Conceptual Change through Socially Constructive Interaction in the Classroom

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Abstract

While collaborative learning is common in schools, most research has focused on small group collaborative processes, in one shot practice. In order to investigate the nature and the mechanism of collaborative learning in a larger group, this paper presents analysis of a classroom discussion in which 21 third-graders (8- to 9-year-old students) collaboratively discussed predictions about the results of a series of experiments as a whole class over 12 course hours and became able to grasp a rudimentary scientific concept of atomic theory.

We analyzed students' levels of achievement, conversation patterns, selection sequences of predictions of the experimental results, and the contents of their utterances of two students who were most active. The results revealed that all the children succeeded in expressing their grasp of rudimentary atomic theory, yet their routes to this achievement were individualistic and diverse. A preliminary qualitative analysis of two children's utterances shows that while their models were similar during the first half of the course, their differences became more explicit toward the end, which resulted in intense discussion between the two. The diversity observed in the entire course of this class and these two children's explicit, focused dialogue could have contributed to the successful conceptual change for all class members.

Keywords: Collaborative conceptual change, HEI class, Socially constructive interaction,

Introduction

While the amount of research on collaborative learning has increased sharply in the last 10 to 15 years, many studies deal with small groups of learners in mostly one-time practice. Studies of entire-class discussions, which are the norm in regular schools, are still few.

In regular elementary to middle school classes in Japan, it is quite common for 10 to 20 students to discuss their ideas about textbook descriptions and experiment demonstrations, under the teacher's guidance. In science classes, this is a common practice aimed at helping the students change their concepts from rules of thumb to more scientifically rigorous ones. Understanding what actually happens in these practices should be beneficial for developing practically feasible collaborative classrooms.

In the similar vein, in STEM education engaging the learners in demonstrations and experiments has been considered effective. In real classrooms, these activities often take place in a series of course hours rather than in one time practice. Understanding how these cumulative activities may affect children's conceptual change would also be informative regarding the quality of such classes.

In order to address these needs, this paper presents analysis of the learning processes observed in a well-designed STEM class. In the class, 21 third-graders collaboratively discussed predictions of the results of a series of experiments and were able to grasp a rudimentary scientific concept of atomic theory. The children were encouraged to discuss alternative predictions of carefully ordered experiments as a whole class in order to realize that water cannot enter "where there is air and vice versa" with justifications ranging from heavily relying on their daily experiences to abstracting theory-like reasons based on accumulated observations of the results of previous experiments.

For this class, we tried to answer the following questions.

1. How well did the 21 children understand the concept at the end of the course?

2. What was the trajectory of understanding of the whole class qualitatively? More concretely, in terms of choices of the experiment results and the number of similar explanations by the children, did the class converge toward the "same" answer (as possibly expected by many teachers as well as some convergence-oriented theoreticians), or was divergence among the children maintained? Divergence here means that each individual child creates his or her own explanations of understanding, even at the very end of the course, with some different degrees of understanding underlying their seemingly or apparent "same successful" understanding (e.g., "everybody answers correctly"). It is important to make this distinction so that the teacher can create a class atmosphere that focuses on either divergence or convergence. In our own preliminary study, orientation toward more diversity has been identified as having more potential for successful collaboration.

3. What was the qualitative nature of the children's process of conceptual change, if it happened? In order to gain some insight, we analyzed the utterances of the two most active participants. We analyzed how they changed their expressions of their models as the course developed.

Research context: Hypothesis-Experiment-Instruction

Our research context here is the series of science classes designed using the Hypothesis-Experiment Instruction (HEI) framework (Itakura, 1963) and the target content of the "Air and Water" unit (Itakura, 1970). The objective of this unit is to understand that water cannot enter where there is air and vice versa, to serve as the basis of a rudimentary grasp of atomic theory. HEI is a strategy to teach basic scientific concepts. An HEI "unit" consists of multiple such "problems," or experiments, carefully ordered to guide the development of scientific concepts underlying the problem set. The teacher uses a problem set sheet for each experiment; the sheet explains the experiment and alternatives of possible answers. Each student chooses one alternative, and the result of their selections is written on the blackboard so that the students know the distribution. They then are encouraged to give reasons for their choices, to question others, and to discuss among themselves in order to make a better prediction. They are allowed to change their prediction before the experiment that will confirm the correct answer. At the end of the class, each student writes comments about the activities. By repeating this activity to cover the entire set of problems in a unit, each student in an HEI class is expected to integrate the results of the experiments in her/his own way in order to formulate an individualized "hypothesis," or the student's rudimentary scientific concept.

The "Air and Water" unit consists of the 11 problems explained in Table 1. These problems can be classified into two subsets, Problem 1 (P1) through Problem 6 (P6) and the rest. The first set deals with problems whose answers are justifiable with daily experiences. In contrast, situations of P7 to P10 do not occur often in children's daily lives; thus, they are difficult for children to imagine.

Table 1: Wordings of the 11 problems in the "Air and Water" HEI unit

P1	When an empty glass is pushed into water upside down, will the water come into the glass?
P2	If you place a crumpled piece of paper in the glass and do the same as in Problem 1, will the paper get wet?
P3	An upside-down glass with water inside is in the water. When you lift it up through the surface of the water, what will happen to the water in the glass?
P4	What will happen when you suck air through a straw from an upside-down glass in the water?
P5	Which dropper sucks more water, one whose tip is deep in the water or one whose tip is shallow?
P6	Can water be sucked through a 1m straw?
P7	A can of juice has just one hole on top. When the can is turned upside down, will some juice come out of it?
P8	Will some juice come out of a can that has two holes on its top and is turned upside down?
P9	Suppose you put the can used in problem 8 deep into the water, keeping your finger tight on one of the holes. Will some water go into the can?
P10	What will happen to the can in problem 9 if you remove your finger?
P11	Will some soy sauce come out of its container if you put your finger onto the hole on its top?

The latter problems require learners to rely on their newly formed "hypotheses," from accumulating predictions and observations of the experimental results in the previous problems. The learners are expected to realize that water cannot enter where there is air and vice versa, with justifications starting from relying on their daily experiences to abstracting theory-like reasons. The last problem, P11, can be answered by relying on either daily experiences or newly learned understanding, or both. This is to confirm their achieved levels as well as to let the children connect the hypotheses to daily life, so that they may see that their clearer understanding is usable in everyday situations.

The targeted concept of this unit is "water cannot enter where there is air and vice versa," according to Itakura (1970), the developer of this curriculum. From the perspective of modern science, we should use such concepts as "atmospheric pressure" and "surface tension" to fully explain the results of the P7 through P10 experiments; however, the learners were not expected to understand these concepts in this unit. Instead, the emphasis was on having the children experience "how to think scientifically." The idea of "water cannot enter where there is air and vice versa" itself is not sufficient for high school education, but it is adequate to give a general justification to cover all of the 11 experiments. Thus, becoming able to predict the results of an experiment and to justify the prediction requires a change in concept, tying experience-based rules of thumb to more scientifically justifiable explanations.

In order to identify the levels of conceptual change discussed here, we use the four-level model that ties the children's daily experiences and the scientific concepts (Miyake, 2009) listed in Table 2. The learner can create a rule of thumb based on one incidence of experience (e.g., coming too close to a heated stove lets the child create a useful rule of thumb of "red, warm, could be extremely hot, to be avoided"). Usually these experiences should be repeated numerous times so that the child can create a more stable rule of thumb and understand the world around her/him. These are individually created, experience-based "concept" levels of Level 1 (based on one incident) and 2 (repeated and summarized). The other side of the model, Level 4, includes the consensus reached by the scientific community, the state-of-the-art concepts shared by professionals. These are the concepts explained in textbooks and expected to be taught at school. In between, at Level 3, is a wide zone for learners needing to change their Level 2 basic experience-based rules of thumb to Level 4 scientifically community-shared concepts. Many instructional methods have been developed and tested to facilitate this conceptual change (Vosniadou, 2008), Some of these methods heavily utilize the power of social construction in the form of collaborative design (c.f., Roschelle, 1992; Howe,et.al. 2005; Vosniadou, et.al.2007; Miyake, 2008). HEI is such a method (Saito & Miyake, 2011).

According to this model, the targeted conceptual change for the "Air and Water" unit is to reach Level 3, starting from Level 2.

Table2 : Four-stage model of conceptual change

Theories constructed through collaboration	Lv.4	Scientific concept, created and shared in the scientific community
	Lv.3	A socially constructed, yet individually understandable "story" tying abstracted ideas created on their own as well as borrowed from others and the the rules-of-thumb accumulated in daily life.
Knowledge and rules from individual experience	Lv.2	A rule of thumb created by accumulating one's own (yet many) experiences from different situations
	Lv.1	A rule -of- thumb based on one incidence

Children's conceptual change

Data

The data come from the "Air and Water" unit in an HEI class conducted in May and June 2002. Twenty-one third graders participated in 12 lessons taught by a highly experienced HEI teacher, Yuko Saito, who voluntarily kept records of the distributions of students' predictions before and after the class discussions, the students' discussions using hand-written notes, and voice recordings. She also kept copied records of the notes taken by all the students during class. The transcribed voice recordings and the copied notes are the data we analyzed here.

Predictions of answers to the problems

Fig. 1 plots the percentage of correct predictions made by the children upon reading the explanation of the experiment, prior to discussion.

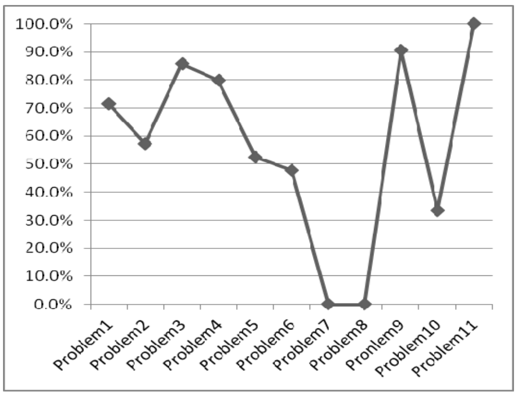


Figure 1: The percentage of correct predictions.

All the children made correct predictions for the last experiment, whose result was not readily obvious from daily experiences. It could be assumed that the entire class somehow successfully formed a rudimentary concept of physical identity, at least with regard to whether or not air and water could share the same physical space.

However, this conceptual shift did not occur smoothly. For P7 and P8, the problem situation significantly deviated from the children's daily experiences, thus making it particularly difficult for them to make correct predictions. After their complete failure on these problems, the children somehow recovered their performance over P9 and P10, and were able to correctly predict 100% on the transfer problem of P11.

Shift of levels of the children's concepts

Because the shift pattern of predictions indicated successful learning at least at the end, we could expect to observe a corresponding shift of concept levels in the children's utterances and the note descriptions. We coded the contents of the students' discussions during the classes and the written comments after the classes according to the levels described in Table2. The operational definition used for this coding and the corresponding example of each level are presented in Table3. The correspondence rate of coding by two coders was 94%.

Table3: Categorization for level of conceptual change in "Air and Water"

	Operational definition	Examples
Lv.3	Explanation based on understanding of "water cannot enter where there is air and vice versa, "which could lead the learners to correctly answer one or more problems.	"The seal stops the air. When the air can't move, the water won't move, either" for P11
Lv.2	Explanation based on generalized rules of thumb	"When the can has two holes, water can move" for P10
Lv.1	Explicit reference to a particular experience	"I have tried such an experiment with a wash bowl in the bath." for P1

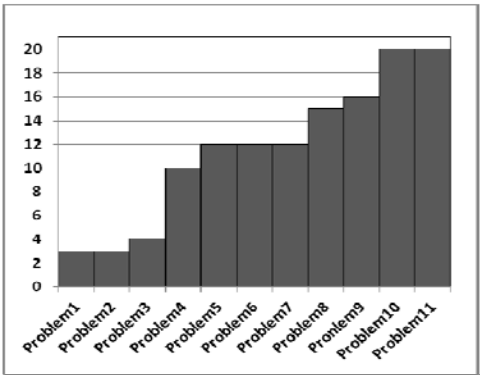


Figure 2: The accumulated number of Lv3 expressions

If the class successfully changed their concept, each student could express Lv 3 understanding at least once. Figure 2 plots the accumulated number of students whose justification fell at Lv 3 for each problem.

Twenty of the 21 children's expressions of reasons for their choices were coded as Lv 3 explanations at the end. Thus, we could conclude that the class was successful in helping each child construct a starting scientific model about air and water.

Quantitative analysis of the children's collaborative learning paths

Shift pattern of predictions of each student

What was the qualitative trajectory of this successful conceptual shift in the whole class? In terms of choices of alternatives of the experiment results and the similarities of explanations given by the children, did the class converge to the "same" answer, or did the individual students diverge?

Each student could choose one of three possible predictions for each problem. This allowed many possible paths of choices, but for 7 of the 11 problems, more than half of the students chose the same prediction (Fig. 1). If students had chosen the same prediction because they understood in a similar manner, there could not have been so many patterns of choices. When we asked teachers who often teach HEI classes how many courses there could be for an 11-problem unit, they typically said there would be only three or four paths in one class of 20 to 30 students. For analysis, we checked the alternative that each child chose for each problem. We then compared the sequence of such predictions for each child against that of the other children. Every child had a unique sequence of alternatives for the 11 problems; thus, we concluded that there were 21 paths of selections. For P1, P5, and P10, student's selections were evenly distributed among the three alternatives. Thus, they did not tend to converge to fewer selections toward the end of the unit. This diversity could have made the interaction among students constructive, promoting conceptual change in the class, as confirmed above.

Similarity of models used in discussions

As for the similarity of explanations given by the children, did the class converge to the "same" answer, or did it diverge among them? A simple prediction could indicate convergence, as some previous research indicates (c.f., Roschelle), however, a detailed analysis of individual paths of understanding indicates the opposite, that they diverge as the discussion progresses (c.f., Miyake, 1986). In order to test this idea, we counted each child's utterances for each problem, as an indicator of convergence of their models. When their models converge, the learner who sufficiently explains one problem would not be motivated to repeat it for another, while a new member who comes to a definite understanding based on the model might wish to express it for a different problem. This would give us a relatively even number of utterances among the children, as well as a relatively smooth decline of the number of utterances from the beginning problems to the ending ones.

Fig. 3 plots the number of utterances for each problem. We do not observe any clear decline of utterance frequencies across the problems. The children seem to have been motivated to speak up for some problems and not for others, even in the middle of the course, though a clear decrease is observed toward the end.

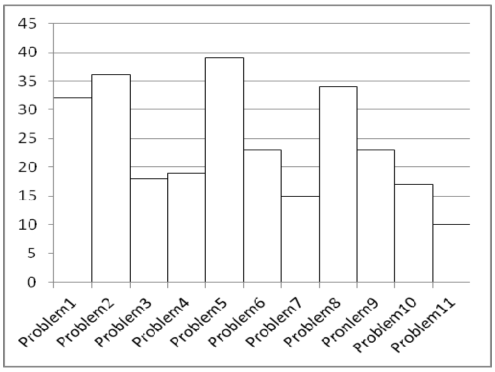


Figure 3: Number of utterances during discussion for each problem in the "Air and water" unit

When we counted the number of utterances for each child, we found a clear pattern of some kids talk more while some don't. The pattern may mean that the children could learn a lot while just being silent, attentively listening the others' talks and discussions (Saito&Miyake,2011).

Qualitative aspects of the process of collaborative conceptual change among the core members

Shift pattern of predictions

In order to investigate the qualitative aspects of the conceptual change process in this class, we selected the two most active children (A and B), and analyze the contents of their utterances. The purpose of this analysis is to understand the results described above. Quantitative analysis of the pattern indicates more diversity than normally expected by both teachers and researchers who believe in a convergent pattern of collaborative conceptual change. The qualitative aspects of the processes imply value in this diversity. We would like to know whether the most active two worked as a convergent target model for final success, or if their divergence contributed to their success. Were the two similar to each other in making predictions by choosing similar alternatives, sharing similar models for justification at the beginning, and gradually converging and uttering their understanding to compensate each other so that the rest of the class could use their model as a target and "learn" after them? Or were they different until the end to stimulate the thinking of the rest of the class? For analysis, we examined their prediction paths from their chosen alternative for each problem, and inferred the cognitive models they could have adopted, based on their utterances.

First, we compared the prediction paths of A and B, and then inferred their models based on what they said and how they said it (Table 4).

Table 4 : Predictions and justifications of A and B for each problem

	A	B
P1	○ I tried this yesterday in the bath. There was no water at the top of the tuned-over bucket; there could be air there.	○I tried this also. The turned-over bucket is heavy to pull up. There may be air in it (to make it heavy).
P2	○The paper would not get wet, when even half the cup is filled with air.	○Air comes first, so the paper in the cup would not get wet.
P3	○I tried this; the water was to the top of the glass, maybe because of the buoyancy force.	○Just pulling up the glass would not do anything. The water inside stays there.
P4	○When sucked there would be nothing in the glass, so the water should come up.	○The air would escape if there is enough time (for the air to do so).
P5	○The strength of push does not have anything to do with it.	○I have tried this with a toy; when I pushed it hard, the water rushed out.
P6	○Where there is no air, water should comes up, even when the length is 1m.	○Teacher said she would do her best, so I think she could do it.
P7	×If there were a hole on top, the juice would come out, but with a little hole on the bottom, the juice would only drip.	×When I made a hole in a small drink bottle, the juice dripped. When I made the hole bigger, then juice came out continuously.
P8	×(SEE TABLE 5 for detail)	×(SEE TABLE 5 for detail)
P9	○Because the upper hole is covered, the water would not go in.	○ (no mention of justification)
P10	○Now there is a hole on top, so the water pushed in, and pushed the air out.	×Water will come in about halfway. →○This time a large amount of water will come in.
P11	○When some air goes in, it pushed the soy sauce. If you cover the hole, no air goes in, so no sauce would come out.	○I tried a similar thing, and only a little soy sauce came out, so it would not come out.

N.B. ○is the correct prediction, × indicates a wrong choice

Both students chose correct answers from the beginning to the middle (P1 to P6), indicating they possibly shared the model correctly enough to choose the correct answer. Yet in the latter part of the course, they did not answer correctly, and their choices differed for P8 and P10. This pattern could mean at least two things. First, they were similar to each other when they based their judgments on their experiences (i.e., they shared more or less the same set of experience-based rules of thumb), but their shifted concepts differed. Second, they may have held different models or rules of thumb from the very beginning, both of which were correct enough for each to choose the correct answer (for different reasons); and the difference became sharper as the problems became more difficult and required more sophisticated use, or expressions of justification for their choices.

Diversity of models

A closer look at the students' utterances indicates that for P1 through P6, though both students based their justifications on their daily experience, they apparently formed some generalizable model of "when air goes out, water gets in." This explanation became more sophisticated as the problem progressed. Both talked about their bath experiences in P1. However, for P5 student A mentioned "when there is the same amount of force to push, the amount of air coming out should also the same," whereas student B said "because the same amount of air is lost, so should be the amount of water." These explanations were applicable not only to the problem at hand but also to previous problems, indicating increased abstraction levels.

Yet slight differences were observed even in these early-stage justifications. While A repeatedly used the word "top" in his explanation, B did not use it at all. This difference becomes more readily apparent in their justification explanations after P7, where the children's models stopped working.

For P7, A's repeated use of the word "top" indicated that he was trying to use the same model until P6. However, B began to consider the size of the hole, introducing a new factor in his model (he did not mention size before P7). For P8, their explanations clearly differed as they engaged in a lively discussion in front of the class. Table 5 presents details of the beginning of their explanations.

Table5: Example of utterances of A and B during P8 discussion

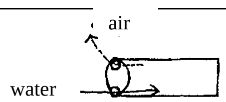
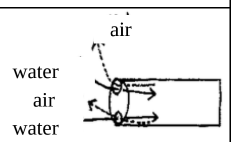
A	B
This time, there are two holes at the bottom of the can. I think, if one hole is above the other, it is easy for the air to enter from that hole and the juice would come out from the other hole below. But in this problem, both of the holes are on the bottom so no air could get in. That is, because the air is outside, no juice could come out, or no air could go in either. The two are separated at the bottom.	For me, it does not matter which hole lets the juice out, but the air goes in from here, it goes up to fill half of the can, then the juice would get pushed out from the other hole and drips out.

A distinguished between the positions of the two holes punched in the can. This distinction enabled him to explain "if one hole is above the other, it is easy for the air to enter from that hole," and "the juice would come out from the other hole below." From these utterances, we infer that A's model has components like "air is above, while water is below." His perspective is on the relative positioning of the air and water. We call this model the "positioning model." In contrast, B mentioned that "it does not matter which hole lets the juice out." Thus, we infer that he did not pay attention to the positions. Instead his explanation that "air goes in …to push the juice out" indicates that he focused more on the interaction between air and water. We call this model the "interaction model."

For the entire discussion of P8, A kept using the same model, emphasizing the significance of the relative positions. His last comment was "if there were any air in the can, it stays on top, so no juice would come out. In contrast, toward the end of this discussion, B began referring to the relative positions of the two holes in his model as "the air, when it somehow gets in, may move through there to reach the top, and the air on the top would let the juice come out from the bottom," indicating his awareness of the possible integration of A's model into his. Many questioned B's choice, so B had to explain his position repeatedly. This could have contributed to B's refinement of his model, while A could stay with his older model.

Preliminary analysis indicates that A and B preserved their differences and never converged to the same model. At the end of class, their explanations solicited by the teacher made this difference clear. Both drew their models on the blackboard, with explanations (Table 6).

Table 6: Last drawings and comments of A and B during P10 discussion

A	B
 Though my choice is the same as B, the air becomes foamy when water comes, doesn't it? As the foam climbs up and up, stops on top and goes out. The bottom hole lets out not air, but water. The bottom is water first.	 Because there are holes on both, perhaps a lot goes in. Water goes in like this, and the water rushes out.

This difference between A and B was maintained even at the very end of this course. We cannot deny the possibility that this difference kept both A and B engaged in the discussion, which remained the focus for the rest of the class and made everyone stay on task, thus fostering successful conceptual change for the whole class.

Conclusion and Discussion

Analysis of the data gained from this HEI class on "Air and Water" indicated three patterns. Through the course of 12 classes covering 11 experiments or problems, the 21 children discussed their predictions of possible answers. This design successfully led them to change their experience-based rules of thumb into more scientific understanding of "air and water do not share the same space." Each child's path of this conceptual change was unique, allowing each to create her/his own understanding. As indicated by qualitative analysis of the utterances of the two most active students, each could preserve her/his own model, possibly from the very beginning to the end. Yet this diversity among the children could be the source of prolonged discussion on the same topic for the length of this course, allowing both fast and slow learners to change their models. We plan to devise a better way to infer the cognitive models from these sporadic yet rich and complex utterances of children, in an effort to determine conditions for successful classroom discussion patterns that lead to conceptual change for every individual child in regular classes.

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