data and qualitative analyses were presented to compare high and low-achievement groups’ discourse and their application of epistemic practices. The results found that predicting and coordinating theory and evidence were key practices that predicted students’ individual posttest performance and the group interactions were related to the group understanding.

Introduction
One problem in science education is that students neither construct in-depth conceptual understanding nor are they able to analyze and apply scientific thinking processes (National Research Council, 1996). A myriad of studies on conceptual change have investigated the nature and process of conceptual change, pedagogical strategies to foster conceptual change and improve higher-level thinking. One common instructional strategy is to confront students with discrepant events, causing cognitive conflicts, which is widely accepted to be essential for 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 fail to change their theories when faced with conflicting evidence (Chinn & Brewer, 2001). Accordingly, other factors must be considered, such as peer interactions and engagement in the epistemic practices of science. We propose a new theoretical framework - the collaborative scientific conceptual change (CSCC) model - to explain conceptual change processes.

Collaborative Scientific Conceptual Change Model
Conceptual change is not easy to achieve because students tend to use their intuition to explain science concepts, which can lead to superficial understanding that may be resistant to instruction (Chi, 2005). Posner et al (1982) believe that conceptual change is a rational process “by which people's central, organizing concepts change from one set of concepts to another set, incompatible with the first” (p. 211). In addition to the cognitive aspect, social constructivists insist that knowledge develops through social negotiation and through the judgment of the application of the ideas of others. The distributed nature of cognition suggests that conceptual change requires communication among people (Pea, 1993). The features of collaborative learning may help students converge differentiated meanings as they construct meanings for scientific concepts. Peer discourse may create an awareness of the need for knowledge revision and encourage the deep processing needed for conceptual change (Roschelle, 1992), and may help create joint interpretations through phases of negotiation focused on shared information (Suthers, 2006).

However, collaborative learning is not always productive as students may not see science as a process of formulating researchable questions, conducting experiments to test ideas, and formulating evidence-based argumentation (Carey & Smith, 1993; Sandoval & Reiser, 2004). Southerland, Sinatra, and Matthews (2001) believe that knowledge is “understood to be based on an assessment of evidence (in the case of scientific knowledge, the evidence would be judged using scientific epistemic criteria)” (pp. 337-338). Students need more opportunities to develop sophisticated epistemic practices such as testing and modifying ideas through experimentation and evidence-based argumentation. Computer tools may support coordinating social interactions and provide opportunities for learners to test their ideas, and coordinate theory and evidence in coherent ways.

Taken collectively, we suggest an integrated model – the collaborative scientific conceptual change model (CSCC), which involves three major elements within conceptual change: the cognitive conflict, the collaborative discourse, and the epistemic practices of science. 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 are inclined to use to explain phenomena. This framework stresses two factors in student conceptual change: the effect of social interactions and the shift towards
epistemic practices of science. The reciprocally facilitating relations between collaborative discourse and epistemic practices combine the two perspectives together. On one hand, in the computer-supported collaborative learning context, 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. In this paper, we report 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 the study, computer simulations were used as a media to provide opportunities for students to conduct science observation, collaborative argumentation, and experimentation.

Methods
The participants were 145 middle school students from two public schools who participated in this study as part of their science instruction. Two different teachers, Teacher A and Teacher B, were experienced science teachers. The teachers randomly assigned students to groups. Twenty focal groups’ interactions were videotaped.

To facilitate students’ understanding of the aquarium ecosystem, we developed two NetLogo simulation models (Wilensky & Reisman, 2006). The two simulations (the fishspawn model and the nitrification process model) present system characteristics at different scales. The fishspawn model is a macro level model, simulating how fish reproduce in a natural environment. The nitrification process model is a micro level simulation of how chemicals reach a balance in an aquarium. This simulation allows students to examine how bacterial-chemical interactions affect the water quality represented in the macro level simulation.

To assess learning, students completed pre- and posttests, which asked students to draw all the parts of an aquarium and label the diagram, followed by questions and problems to elicit knowledge about the aquarium ecosystem. For the 20 focal groups, videotapes of students working with the computer simulations were transcribed.

Pre- and post-tests were scored using a structure-behavior-function (SBF) coding scheme as a measure of conceptual understanding (Hmelo-Silver, Marathe, & Liu, 2007). SBF theory describes a complex system’s multiple interrelated levels, and its dynamic nature (Goel et al., 1996). Prior research has demonstrated that this is a sensitive measure of student complex system understanding (Hmelo-Silver et al. 2007; Liu et al., 2006). Parts of the system, such as fish or filter, were coded as structures. Mechanisms were coded as behaviors (e.g., the behavior of plants is to absorb carbon dioxide and produce oxygen through photosynthesis). Functions were coded for roles of different parts (e.g., function of filter is to clean water).

Two coding schemes (see details in Liu, 2008) were applied to the transcribed discourse at the level of conversational turns. The collaborative discourse codes were designed to uncover cognitive and metacognitive processes underlying the groups’ discourse as well as the facilitators’ roles. The epistemic practices codes examined how students engaged in the practices embodying scientific ways of thinking and how learners engage in knowledge construction (Duschl & Osborne, 2002) to build their understanding. An independent rater coded 20% of the data and the overall agreement was greater than 90%.

Results
Multilevel Analysis
To investigate how group interactions and teachers’ facilitation influence individual students’ learning gains, multilevel analysis (MLA) is used to analyze the hierarchically nested data (Snijders & Bosker, 1999). In this research, there are three levels of hierarchically nested data: individual student (Level 1), group interaction (Level 2), and teachers’ facilitation (Level 3). The MLA analysis focused on identifying the variables in collaborative discourse and epistemic practices that could predict individual student’s posttest performance as a function of group-level interaction and teacher-level characteristics. The multilevel model was constructed using the group-level interaction categories and teachers’ facilitating categories as predictors of the dependent variable – TotalBF scores in the posttest. We use the total behavior and function scores as the dependent variable as this accounts for variability in deep understanding (Hmelo-Silver et al, 2007). The significant coefficient for the fixed variables demonstrates which characteristics of collaborative discourse and/or epistemic practices at the group level predict individual students’ learning outcomes in the posttest.

The goal of the MLA was to explore how group-level variables affected students’ learning. For the measures of collaborative discourse and teacher’s facilitation, only Warranted claims significantly predicted learning outcomes ($\beta$=95.82, $t(58)=2.16$, p=.03). This indicates that the more warranted claims produced in the group discourse, were associated with higher learning outcomes.

Of the epistemic practices, three codes were significant predictors for TotalBF: Coordinate Theory-Evidence ($\beta$=104.19, $t(72)=2.74$, p=.01), Modify Knowledge ($\beta$=−144.16, $t(72)=−2.11$, p=.04), and Predict ($\beta$=54.80, $t(72)=2.18$, p=.03). This suggests that engaging in two of these three sophisticated epistemic
practices within a group was associated with enhanced learning outcomes. We are not sure how to interpret the negative effect of modifying knowledge, however in inspecting the frequencies, we note that this is a very low frequency event and this may be a result of a restricted range so we would be cautious about any generalizations.

**Qualitative Analysis**
The qualitative analysis takes a close look at the conversational discourse within groups of students to provide further evidence for the inferences drawn from previous quantitative analysis and to identify the patterns occurred in group interactions that may have effect on the quality of collaborative activities. Four groups (including two highest-achievement and two lowest-achievement) were selected based on the group mean score of TotalBF scores and their final understanding level of the Nitrogen Cycle, which is essential for understanding the whole system.

**Differences in Discourse Patterns**
Compared to the two lowest-achievement groups, both highest-achievement groups made more efforts to ask explanation questions and generate warranted claims. The lowest-achievement groups asked more fact questions. Different types of questioning provide different opportunities for students to learn. Explanation questions require peer students to justify their responses, thus engage the group in the scientific practices of explanation and argumentation and provided an invitation for the group to generate warranted claims and check the accountability of proposed ideas (Duschl, Schweingruber, & Shouse, 2007). The following excerpts from one high-achievement group illustrate how an explanation question drove warranted claims and affected the tool-based activities:

139. Brad: Look at this, why is there so many small fish?
140. Ada: Increasing the water quality increases spawning. So let's leave everything alone.
141. Ada: So you guys want to try what the higher one (water quality) does. Okay, ready?
142. Ada: Look at the spawn, is like 1460 right now.

In the dialogue above, based on what he saw in the Fish Spawn simulation model, Brad asked an explanation question (Turn 139), “why is there so many small fish?” This question drove Ada’s warranted claim (Turn 140), “Increasing the water quality increases spawning.” And Ada continued to run an experiment in the model to test his justification. This example illustrated how simulation models mediated students’ high-level thinking by stimulating explanation questions and affording opportunities to test one’s warranted claims.

In contrast to explanation questions, the answers to fact questions are straightforward and largely oriented towards retrieving declarative knowledge and engaged less cognitive activities. That is, fact questions may only stimulate students to search information in their existing knowledge and they may fail to make causal connections. In simulation-based learning, students often come up with a lot of fact questions, such as “what is the yellow?”, “what is the blue?” “What just happened?” These questions do stimulate students to describe their observation or even come up with a theory. However, the fact questions failed to help students develop causal relations between what they observed and the generated theory.

**Differences in Epistemic Practices**
The highest-achievement groups engaged in more practices like predicting, designing experiment, and coordinating theory-evidence during the collaborative activities. These are sophisticated epistemic practices that scientists use to conduct scientific exploration. To illustrate, an example from a high-achievement group discussion presented how this group of students used the simulation tools to explore science:

130. Ada: The water quality do nothing to the fish ...
131. Brad: I think that it will go up in like a second...
132. Ada: If you increase the number of pspawn, the water quality goes down. It’s negative now.
133. Ada: The water quality decreases because of the population.
134. Brad: Try it.
135. Ada: Look at this, look at this. It goes down to zero, right?
136. Ada: Negative 400.
137. Brad: The water quality decreases.
138. Siddarth: Yes, it did make sense. If you increase the filter flow the water gets clean, and then it kills all the things that kill the fishes.
At the beginning, the students presented alternative hypotheses on “water quality”. Ada at first predicted that water quality had nothing to do with fish (Turn 130). Brad predicted the water quality should go up (Turn 131), and Ada came up with a hypothesis to predict the relation between water quality and population (Turn 132). Then Brad suggested to do an experiment saying “Try it” (Turn 134). Through the observation, Siddarth concluded that increasing filter flow made the water clean and it killed all the organisms in the tank (Turn 138). Judging the content, the students presented a lot of problematic propositions. However, they were operating in the way that scientists normally do. First propose problematic hypotheses, then conduct an experiment to test them, and finally draw a conclusion that might still be problematic. An important finding from recent work is that students with more sophisticated epistemologies seem to take better advantage of inquiry-based learning opportunities (Windschitl & Andre, 1998). As theory theorists assume that even young children have their own theories to explain the world, it is important to acknowledge the capability of young students to learn science. Therefore, although the reasoning was not perfect and lacked coherence here, the group in the example did exhibit the tendency of using scientific way of thinking as well as sharing distributed cognition to co-construct conceptual understanding of the materials presented in the simulation model.

By contrast, the low-achievement groups tended to be more engaged in simple knowledge exchange without questioning and reasoning. Despite the importance of sharing knowledge among peers, to develop scientific understanding of the world, it is extremely important to provide student sufficient opportunities and experiences to develop their theories to explain the scientific phenomena. The following excerpts from one low-achievement group illustrate one typical example:

138. Robby: What did you put so far?
139. Jean: The fish urine drinks ammonia, the ammonia urine.
140. Robby: Wait, the fish water bring ammonia
141. Jean: No, the fish urine.
142. Robby: Yea, the fish urine I meant. Yeah
......
214. Jean: How all the acids and the fish react in the tank
215. Robby: I just put how the acids and the fish react.

It is easy to tell that the goal of Robby and Jean was to give a reasonable answer to the question. They were sharing answers without reasoning with each other. Instead, they were just mechanically copying each other’s ideas. This further corroborates that the practice of knowledge exchange is not sufficient at all to foster collaborative scientific conceptual. It is essential to involve other epistemic practices such as hypothesis testing, debate and argumentation, to occur in situated and collaborative contexts.

**Discussion**

The MLA analyses found that predicting and coordinating theory and evidence were key practices that predicted students’ individual posttest performance. The qualitative analyses compared the high and low-achievement groups and found that the features of group discourse and the epistemic practices were related to the group understanding. These results are consistent with the CSCC framework, which stresses the importance of high quality collaborative discourse and scientific epistemic practices. Scientific knowledge is comprised of theory and empirical evidence. It is crucial to interrelate these two pieces together to understand what science is and how it works (Kuhn & Pearsall, 2000). Coordinating theory and evidences produces explanations to integrate hypothesized theories and collected evidences from the simulating activities. The results of this study implicate that students need opportunities to experience the mechanisms of collaborative scientific conceptual change and need to use the intentional and deliberate mechanisms that scientists use to restructure knowledge in a social process. These intentional mechanisms often include cycles of hypothesizing, testing hypotheses, generating theories, negotiating, and revising theories. Further research is needed to refine the theoretical framework by addressing questions such as how students’ collaborative discourse and/or epistemic practice patterns evolve during the conceptual change process.

**References**


