Problem-centred inquiry in collaborative science learning

Carol K. K. Chan

This study examined students' collaborative learning activity and assessed whether fostering problem-centred explanation would increase their performance on conceptual change measures. The domain of investigation is biological evolution. Participants were 60 high-school students randomly assigned to three experimental conditions: (a) Problem-centred explanation, (b) Argumentation, and (c) Knowledge-Activation. Different experimental prompts were provided to foster various kinds of collaborative constructive activity in order to assess the differential effects on conceptual change. The findings showed that problem-centred explanation group outperformed the knowledge-activation group and scored higher than the argumentation group on a number of measures. Students' constructive activity, which involves viewing knowledge as problematic and constructing explanations to deal with such difficulties, may play an important role in collaborative learning.

Keywords: peer collaboration, science learning, conceptual change, problem solving

Problem-Centred Inquiry in Collaborative Science Learning

The idea that peer interaction fosters learning is most widely accepted. Different strands of studies that have examined peer learning include those on peer interaction in developmental tasks (Dimant & Bearison, 1991; Doise & Mugny, 1984), cooperative learning (Slavin, 1983), peer tutoring (Mathes & Fuchs, 1994; Topping, 1988) and pedagogical methods such as jigsaw classrooms (Aronson, 1978). A theme of emerging interest in cognition centres around examining peer interaction as collaborative learning (Hoyles & Forman, 1995; Levine, Resnick, & Higgins, 1993; Resnick, Levine, & Teasley, 1991; Salomon, 1993). From this perspective, learning is examined as the social construction of knowledge: students construct knowledge and understanding as they engage in discourse and activity with their peers about shared problems. Emphasis is placed on learning as problem solving as peers jointly construct new understanding. Peers are of equal status with shared goals, and such goals may evolve in the course of tackling the task domain (Forman & Larreamendy-Joerns, 1995).

Faculty of Education, University of Hong Kong

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Peer Collaboration in Science Learning

There is substantial evidence that the processes of articulation, conflict, and co-construction provide cognitive benefits for peer collaboration (Crook, 1995). Collaborative scientific problem solving has received considerable attention; scientific understanding is now seen as involving both a personal and social process. A common approach to fostering scientific understanding is to encourage students to make their ideas explicit and to compare their ideas to those of their peers It is believed that engaging students in scientific discourse will help them articulate their own viewpoints, identify conflict, and evaluate alternative conceptions which could then lead to reformulation of beliefs (Driver, Asoko, Leah, Mortimer, & Scott, 1994; Duschl & Gitomer, 1991; Lonning, 1993; Palincsar, Anderson, & David, 1993).

Although a number of studies have shown positive results of peer collaboration on science learning (e.g., Amigues, 1988; Howe, Tolmie, & Rodgers, 1992; Lumpe & Staver, 1995), much less has been known about the processes involved in the collaborative construction of knowledge. Whereas some emphasized conflict and argumentation in scientific discourse (Amigues, 1988; Eichinger, Anderson, Palincsar, & David, 1991; Howe et al., 1992), others focused on the importance of shared meanings (Roschelle, 1993). Considerable differences have been found in how students approached the collaborative learning situations. For example, in the study of Eichinger et al.(1991), students argued merely to defend their claims rather than sought out what needed to be explained. Equivocal findings were obtained in ideational confrontation (Chambers & Andre, 1995; Champagne, Gunstone, & Klopfer, 1985; Hewson & Thorley, 1989); students' regard for social norms often outweighs theory-evidence coordination (Pintrich, Marx, & Boyle, 1993). There is a need to examine the group processes which foster joint understanding.

Constructive Learning Activity in Peer Collaboration

Collaborative learning is most productive when it involves student engagement in constructive learning activity. There is substantial evidence showing the importance of explanatory activity in scientific understanding in both individual and peer contexts (Bielaczyc, Pirolli, & Brown, 1995; Chi, de Leeuw, Chiu, & LaVancher, 1994; Miyake, 1986; Okada & Simon, in press). Investigators of students' constructive activity in learning have identified two contrasting approaches: routine versus problem-centred (Bereiter & Scardamalia, 1993; Chan, Burtis, Scardamalia, & Bereiter, 1992). Whereas some students simply assimilate or reject new information, others treat new information as something problematic which needs to be explained (Chan, 1995; Chan, Burtis, & Bereiter, in press). When probed to reflect on their existing conceptions, students were able to recognize difficulties in their knowledge–they felt uneasy, puzzled; some were even able to formulate such knowledge conflict into productive questions of inquiry (Chan, Burtis, & Bereiter, 1993).

The idea of identifying knowledge lacks and generating explanations is of particular importance in the context of collaborative scientific problem solving. Although knowledge activation has been commonly employed in science learning, emphasis has been placed on what students already know rather than what they need to know. For example, conceptual-change teaching often involves an awareness phase: Students are asked to elaborate on their existing conceptions and argue why they think certain ideas are better in solving the problems (Champagne et al., 1985; see meta-analysis, Guzzetti & Glass, 1994). It is believed that elicitation of prior knowledge would help students recognize conflict and reformulate their ideas. Despite enthusiasm with the contradiction paradigm, knowledge activation is of limited use (Guzzetti & Glass, 1994; Hynd & Alvermann, 1989), and conflict is often undetected (Dreyfus et al., 1990; Champagne et al., 1985). Furthermore, it has been shown that peer conflict is effective only when accompanied by internal conflict resolution procedures (Howe et al., 1992; Tao, 1996).

Much less attention has been given to collaborative problem-centred inquiry, that is, how students jointly identify knowledge lacks, formulate them into questions of inquiry, and generate explanations to deal with such problems. It is argued, here, that without an understanding of knowledge as problematic and as requiring explanation, knowledge activation and argumentation might be of limited use. For meaningful conflict to take place, students need to personally recognize the difficulties of their existing conceptions. While explanation has now been recognized as playing a central role in improving understanding (Chi et al., 1994), identifying knowledge conflict and formulating problems may help to elicit explanatory activity.

There is some research evidence which provides support for the importance of problem-centred explanation in peer collaboration. Reciprocal teaching, a most successful instructional program designed to help low-achieving children to improve on their comprehension scores, involves teaching children the strategies of summarizing, prediction, clarifying and questioning (Palincsar & Brown, 1984). Requesting and engagement in explanation have been shown to play a central role in successful performance in group learning (Webb, Troper, & Fall, 1995). Research on distributed expertise has focused on helping children become a community of scientists working collaboratively to pursue understanding of complex subject matter (Brown & Campione, 1990). In studies on computer supported intentional learning environments, elementary school children have demonstrated considerable success in their ability to engage in discourse which included posing questions, formulating explanations and pursuing inquiry in collaborative knowledge building (Scardamalia & Bereiter, 1994).

The Present Study

The goal of this study is to examine collaborative, problem-centred activity in scientific understanding. One approach is to conduct detailed discourse analysis in peer collaboration (Chan, 1995). The approach taken in this study is to investigate whether maximizing students' tendency to engage in different kinds of collaborative constructive activity differentially affects their learning outcomes in conceptual change. Using different approaches to examining peer collaboration should help provide different sources of data in support of problem-centred learning. Specifically, the objective is to test whether problem-centred explanation, which involves helping students to identify knowledge conflicts and generating explanations, helps foster conceptual change.

The domain of investigation is biological evolution. This topic was selected because evolution involves the understanding of a complex body of knowledge. As well, it is a topic which has not been formally taught to high-school students. The focus on conceptual understanding and the level of difficulty of the domain in question would be conducive for examining problem solving strategies in collaborative learning.

An experimental-control pre-posttest design was employed; three conditions were compared: (a) a problem-centred explanation group with prompts given to help students to jointly identify their knowledge lacks and to generate explanations; (b) an argumentation group with prompts given to help students to provide justification for their beliefs; and (c) a knowledge-activation group with prompts given to students to help them recall what they already knew. The design of the conditions was to compare problem-centred explanation with common approaches employed in conceptual-change studies in science learning. As discussed above, argumentation without an understanding of knowledge difficulty and shared learning goals may be of limited use. Nevertheless, because argumentation may involve elaboration and explanation, it is considered to be more effective than mere recall of prior knowledge. It is hypothesized that both the problem-centred and argumentation groups would outperform the knowledge-activation groups; and the problem-centred group would perform better than the argumentation groups on conceptual change measures.

Method

Subjects

Participants included 60 grade 11/12 students in a middle-class suburban school in Toronto, Canada. Students represented a range of abilities in their classes. They had had no formal instruction on Darwinian evolution.

Conditions

Students were asked to work in pairs, and each dyad was assigned to one of the three experimental conditions: (a) Problem-Centred Explanation, (b) Argumentation, and (c) Knowledge Activation. There were 10 pairs of students in each of the three conditions. Experimental cues were provided to foster different modes of collaborative learning in order to assess their differential effects (Table 1).

Table 1 Examples of Experimental Cues for Different Collaborative Learning Conditions

Problem-Centred Explanation	Argumentation	Knowledge Activation
	Identification Phase	
	Discuss with each other what you know about evolution. Do you have any ideas how animals evolve?	
	Awareness Phase (Domain-Related)	
Do you find evolution (of animals) interesting? Discuss why you think it is interesting. Are there certain aspects which are not only interesting but also intriguing?	Do you find evolution (of animals) interesting? Discuss why you think it is interesting.	Discuss with each other what you know about evolution (of animals). Try to remember as many things as possible.
Discuss with each other your ideas about evolution. What do you think about your ideas? Is there anything puzzling to you? Is there anything that doesn't seem to make sense? Explain why you think so.	Discuss with each other your ideas about evolution. What do you think about your ideas? Give reasons and explain your beliefs about how animals evolve?	Discuss with each other what you know about evolution (of animals). Tell each other what you have heard/read before.
What do you think about his/her questions? Is there anything you don't quite understand? Help each other to think more about the questions. Do you have any ideas about these problems?	What do you think about his/her ideas. Explain why you agree or disagree with his/her ideas. Why do you think your ideas may be better?	Discuss with each other what you know about evolution (of animals). Tell each other what you have seen in museums/ newspapers/TV, etc.
	Awareness Phase (Specific Situation)	
Discuss with each other what you think about how ducks evolved webbed feet? Is there anything puzzling or hard to understand? Explain why you think so.	Discuss with each other what you think about how ducks evolved webbed feet? Explain why you think so.	Discuss with each other how ducks evolved webbed feet.
	Awareness Phase (Summary)	
If you had an opportunity to talk to an expert, what are some things that you do not know but would really like to find out.	Summarize your present understanding of evolution.	List the three most important things you would tell someone about evolution.
	Contradiction and Reformulation Phase	
	Discuss with each other what this statement makes you think about evolution? What do you think about this statement and evolution?	

Problem-Centred Explanation

Students were asked to discuss with each other what they found puzzling or problematic about evolution, and to generate explanations to deal with such problems. The experimental cues were provided to prompt students to reflect collaboratively on their knowledge gaps, formulate questions and construct explanations for the domain in question.

Argumentation

Students were asked to discuss and explain to each other their ideas about evolution. They were prompted to explain why they believed certain ideas were correct and to provide justifications for their arguments. The experimental cues were designed to resemble what was commonly carried out in the conceptual-change contradiction paradigm–prompting students to examine the differences between their own and others' ideas and maximizing ideational differences. Students were not grouped based on differences in prior beliefs; they were prompted to focus on alternative ideas and conflict which arise in the discussion.

Knowledge-Activation

Students were asked to discuss with each other what they had heard or what they already knew about evolution. The experimental cues were designed to prompt students to recall their existing knowledge and to organize their knowledge topically.

Procedure

Pretest

Student dyads were assessed individually for their prior knowledge. They were given a written test on evolution based on questions which had been developed in previous research (Bishop & Anderson, 1990; Chan et al., in press). The pretests, which lasted for about fifteen minutes, were administered for assessing posttest changes and to ascertain whether these students held typical misconceptions. Three sets of questions were included: (a) knowledge-application questions (counter-balanced across groups and pre-posttests), (b) forced-choice ratings, and (c) rating of eight propositional statements about evolution.

Test

Student dyads were presented with different experimental cues according to their assigned conditions. The experimental cues were written on cards and placed in front of the dyads. They were asked to refer to the experimental cues to guide them in their discussion. The experimenter intervened only when students got stuck in the discussion: some general direction was given referring them to the cue cards; no content cues were provided.

Identification phase. All three groups were first presented with a common experimental cue asking them to summarize their existing understanding of evolution. This knowledge-activation cue was used to elicit students' existing conceptions so as to provide a basis for subsequent discussion.

Awareness phase. There were three components in this phase as described below:

(a) Domain general. Students were asked to discuss with each other their understanding of evolution. According to their assigned conditions, students were asked to recall what they already knew (knowledge-activation group), to explain and justify their ideas (argumentation group), and to identify what they did not understand and generate explanations (problem-centred explanation group).

(b) Specific situation. Students were then asked to refer to a specific situation, a question to which they had responded in the written test–how ducks evolved webbed feet. The experimental cues were differentially designed to prompt them to tell their answers (knowledge-activation group), to give justifications for their responses (argumentation), and to explain what they did not understand about the problem situation (problem-centred explanation).

(c) Summary. Students were asked to list the three most important things in evolution (knowledge-activation group), to summarize their present understanding (argumentation), and to identify what they would like to find out about evolution (problem-centred explanation).

Contradiction and reformulation phase. Instructions for all three groups were identical for the contradiction and reformulation phase. Following the awareness phase, students were presented with five scientific statements about evolution which had been developed and tested in earlier studies (Chan et al., in press). Students were told that these statements were scientifically accepted, and that they were to discuss with each other and negotiate their understanding about evolution based on their understanding of the statements (Appendix).

Posttest

Students were then assessed individually for posttest conceptual changes. They were asked to respond to a written test which included the following: (a) a knowledge-application question, (b) a knowledge-transfer question, (c) rerating of forced-choice questions, and (d) rerating of belief statements (see Appendix).

Measures

Knowledge Application and Transfer Questions

Two open-ended questions, knowledge application and knowledge transfer, were included to assess students' conceptual understanding of evolution. The knowledge-application measure included two parallel questions counterbalanced across conditions and pre-posttests. The knowledge-transfer measure, which involved having students solve a problem using information about evolution, was only administered at posttest.

A 5-point scale was developed to rate the knowledge application and transfer questions. The rating scheme was based on previous research on conceptual change in evolution (Chan et al., in press). A rating of 1 was assigned to non-responses or responses which did not show an understanding of the question. A rating of 2 was assigned to responses indicating naive conceptions. A rating of 3 was assigned to responses showing incorrect assimilation of scientific information. A rating of 4 was assigned to responses indicating the emergence of new understanding. Finally, responses indicating the Darwinian conception were rated 5. Examples of student responses are shown in Tables 2 and 3.

Interrater reliability was obtained by having a second rater score a random subset of protocols (50%). Sixty protocols on knowledge-application and thirty on knowledge-transfer questions were rated. The interrater reliabilities were 0.92 and 0.93 (Pearson's r) for knowledge-application and knowledge-transfer measures respectively.

Forced-Choice Ratings

Students were asked to respond to a set of four forced-choice questions on how ducks evolved webbed feet (Bishop & Anderson, 1990). They were asked to rate on a continuum (5-point-scale) the extent to which they agreed with two opposing statements representing the naive and scientific conceptions.

Table 2 Rating Scheme for Assessing Responses to Knowledge-Application Question

	Descriptions	Protocol Examples
1	Irrelevance	Cheetahs are very skinny and they have long legs not like their ancestors because they were fat and short-legged (#092).
2	Naive Conceptions	Arctic foxes began to develop their necessities, and fur is one of their necessities to keep them warm (#048).
3	Incorrect Assimilation of Scientific Information	The cheetahs started to run fast to get away from predators or it just started to run fast by chance. Because they used their speed, this characteristic stayed (#011).
4	Emergence of Scientific Conceptions	Because their prey was very fast, and the ones that by chance were fast could get them, they survived while the slower ones did not (#064).
5	Scientific Conceptions	The foxes with thin fur died out, and the ones who by chance (mutations) had a thick fur lived, and gave their genes to their offspring. After some time, the 'thick fur' gene was predominant in the fox population (#082).

Table 3 Rating Scheme for Assessing Responses to Knowledge-Transfer Question

	Descriptions	Protocol Examples
1	Irrelevance	I think the chemicals in the insecticides were not as strong as before (#014).
2	Naive Conceptions	Insecticides are not effective anymore because the species has developed a resistance to the poison in order to survive (#023).
3	Incorrect Assimilation of Scientific Information	Being exposed to DDT so much, flies that survived built up a tolerance to the insecticides. The DDT could have caused a genetic change to occur which could then be passed onto their offspring (#045).
4	Emergence of Scientific Conceptions	There were a few species of flies around that were immune to insecticides, so that when ordinary flies were killed off, flies which were immune survived and bred faster (#047).
5	Scientific Conceptions	There were chance mutations in some of the early flies that permitted them to withstand the DDT, and therefore their offspring could withstand the insecticide. Each generation that survived was not hurt by these substances and a whole new species developed (#031).

Student responses were scored according to how closely their ratings resembled the scientific conception. For example, students who correctly rated 5 (or 1 depending on the direction of statements) would get 5 points, and those who rated 2 would get only 2 points because their views were more different from the scientific conception.

Belief-Verification Ratings

Students were asked to indicate on an 11-point scale whether they agreed or disagreed with eight statements about evolution. An example of the statements is as follows: *Evolution is directed by needs and purposes of animal species.* Experts' ratings as a criterion measure had been obtained in a previous study (Chan et al., in press). Correlations between each student's ratings and the criterion measure were computed. A high positive correlation would indicate close resemblance to the experts' beliefs, which presumably represent the scientific conceptions.

Results

Students' pre- and posttest scores on the

Table 4 Pretest and Posttest Conceptual Change Scores as a Function of Experimental Conditions

	Problem-Centred Explanation	Argumentation	Knowledge Activation
		Knowledge Application	
Pretest	2.20 (1.10)	2.40 (1.05)	2.30 (.86)
Posttest	3.30 (1.13)	2.95 (1.19)	2.45 (1.10)
		Knowledge Transfer	
Posttest	3.0 (1.12)	2.55 (1.28)	2.30 (.85)
		Forced-Choice Ratings	
Pretest	2.43 (.68)	2.40 (.76)	2.22 (.73)
Posttest	3.09 (.74)	2.59 (.78)	2.35 (.86)
		Belief-Verification Ratings	
Pretest	−.42 (.46)	−.27 (.46)	−.35 (.38)
Posttest	.24 (.49)	−.01 (.56)	−.17 (.49)

four conceptual change measures across the three conditions are shown in Table 4. Regarding gender effects in science learning, there were no significant main effects or interactions associated with gender on any of the conceptual change measures. Therefore, all data were collapsed over gender in the analyses.

Knowledge Application Measure

Differences on pretest scores were nonsignificant, indicating that the three groups did not differ in their prior knowledge. To control for possible differences caused by different questions (cheetahs vs. foxes), question order was included in the analyses. The two-way analysis of covariance (Condition × Question Order) using the knowledge-application posttest scores as the dependent variable and the pretest scores as the covariate showed significant effects for condition ($F(2,53) = 4.87$, $p < .02$) and question order ($F(1,53) = 4.98$, $p < .04$); there were no significant interaction effects. Although one of the questions (cheetahs) appeared easier, the non-significant interaction effects indicated that condition effects were not a function of question effects.

Multiple comparisons (user-defined contrasts with 1 d.f.) were conducted to examine group differences. A significant contrast effect was obtained ($F(1,53) = 9.53$, $p < .01$) between problem-centred explanation and knowledge activation favoring students in the problem-centred explanation group. The other contrast effects were not significant.

Knowledge Transfer Measure

An analysis of covariance was conducted on knowledge-transfer posttest scores using pretest knowledge-application scores as the covariate to control for prior-knowledge differences. Multiple comparison analyses showed a significant contrast effect between problem-centred explanation and knowledge-activation ($F(1,56) = 5.49$, $p < .03$) favoring the problem-centred explanation group. A marginally significant contrast effect was also obtained indicating that the problem-centred group outperformed the argumentation group ($F(1,56) = 2.91$, $p < .09$). The contrast between knowledge-activation and argumentation groups was not significant.

Forced-Choice Ratings

The analysis of covariance using the posttest scores as the dependent variable and the pretest scores as the covariate indicated a significant condition effect ($F(2, 56) = 3.27$, $p < .05$). Multiple comparison analyses showed a significant contrast effect between problem-centred explanation and knowledge activation ($F(1, 56) = 8.87$, $p < .01$) favoring the problem-centred explanation group. As well, a marginally significant contrast effect was obtained ($F(1, 56) = 3.26$, $p < .08$) suggesting that students in the problem-centred group generally scored higher than students in the argumentation group. There was no significant contrast between knowledge-activation and argumentation groups.

Belief-Verification Ratings

An analysis of covariance was conducted on the posttest belief-verification scores using pretest scores as the covariate. A significant condition effect was obtained ($F(2, 56) = 4.74$, $p < .02$). Multiple comparison analyses showed significant contrasts between problem-centred explanation and knowledge-activation ($F(1, 56) = 8.87$, $p < .01$) favoring the problem-centred explanation group. Another significant contrast was obtained between problem-centred explanation and argumentation ($F(1, 56) = 4.71$, $p < .04$) indicating that students in the problem-centred group outperformed those in the argumentation condition. The contrast between knowledge-activation and argumentation groups was not significant.

Discussion

The goal of this study was to examine collaborative constructive activity in science learning. Specifically, we sought to examine the effects of problem-centred approaches on students' conceptual change by comparing different collaborative conditions. Our findings show that students in the problem-centred explanation group performed better than the knowledge-activation groups on all conceptual-change measures; they also obtained higher scores than the argumentation group on a number of measures. Although trend effects were obtained on some measures, there were no significant differences between the argumentation and knowledge-activation groups.

Currently, much emphasis has been given to encouraging students to talk about science (Lemke, 1990). Nevertheless, the benefits of collaborative science learning must be examined with regard to the kind of collaborative constructive activity students engage in. For instance, activating prior knowledge which is inconsistent with text information does not, by itself promote learning (Alvermann & Hague, 1989; Hynd & Alvermann, 1989). Although activation of prior knowledge might help students to become more alert to the contradictory scientific information, there is increased evidence showing that students are often unable to recognize the conflict (Chambers & Andre, 1995; Dreyfus et al., 1990; Hewson & Thorley, 1989). Consistent with research on explanation (Chi et al., 1994, Miyake, 1986; Okada & Simon, in press) and problem-centred learning (Bereiter & Scardamalia, 1993; Chan, 1995; Chan et al., in press), the higher performance of the problem-centred explanation group suggests the importance of explanatory inquiry within a problem-centred approach. Fostering puzzlements and explanation may help students in collaborative situations to set learning goals for constructing new understanding; the presence of peers is especially useful for monitoring and scaffolding these constructive activity.

Equivocal findings have been obtained in approaches focusing on contradiction and ideational confrontation (Chambers & Andre, 1995; Champagne et al., 1985; Dreyfus et al., 1990). In this study, the problem-centred explanation group outperformed the argumentation group on some measures only. As well, there were no significant differences favoring the argumentation group over the knowledge-activation group. The mixed findings point to the complexity involved in a paradigm focusing on maximizing conflict. While it is true that argumentation (critique of peer ideas) often involves some kinds of elaboration and explanation which may lead to deeper processing, conflict and confrontation, in themselves, may be ineffective. Peer conflicts need to be accompanied with students' internal conflict resolution (Howe et al., 1992; Tao, 1996). Although considering alternative ideas and providing justifications is a powerful strategy in scientific inquiry, it depends on whether students understand the goal of their collaborative inquiry. Scientists, of course, are likely to share a common goal of deepening their understanding of the domain. Yet it is unclear how younger students construct their understanding of the collaborative tasks. It has been shown, as well, that successful problem solvers employ more experimentation in considering alternative ideas and providing justification (Okada & Simon, in press). But one does not know how well students in the argumentation group understood the role of evidence. Students' different representations of task demands may have led to the equivocal findings in collaborative contexts focusing on contradiction.

Discourse Patterns

Although detailed discourse analysis is not within the scope of this report, some examples are included here to shed light on how different collaborative constructive activity may have led to the differential outcomes. Examples of interview excerpts from the three groups are included, and brief interpretations follow:

Knowledge Activation

Naive conceptions were often brought forth by the students as they told their peers what they already knew. Unfortunately, these conceptions were often unexamined in the superficial exchange between the dyad. An example is the following:

S1A:I have heard that..the giraffe..like one of the questions was about the giraffe. I have heard that their necks did grow longer because they needed to reach the leaves on top of the trees because all the leaves on the bottom were gone. [#1]

S1B:Well, I haven't heard much about it, but I mean, I figure that is the way it is. [#2]

S1A:And sharks. [#3]

S1B:Sharks? [#4]

S1A:Like sharks are really the most, they are the best of all. I have heard that sharks are the most evolved animals. They are the best of any kind. You can't improve on a shark at all. [#5]

As shown in this interview transcript, student S1A recalled what she already knew about evolution, a Lamarckian conception [#1]. Although she did provide an explanation for why giraffes developed long necks, such information was not taken up by S1B who merely provided superficial assent to her statement [#2]. There was no critique or inquiry as to whether such an explanation made sense. As prompted by the experimental cues, S1A continued to recall what she remembered about the evolution of another kind of animal [#3]. The superficial exchange between this dyad apparently made it very difficult for them to recognize conflict when confronted with contradictory information.

Argumentation

Students seemed, at times, to focus on differences in their ideas and often got involved in relatively unproductive arguments. Although debating their ideas might lead to elaboration and deeper processing, it seems students might lose the shared goal of collaborative understanding as they externalized their conflict.

S2A:I understand that animals evolve but I think that first it started with animals [ducks] having those characteristics and then they went to the water holes, [it's] more like instincts, and the ones. [#1]

S2B:So you think they evolved and then they went to the places. That doesn't make any sense. [#2]

S2A:No, I think they were already like that, and once they went to the places, then they ...[#3]

S2B:But there's evidence that they weren't like that. There's evidence that they have changed. [#4]

S2A:So you think that everything started the same without any characteristics. Everything was the same at the beginning and then as they moved into different places, they ...[#5]

S2B:That is what evolution is about. [#6]

Compared to the first example, the interview excerpt shows that this dyad was involved in a much more engaged interchange of ideas. Nevertheless, there is still very limited progress in their discourse. S2A started by proposing an explanation as to why he thought ducks evolved [#1 - *first it started with...*]. Instead of attempting to understand S2A's idea, S2B interrupted and refuted the statement [#2]. As S2A attempted to clarify his position [#3 - *No, I think...*] to deal with the disagreement, again, S2B contradicted by posing his argument. Although S2B was able to use terminology favored in scientific discourse (evidence), he did not actually explain what the evidence was [#4]. Instead of inquiring into the discrepancy of their understanding or asking S2B to explain the evidence, S2A asked a rhetorical question challenging S2B's position [#5]; such a question was responded to with an unwarranted statement [#6]. The discourse came to a halt as the dyad was entrenched into their different positions. Although the dyad held different ideas, they had made limited efforts to justify their beliefs using valid evidence by referring to the text or questions. Furthermore, instead of sharing a goal of deepening their joint understanding, this dyad seems to have externalized their conflict, which would likely hinder the process of collaborative understanding.

Problem-Centred Explanation

Students in the problem-centred explanation condition seemed most likely to identify knowledge conflict, construct explanation and engage in open inquiry, leading to progress in the discourse.

S3A:I don't understand why certain species die off and why others live on. It seems arbitrary sometimes. It doesn't seem to make sense. [#1]

S3B:No. I don't [understand] either. That is what I am trying to understand. Like, why evolution is here. [#2]

S3A:I mean, there are some species that are million of years old. They have never evolved. And there are others that evolve every hundred years, they are changing constantly. You can have the same species, you can have a cheetah in one area of the desert that will be slightly different from a cheetah in another area, just through genetic, or through their environment. Well, I mean I don't quite understand why it is so different. The different factors that affect evolution. There must be so many. [#3]

S3B:Are you saying if they are in different environment? [#4]

S3A:I understand that different environments affect it but are there other things? What sort of other things make one species slightly different from others? [#5]

The interview excerpts suggest that S3A first noted some knowledge conflict [#1], and identified some difficulty in her understanding. One does not know whether S3A would have pursued this line of inquiry in an individual context, but in this collaborative peer setting, her inquiry was sustained as S3B restated the problem [#2]. S3B's response then prompted S3A to continue with her search for explanation–identifying the source of difficulty and generating alternative hypotheses [genes or environment] to deal with the problem [#3]. The collaborative inquiry continued as the environmental hypothesis was taken up by S3B posing it in form of a question [#4]. In response to her request for explanation, S3A explained what she believed, which led her to consider about other alternatives and formulate further questions [#5]. There was a co-construction process involving problem identification and collaborative construction of explanations which led to further problem and inquiry.

Problem-Centred Learning in Collaborative Inquiry

Although the discourse data are very limited, and the analysis is open to different interpretations, they may help to provide some information about the different kinds of collaborative, problem-centred activity in peer learning. In the following, some themes are discussed to suggest why problem-centred learning may be important in peer collaboration. It is proposed that recognition of knowledge conflict (puzzlement) may lead to a search for an explanation followed by the construction of an explanation. Such constructive activity is scaffolded and monitored in the peer collaborative context.

1) Recognizing Knowledge Conflict

Conceptual change studies have shown that students are often unable to recognize the discrepancy posed by anomalous information or to become dissatisfied with their conceptions (Dreyfus et al., 1990). A distinction needs to be made between external versus internal cognitive conflict. It is not enough just to confront students with contradictory information. Similarly, maximizing peer conflict may not be adequate because students may just argue to defend their positions rather than examine evidence for alternative explanations. In problem-centred explanation, students are encouraged to seek out internal knowledge conflicts, that is, what they find puzzling or hard to understand. Articulation of their uneasiness is likely to be echoed by their peers' similar understanding which may help sustain the line of inquiry. Because students' prior conceptions tend to be different from the scientific information, a sense of uneasiness and delayed interpretation would help them to refrain from making direct assimilation. As well, puzzlement may help them to become more aware of how information from peers and text differs from what they believe, which may then trigger requests for explanation.

2) Formulating Questions in Search of Explanation

The advantage of engendering puzzlement is that it may lead to formulation of questions to resolve the conflict. Requests for explanation in the form of questions may help students to formulate learning goals for new understanding. Conceptual change studies have emphasized having students identify what they already know and justify their beliefs. But it is necessary to extend the idea of knowledge activation from what one knows to what one does not know. There is some evidence suggesting that even elementary school children can act as a community of learners and scientists posing questions, constructing explanations, and pursuing inquiry (Scardamalia & Bereiter, 1994). Indeed, the ability to pose productive questions is crucial in scientific inquiry. Collaborative learning situations provide a good opportunity for students to pose problems and jointly to formulate questions for inquiry. In the course of working together, students go through phases of understanding and non-understanding (Miyake, 1986) and peers often help monitor and scaffold the construction of new learning goals. Initial evidence has been presented showing that students are able to upgrade their questions as they engage in collaborative inquiry (see interview excerpt). Students' awareness of what they do not know may open up their pursuit of what they need to know to restructure their knowledge.

3) Construction of Explanation

As students engage in recognizing difficulties and formulating questions, it may lead to another positive effect–elicitation of explanations. Research on self-explanation has shown its potent role in improving scientific understanding (Chi et al., 1994). In peer-collaborative learning situations, as students pose questions, they may scaffold each other to construct explanations and generate alternative hypotheses. Furthermore, instead of just giving ad-hoc explanations to justify one's beliefs, students engaged in problem-centred inquiry are more likely to look out for discrepancy and refrain from premature closure. Explanations are not proposed as final as they may lead to further problems. Therefore, there is a process of progressive problem solving as students seek continually to upgrade their explanations as they pose new problems. As they view their knowledge as problematic and as requiring explanations, students are engaged in an ongoing process of problem recognition and problem resolution.

Limitations and Future Directions

Some cautions are necessary at this point. First, three experimental conditions were included to test the differential effects of problem-centred explanation, argumentation and knowledge telling. It would be useful to include another condition where students were given no prompts so as to compare problem-centred explanation with collaborative activity in spontaneous situations. Second, although experimental cues were designed to promote different modes of collaborative learning, what students brought to the learning situations needs to be more closely examined. It may be agreed that, generally speaking, students in the problem-centred explanation group were more engaged in formulating questions and generating explanations whereas students in the other two groups were more engaged in argument and knowledge telling. However, observations suggested that some students brought with them problem-centred versus routine approaches to knowledge activation, argumentation and identifying knowledge lacks. To illustrate this issue, consider the following: When asked to list the three most important things in evolution, some students in the knowledge-activation group would indicate the need to construct a coherent account for explaining evolution rather than simply listing three things. A similar phenomenon occurred in the argumentation group: the experimental prompts could produce discussion merely to defend one's ideas or provoke meaningful conflict that led to deeper inquiry. As well, when prompted to reflect on their knowledge gaps, some students were actively seeking out knowledge problems whereas others were merely producing trivial questions to meet the task demands. In brief, our experimental prompts would help to maximize the differences of collaborative activities but differences in how students approach the tasks also need to be considered.

This study employed performance data to examine the efficacy of problem-centred inquiry in collaborative science learning. Detailed discourse analyses are required to track the processes of collaborative conceptual change. For example, how does learning differ when students generate questions in an individual versus a peer context? How is peer conflict related to internal conflict resolution? As scientific inquiry is premised on the generation of promising questions, how students help each other to construct productive questions and sustain their inquiry needs to be examined in future investigations.

Conclusion

This study examined students' collaborative constructive activity in science learning and provided some support for the role of problem-centred explanation in conceptual change. Although it has been widely accepted that peer interaction fosters learning, the benefits probably stem from student engagement in collaborative constructive activity. This study has focused on examining one form of constructive activity, problem-centred learning, which involves a continual and cyclical process of identifying knowledge lacks, formulating questions and constructing explanations. Such constructive activity is scaffolded and monitored in peer collaborative contexts. Scientific understanding involves both individual and collaborative learning. Investigations of how students engage in problem-centred discourse may help shed light on the processes of scientific inquiry and collaborative knowledge building.

Appendix

Conceptual Change Measures

Knowledge-Application Questions

A) Cheetahs (large African cats) are able to run faster than 60 miles per hour when chasing prey. How would a biologist explain how the ability to run fast evolved in cheetahs, assuming their ancestors could only run 20 miles per hour?

B) Arctic foxes have thick fur and live well at very low temperatures. How would a biologist explain how thick fur evolved in Arctic foxes, assuming their ancestors did not have thick fur?

Knowledge Transfer Question

In the past, aerosol insecticides (DDT) were used to kill flies. Today, such insecticides are not harmful to flies anymore. How would a biologist explain why insecticides caused harm to flies in the past but failed to do so now?

An Example of Forced-Choice Ratings

The trait of webbed feet in ducks:

Appeared in ancestoral ducks because they lived in water and needed webbed feet to swim.	1 2 3 4 5	Appeared in ducks because of a chance mutation.

Examples of Belief-Verification Items

Evolution is directed by needs and purposes of animal species.

Evolution is a battle of stronger species killing off weaker ones.

Evolution depends on changes which first occur in the environment.

Evolution depends on changes which first arise by chance.

Examples of Text Statements

An animal cannot evolve by adapting to its environment. It is the environment which selects the well-adapted animals. A deer cannot choose to evolve long legs although long legs are important for survival. Some deer, however, may be born with longer legs which allow them to run faster. These individuals have a better chance of surviving and leave more offspring.

No matter how much the environment has changed, new characteristics might not appear in an animal. A particular species of moth has become darker as the environment has been soiled by pollution. This is not because pale-coloured moth developed a dark colour to hide from its predators, but because there were already a few dark moths around, and these survived better and became more numerous.

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Carol K.K. Chan

Carol K. K. Chan is currently an assistant professor at The University of Hong Kong. She received her Ph.D. in Applied Cognitive Science in 1993 from the Ontario Institute for Studies in Education (OISE), University of Toronto. She has worked as senior research officer at OISE and taught at Saint Mary's University, Canada. Her research interests are in the areas of problem solving, text processing and peer collaboration. Current research projects include collaborative problem solving of high-school students learning science and preservice teachers learning to teach.