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Does Collaborative Learning Lead to the Construction of Common Knowledge?

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Abstract

This study investigated whether collaborative learning leads to the construction of shared knowledge among participants. In this study, college student pairs collaborated to learn a biology text on the human circulatory system. The results showed that pairs shared not only correct knowledge that was presented in the text, but also incorrect knowledge and/or knowledge that had to be inferred from the text. In addition, pairs who interacted more shared significantly more inferred knowledge than those who interacted less did. Taken together, these findings indicate that interaction enables dyads to construct new knowledge and their representations tend to converge after collaboration.

Introduction

Traditional cognitive psychology has mainly focused on how information is processed within individuals' minds, that is, how individuals represent stimuli, learn new things, solve problems, make a discovery, etc. As a consequence, even when people learn collaboratively, learning has been mainly defined in terms of what individuals learn and not much attention has been paid to the collaborative aspect of knowledge construction that is shared by both partners. This study to be described below was an attempt to examine whether a shared activity such as collaborative learning would lead to the construction of shared knowledge.

Learning often occurs in the context of a group or community, and many researchers propose that learning, a *cognitive* activity, is a joint *social* activity (Lave & Wegner, 1991; Levine, Resnick, & Higgins, 1991; Resnick, Levine, & Teasley, 1991; Rogoff, 1998; Tudge & Rogoff, 1989; Vygotsky, 1978). To say that a cognitive activity is a social activity sounds contradictory at first, but the notion of "socially shared cognition" has been instantiated in two ways: It has been used to refer to shared cognitive activities such as group problem solving (e.g., Larson & Christensen, 1993) or shared representations such as a team mental model (e.g., Klimoski & Mohammed, 1994) or a community memory (e.g., Orr, 1992). Even if we operationalize socially shared cognition to be shared representations that all members of a group have in common, the question remains as to whether this shared representation can come about from a joint social activity such as collaborative learning.

In order to hypothesize whether a shared representation is constructed, we need to reconsider what individual learning is. Learning requires people to process incoming material (such as an expository text) and to integrate it with their prior representations. Thus, we assume that when individuals can learn by themselves, and they do so by actively constructing new knowledge or skills and/or revising their incorrect understanding (Chi, in press). Although such active construction of knowledge is critical regardless of whether people learn alone or together (Jeong, under review), learning in a collaborative context gives rise to an additional question: Is each member of the dyad constructing and revising her own individual representation, or are they jointly constructing one representation, or is it a hybrid of the two?

If learning is the construction and revision of representation, then there are at least two hypotheses about what might be happening during collaborative learning. In the first case, collaborating partners may each be constructing and revising her own representation, taking the partner's comments and explanations simply as additional input or feedback. In this case, they would each be constructing their own representation, albeit simultaneously. So, partner A and B each would construct their own unique representations, A and B. Representations A and B may be totally distinct or they may overlap, but since partners are constructing and revising their own representations, their representations would not resemble one another. The overlap in their representations, if existed at all prior to collaboration, would not likely to change with collaboration either.

On the other hand, another possibility is that collaborating partners may be constructing and revising jointly a shared representation C. Regardless of whether the shared representation C is constructed *in addition to* or *instead of* their own representations A and B, the resulting representations would reflect the joint learning activity they engaged in during collaboration in that partner A's representation shares portions that are similar to partner B's representation. With collaboration, A and B share more and more parts in common, so that the common representation C gets larger with greater collaboration, whereas the representations unique to A or B would get smaller with collaboration (see Figure 1).[1]

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[1] Although not examined in this study, a third possibility is that collaboration might encourage the two partners to construct a single representation that is either A or B (that is, they converged upon one of the partner's representation), or neither A nor B, but X.
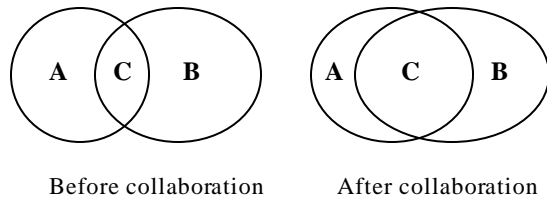
Figure 1: Changes in the shared representation due to collaboration.

In this paper, we define "shared knowledge" as the knowledge that is common to both partners' representations. The question that we need to address is whether this common knowledge is indeed constructed from collaboration. For example, if people knew that alcohol in moderation reduces the incidence of heart attack, then this is a piece of common knowledge. Such a piece of common knowledge is likely to arise from similar experiences with the environment, but not necessarily from collaborative construction in face-to-face interaction. Members of a group or a culture would possess a set of common knowledge as a result of exposure to the same news media (e.g., there was a fire in New York last month), textbooks (e.g., $e=mc^2$) or simply being in the same culture (e.g., it is okay to eat in a classroom).

Researchers from anthropology and linguistics have observed that various kinds of groups that have histories of interaction tend to share a set of common knowledge. For example, Orr (1990) reported that people who practice the same job (e.g., photocopier repair technicians) hold a community memory about machines and customers. Similarly, teams are reported to have a shared mental model about their task requirements, procedures, and their responsibilities, which in turn helps them to work more efficiently especially in emergencies (Cannon-Bowers, Salas, & Converse, 1993; Klimoski & Mohammed, 1994; see also Hazlehurst, 1994 and Sherif, 1936). Thus, it seems that there exists common knowledge, whether it is memory, team mental model, or a way to interpret an image, common to interacting group members in the real world.

However, these observations of common knowledge may arise because the group all experienced the same input, rather than because they co-constructed it. It is difficult to tease these two interpretations apart, because people often share input as well as co-construct during collaboration. Thus, to clearly differentiate the two, we need to examine and demonstrate that some new or incorrect knowledge, *knowledge that cannot be experienced directly from the environmental input* (such as incorrect knowledge or inferred knowledge) has been constructed and shared after collaboration and that construction of such knowledge is clearly linked to the extent of interaction.

Very few studies have even attempted to capture the existence of shared knowledge that resulted from collaboration rather than direct experience. Roschelle's (1992) study did attempt to show a convergence of representation while one high school student pair was learning physics concepts of velocity and acceleration. The students' representation became more similar to each other's after collaboration. How-ever, it was difficult to assess whether the resulting converged representation reflects knowledge that both experienced or was co-constructed, especially based on a single case.

In general, the evidence for socially shared cognition has relied on qualitative evidence based on a select few cases. One of the goals of this study was thus to provide quantitative evidence using clear operationalization of shared knowledge. In this study, college student pairs were asked to collaborate to learn a biology text about the human circulatory system. We were interested in exploring and identifying the role of several variables in collaborative learning, their collaboration was unstructured other than the instruction to collaborate and to talk. Students were individually pre-tested and only those who had inaccurate mental models about the circulatory system (see method section for what constitutes inaccurate models) were allowed to participate. After the pre-tests, students were paired with another student who was equally naive about the topic and collaborated to learn the text and then came back for an individual post-test. Students were given two tests before and after collaborative learning: Terms Task and Blood Path Drawing Task. The Terms Task was to assess what students knew about the topic, specifically about various terms important in understanding the circulatory system. The Blood Path Drawing Task was to assess what students knew about the blood flow in the human body.[2]

Method

Participants

Twenty (nine male and eleven female) pairs of undergraduate students at the University of Pittsburgh participated in the study for course credit. Students were asked to participate if they had not taken any college-level biology classes. Students were asked to stay in the study only if they had inaccurate models (see later coding section) at the pre-test, did not have relevant personal experiences (e.g., open heart surgery), and could be paired with another student of the same gender who could come in around the same time for collaborative learning session. The pairs did not interact with their partner prior to the study except in one pair.

Materials

Text The text used in Chi et al. (1994) was used with a slight revision (the text was originally taken from the chapter on the human circulatory system in a high school biology text by Towle, 1989). The resulting text contained 73 sentences. They were presented in a binder with each sentence printed on a separate page.

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[2] A set of Knowledge Questions was also given to students, but are not included in this paper. It was administered at the post-test (after Terms and Blood Path Drawing Tasks) and did not allow comparison between pre-test and test as to how much new common knowledge was constructed after collaboration.

Terms Task Students were given 19 terms about the human circulatory system (e.g., atrium), and asked to talk about everything they knew about each term, even if it seemed unimportant to them.

Blood Path Drawing Task Students were provided with an outline of a human body (with a heart in it) and asked to draw the blood path of the circulatory system. They were asked to talk about everything that came to their mind as they drew.

Procedures

Pre-test Participants were tested individually on the Terms Task and the Blood Path Drawing Task. This session was audio-taped. The pre-test session took about 15 to 30 minutes. At the end of the session, they were asked not to do outside reading on this topic while the study was in progress.

Collaborative Learning About a week after the pre-test, students were paired with a partner to learn the text. Since most of them had never met each other, they were given some time to get to know each other before the session started: after the experimenter introduced them and initiated conversation (e.g., who were their psychology instructors), she left the room supposedly to check the equipment. The experimenter watched their interaction from a monitor in another room until they seemed to be comfortable with each other. Most students quickly established a rapport with each other (in about ten minutes), discovering a common friend or exchanging information about classes.

Students were asked to help and encourage each other to learn and understand the materials during the collaborative learning session. They were asked to read the text out loud at least once. Participants were informed that they would be tested after the learning was over (a few sample test questions were provided). The pairs shared the text binder, and were provided with paper and pens in case they wanted to take notes or draw. This session was audio- and videotaped. The experimenter was not present in the room during this session, but could hear and watch them from the control room. Participants knew that the experimenter could hear them, but not necessarily that she could watch them. They were allowed to take as much time as they needed to study the text. The actual learning session took about an hour on average, ranging from 40 minutes to one hour and 45 minutes

Post-test Participants were tested individually on the Terms task and Blood Path Drawing Task about a week after the collaborative learning session. This session was audio-taped. Post-test sessions ranged from 45 minutes to 2 hours.

Coding

All the sessions were transcribed. From the protocol, three measures were collected. First, individual knowledge pieces (KPs) students knew were coded using a template from the students' answers in the pre-test and post-test. Second, students' mental models about the human circulatory system

were analyzed. Third, turns the two students took during the collaborative learning session were coded in terms of whether the turn was relevant to their partner's previous contributions. A more detailed coding scheme is reported below along with the reliability measures. A second coder coded 20% of the data independently from the first coder. The coding of the first coder was used throughout.

Template Scoring A template was created to assess how much students knew about the topic presented in the learning text. The template was created based on the information presented in the text. The 73 sentences in the learning text were segmented and collapsed into individual knowledge pieces (KPs) that roughly corresponded to a proposition (e.g., "aorta is an artery"). The template contained a total of 173 KPs. There were two types of KPs: KPs that were explicitly stated in the text (Stated KPs) and KPs that could be inferred from the text (Inferred KPs). An example of a Stated KP is "atrium is the upper part of the heart" which is directly stated in sentence 20 "Each upper chamber is called an atrium." An example of an Inferred KP is "the heart has four chambers." This KP is not explicitly stated in the text but can be inferred by integrating sentence 17 "The septum divides the heart lengthwise into two sides" and sentence 19 "Each side of the heart is divided into an upper and a lower chamber." The template contained 115 Stated KPs and 58 Inferred KPs. The KPs were coded from the students' protocol during the Terms and the Blood Path Drawing Task. The agreement between the two coders was 87%.

Mental Model Analysis Students' initial and final mental models about the human circulatory system were coded to assess changes in how individual knowledge is integrated to form a coherent model of the circulatory system as a whole. Based on students' protocols during the Terms and the Blood Path Drawing task, each student's initial and final mental models were coded into one of the following models: (1) No Loop (NL) model, (2) Ebb and Flow (EF) model, (3) Single Loop (SL) model, (4) Multiple Loop (ML) model, (5) Single Loop with Lungs (SLL) model, (6) Double Loop-1(DL1) model, and (7) Double Loop-2(DL2) model. The seven models differ from each other in terms of the presence and the kind of incorrect conceptions (e.g., blood returns to the heart by way of the same blood vessels) and/or the correct conceptions (e.g., heart pumps blood to the lungs versus left ventricle pumps blood to the lungs). Both the Double Loop-1 and Double Loop-2 models represent the accurate flow of blood through the circulatory system with Double Loop-2 being the most complete model (see Chi et al., 1994 for more details on this analysis). The inter-rater agreement on mental model coding was 94%.

Turn-taking Each turn that a student took during collaboration was coded whether or not it was relevant to their partner's previous turn. A turn can be relevant in several different ways. A turn was coded as relevant, for example, if students answered questions that their partner asked, repeated and/or continued the statement and topic that their partner initiated, or acknowledged what their partner said. A turn

was defined in this study as a change of speaker in their learning dialogue. The transcript occasionally contained non-verbal (e.g., laughs, gestures) turns, but it was coded as a turn if it had information potentially relevant to the partner. Thus, turns that contain only "ok" or "umm" were coded as a separate turn when it could be answers or acknowledgements. Similarly, turns that contained only gestures were coded as a separate turns if it was communicative (e.g., nodding indicating "yes"). Based on this identification of turns, a second pass over the transcript was done to determine whether each turn was "relevant" to their partner's previous turns. A turn was coded as relevant as long as the turn contained information relevant to their partner's previous contribution in some way (see Jeong, under review, for more details). The reliability for this coding was 85%.

Results

The process and outcome of knowledge construction were considered to be interdependent between the two members of the pair in this study. Thus, the unit of analysis in this study was pairs rather than individuals. Although students' pre-test scores were mostly independent from each other's (unless we start considering cultures), their post-test scores, although tests were individually administered, were partly dependent on their partner's score due to their collaboration. Thus, we calculated common KPs as well as unique total KPs to deal with this dependency. In this section, we first describe how much learning occurred and how much common knowledge was constructed after collaborative learning. We then examine in more detail whether the increase in common knowledge was indeed co-constructed from interaction.

Learning and Common Knowledge

Learning was assessed by addressing (1) the number of Knowledge Pieces (KPs) that were learned after collaborative learning and (2) improvement in the pairs' mental model.

Template Scoring: Knowledge Pieces (KPs) Since template scoring gives scores for each partner, the amount of knowledge that the *pairs* knew as a whole was calculated by: (a) an average score of the two students in the pair and (b) a *unique total* score. These scores can be best understood by looking at Figure 1. Circle A represents what Partner A knows, Circle B represents what Partner B knows. *Common knowledge* is defined as the knowledge that both partners possess, represented by the area C, the overlap of the two circles. For example, if both partners know the KP that the heart has four chambers, then they are said to share that piece of common knowledge. On the other hand, *unique knowledge* is defined as the knowledge that only one member of the pair possesses. Learning for each individual is represented by an increase in the size of each circle (A, B) from the pre-test to the post-test. On the other hand, learning for the pair as a whole can be best represented by examining a *unique total* score that that represents the number of distinctive KPs that the pair knew as a whole (see Table 1).

The average score of pairs increased significantly from 19.70 KPs at the pre-test to 47.70 KPs at the post-test, $t(19)=10.08$, $p<.001$, and the unique total score also increased significantly from 32.15 KPs at the pre-test to 72.85

Table 1: The relationship between various scores.

Scores	Areas in Figure 1
Common KPs	C
Unique KPs	(A-C) or (A-B)
Average KPs	(A+B)/2
Unique total KPs	(A+B-C)

KP at the post-test, $t(19)=11.92$, $p<.001$, indicating that students' understanding of the human circulatory system increased significantly after collaborative learning. The amount of common knowledge also increased significantly from 7.25 KPs at the pre-test to 22.55 KPs in at post-test, $t(19)=6.13$, $p<.001$.

Mental Models Consistent with the overall gain in the KPs, there was an overall improvement in students' individual mental models about the circulatory system after learning. Recall that none of the students had the correct Double Loop models at the pre-test, since students were selected that way for the study. The majority of them started with the Single Loop model (55%), followed by the Single Loop with Lungs model (25%). After learning, the majority of the students possessed the most accurate and complete Double Loop-2 model (52.25%), followed by the next most accurate Double Loop-1 model (37.5%). Thus, learning the text with a partner improved the accuracy of the students' individual mental model as well as increasing the number of individual knowledge pieces that they knew, as in Chi et al. (1994).

To determine whether partners' mental models converged onto the same model, each student's mental model was compared to their partner's. At pre-test, 10 pairs (50%) had different initial incorrect models. As stated earlier, none of the models was the correct Double Loop models. Six of these 10 pairs converged onto the same final mental models. However, five of the six pairs' final models were the correct Double Loop-2 model, so we cannot rule out the interpretation that each partner's model converged on the correct model, independent of interaction.

Collaboration and Common Knowledge

Students were not coming up with arbitrary knowledge (e.g., how to name an ambiguous geometric figure) in this study. They were learning a science text that strongly constrains their interpretation and knowledge construction. Since they all learned the same text, the increase in common knowledge and the convergence toward the correct final model, could be the result of individuals learning the same materials from the text rather than their collaboration. In this section, we further examined whether there was any evidence that collaborative dyads co-constructed knowledge from interaction, rather than merely self-constructing their own knowledge, in the presence of an enabling partner.

Common and Unique Knowledge Although pairs had more common knowledge after collaborative learning, they also knew more after learning. Thus, just looking at the number of common KPs could give a false picture without taking into account the increase in total amount of knowledge due to learning. To address this problem, the percentage of common knowledge (over the unique total KPs) was calculated. The percentage of common knowledge increased after collaboration (from 23% to 31%), whereas the percentage of unique KPs decreased after collaboration (from 77% to 69%), $F(1, 19)=11.05$, $p<.005$. This significant interaction indicates that the increase in common knowledge was not a mere reflection of knowing more. In sum, after collaborative learning, pairs gained more KPs overall, but they learned proportionately more common knowledge than unique knowledge.

Nominal Pair Analysis If some parts of common knowledge is co-constructed (rather than learned individually by each partner), then collaborative pairs ought to learn more common knowledge than nominal pairs who did not collaborate. A hypothetical nominal pair was constructed by randomly pairing each member of the pair with a member of another pair. The results showed that there was an increase in common KPs in nominal pairs as in real pairs, but the increase was greater in real pairs (8% versus 4%). Although ANCOVA (controlling for their pre-test scores), did not reveal significant difference between the two conditions, $F(1,36)=2.36$, $p<.14$, the increase in the proportion of common knowledge from pre-test to post-test was significant in real pairs, $t(19)=2.8$, $p<.01$, but not in nominal pairs, $t(19)=1.20$, $p>.10$. Thus, although part of the common knowledge constructed during collaboration was due to learning from the same text (as can be seen in the small increase of shared knowledge in nominal pairs), it seems that part of the increase in common knowledge can be undoubtedly attributed to collaboration.

Incorrect Knowledge Pieces We also examined incorrect knowledge at the knowledge piece level from the pre-test and post-test answers. In total, pairs had 69.25 incorrect KPs at the pre-test and 91 KPs at the post-test. Out of theses, the real pairs did not share any incorrect KPs at the pre-test, but shared a total of 4 at the post-test after collaboration. On the other hand, nominal pairs had a total of 3 common incorrect KPs at the pre-test, but 0 KP at the post-test. Although the numbers are small, the fact that pairs shared 4 incorrect KPs after collaboration suggest that these incorrect KPs must have been co-constructed with their partners during collaboration, rather than encoded and inferred from the text alone independently from their partner.

Common Incorrect Mental Model As mentioned earlier, six of the ten pairs of students who had different initial mental models converged onto the same final mental model. Of these six pairs, five pairs converged on the correct Double Loop-2 model, which could be attributed to having read a text that described such a correct model. One pair, however, converged on an incorrect model. Both of their models had the same "error": They both thought that blood from the lungs goes back to the heart through the ventricle, rather than through the atrium as in the correct model (see Figure 2). Thus, an incorrect model that both partners share strongly indicates that they somehow co-constructed it.
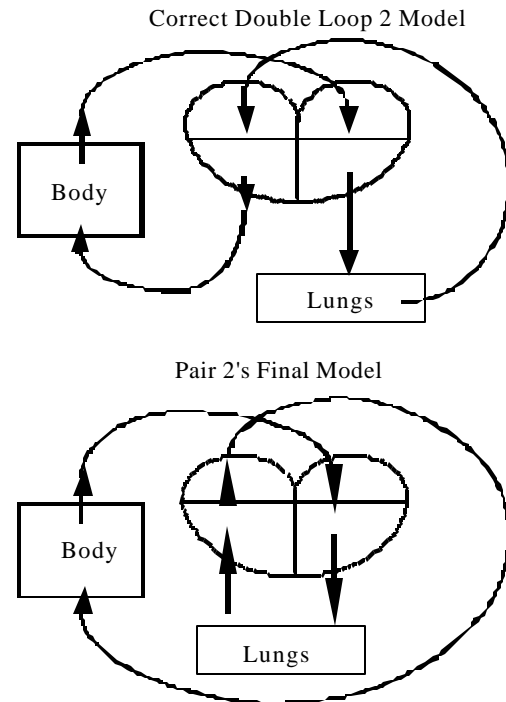

Figure 2: Pair 2's final mental model in comparison to Double Loop-2 model.

Interaction and Common Knowledge If dyads co-constructed common knowledge from interaction, rather than merely self-constructed their own knowledge, it would suggest that the more interaction they engaged in, the more common knowledge they would construct, especially the knowledge that cannot be obtained directly from the text, that is, knowledge that need to be inferred. To test this hypothesis, the pairs were grouped into high-interaction pairs (N=10) and low-interaction pairs (N=10) based on the amount (percentage) of relevant turns they took during collaborative learning.

As can be seen in Figure 3, high-interaction pairs shared more inferred knowledge than low-interaction pairs even after the pre-test difference was controlled, $F(1, 17)=6.10$, $p<.05$. On the other hand, high-interaction pairs did not necessarily shared more stated knowledge than low-interaction pairs, $F(1, 17)=.107$, $p>.10$. Thus, the more interaction pairs engaged in, the more likely they were to construct knowledge that was inferred (i.e., knowledge that was not given in the text). Since the knowledge was never presented in the text, it was more likely that dyads constructed them together through collaborative interaction.
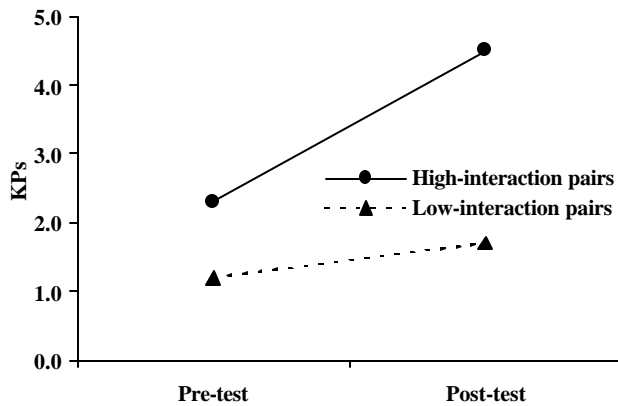
Figure 3: The increase in shared Stated KPs and shared Inferred KPs after collaborative learning in high-learning and low-learning pairs.

Conclusions

In this study, we examined whether collaborative learning, a shared learning activity, leads to the construction of shared knowledge. Among the several potential representational outcomes of collaborative learning, one distinct possibility was that collaborating members of dyads (or groups) would construct common knowledge. To examine whether the common knowledge would really come from interaction rather than sharing the same environmental input, we examined whether students common knowledge when the knowledge cannot be obtained directly from the input. The results of this study showed that collaborating pairs shared more knowledge (correct and incorrect, stated and inferred) after collaboration. Since the incorrect knowledge and the correct but inferred knowledge was never presented in the text, it is more likely that they constructed it during collaboration. Above all, those who interacted more shared significantly more inferred knowledge than those who interacted less did. Even though each of these analyses produced a small effect and/or small amount of data, taken together, these findings indicate that participation in joint activity allows participants to construct a common knowledge.

There are several ways that the pairs went about constructing common knowledge in this study. In one scenario, the two pairs might have contributed to the construction of knowledge more of less equally, each generating part of inferences to complete the knowledge construction. In another scenario, one student might have made an inference, regardless of whether it is correct or incorrect, from the text by herself and tells her partner about it. At this point, the other partner had two choices: he or she could either accept it or reject it (Clark & Schaefer, 1989). It is only when the partner accepted the other's contribution that both of them get to possess the common knowledge. The partner who just heard the inference was more passive than the other person, but nonetheless participated in the construction process.

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