Exploring Convergence of Science Ideas through Collaborative Concept Mapping

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Abstract: This exploratory study examined how groups of sixth grade students worked together to create a collaborative concept map. We selected two contrasting cases based on their initial maps, one heterogeneous group with divergent maps and one homogeneous group with convergent maps. We analyzed group dialogue and collaborative and individual concept maps to understand: 1) if convergence of science ideas occurs during collaborative concept mapping and 2) how convergence or divergence during collaboration influences individual map construction. We found that collaborative concept maps facilitated greater convergence of ideas in groups with initially divergent pre individual maps. Further, the negotiation of divergent science ideas during collaboration led to gains in individual students' science understanding. Implications of findings and directions for future research are discussed.

Concept maps have been used in a variety of educational settings to support meaningful learning (e.g., Daley, et al. 2008) in contexts such as reading (e.g., Nesbit & Adesope, 2006), writing (Sharples, 1994), and measuring conceptual change (e.g., Edmondson, 2000). Concept maps represent knowledge by focusing on relationships between ideas. They consist of concepts delimited by circles and arrows linking two concepts (Novak & Cañas, 2008). Words placed on the arrow explain relationships between concepts.

The use of concept maps has been mainly informed by the cognitivist premise that learning occurs within the individual through the assimilation of new concepts and relationships within existing propositional frameworks. A concept map represents an individual's knowledge structure at a given point in time (Fisher, 2000). However, Roth and Roychoudhury (1994) point out that "the theoretical framework in which concept mapping is grounded is not much concerned with the social construction of knowledge" (p.438). They describe concept mapping as a conscriptional device for social thinking through engaging in discourse, and an inscriptional representation of the groups' shared understanding of concepts and their relations. Further, they assert that new knowledge is constructed in collaborative peer groups, and refer to prior research to claim that this knowledge is taken up by the individual participants through engagement in this social interaction.

Several other researchers have explored collaborative concept mapping activities from a socioconstructivist perspective, and have reported that collaborative concept mapping has potential to support student learning (see Basque & Lavoie, 2006, for a review). In particular, van Boxtel, van der Linden, Roelofs, and Erkens (2002) found in an experimental study that students involved in collaborative concept mapping engaged in elaborate conceptual discourse and co-constructed meaning. They also found that elaborate student discourse influenced individual learning outcomes. Although collaborative mapping research suggests learning benefits, Teasley and Fischer (2008) contend that collaborative activities do not always facilitate individual learning or ensure equivalent learning gains for all individuals. They further state that few studies have explored how collaborative convergence of ideas relates to individual learning outcomes. This issue of convergence and divergence in thinking is critical in collaborative learning. For instance, Stahl (2004) stresses the importance of initially divergent ideas during collaboration. Further, Schwartz (1999) argues that individuals create unique understandings as they attempt to co-construct shared meaning during collaboration.

There is limited research that has investigated what a group map as an inscription represents; that is, whether there is convergence (the construction of shared understanding) in ideas between students as they collaboratively construct a concept map in a classroom, and the effect of collaborative mapping on individual understanding of concepts. In this exploratory study, we examined the level of convergence during collaborative concept mapping. From a socioconstructivist perspective, we also explored if a concept map represents the ideas of an entire group and how collaborative concept mapping relates to individual student understanding. Our premise is that a movement from shared understanding to construction is seen when students generate their own understanding in a new individual context based on previous interactions with others. To document this premise, we employed individual and group concept maps as inscriptional products, and student audio during collaborative concept mapping as a conscriptional process. We first examined the group and individual concept mapping scores of five groups from one science class. We then selected two contrasting cases based on their initial maps, one heterogeneous group with divergent maps and one homogeneous group with similar maps, to explore how the two groups worked together to create a collaborative concept map. Our research questions were: 1) Is there convergence toward a shared understanding of science concepts during a collaborative concept map activity? 2) How does convergence or divergence during the collaborative concept map influence individual map construction?

Methods

Participants and Instructional Context

The study was conducted in a sixth grade science class in a private Midwestern school. Students engaged in a design-based science curriculum to learn about simple machines using the CoMPASS hypertext system to complete a set of design challenges (Puntambekar, Stylianou, & Goldstein, 2007). In this six week curriculum, students brainstormed predictions and questions, conducted research on the CoMPASS hypertext system, and conducted hands on investigations to test their ideas in the same small groups throughout the unit. Students completed five mini design challenges pertaining to simple machines. Students also engaged in several individual and collaborative concept map activities throughout the unit. Practice individual and collaborative maps were constructed during the first half of the unit followed by the pre map in the middle of the unit. Students then constructed post individual maps at the end of the unit. Collaborative concept maps were created at the end of each mini design challenge.

For this study, we used data from the pre and post individual concept maps and students' collaborative maps. Students worked for approximately 45 minutes to construct paper and pencil individual concept maps involving simple machines physics concepts. Students were instructed to draw a concept map with at least nine (on pre map) or 14 (on post map) physics concepts with a description of how the concepts were related. A focus on how the machines work was emphasized in these instructions. In contrast, the collaborative concept map served both as a conscriptional device to aid students in their physics learning and as a group product or inscription of their learning for assessment. For the collaborative concept map, constructed between the pre and post individual concept maps, students were instructed to create a paper and pencil concept map incorporating physics ideas related to pulleys. They worked face-to-face on these maps for approximately 15-20 minutes during their regular science class.

Data Sources and Analysis

We calculated concept map depth ratios to capture the sophistication of science ideas of students in all five groups. Further, we examined the map layout and coded group dialogue captured while students generated their collaborative maps for two contrasting groups, selected on the basis of their initial individual maps.

Individual and Group Concept Map Depth Ratios

For this part of the analysis, we focused on sophistication of concept map propositions. A proposition is two concepts connected by a linking word to form a semantic unit. Modified from prior work (Puntambekar, Stylianou, & Goldstein, 2007), we scored all concept maps based on 1) the number of accurately described concept propositions and 2) the sophistication of science ideas expressed in the propositions. We assigned proposition scores according to a five point scale. This scale ranged from: -1 to 3 (see Table 1). We then calculated a *depth ratio* for each concept map. The depth ratio was calculated by dividing the sum of the scores for each of the propositions on a map by the total number of propositions on the map. A higher depth ratio value signifies more sophisticated understanding of the relationships between concepts. We chose to use the depth ratio to measure student progress because it considers the depth of the propositions regardless of the number of propositions on the map, and gives an average score of the sophistication of all propositions. Two researchers coded 15% of all individual and group concept maps and achieved approximately 90% interrater reliability. One researcher scored the remaining maps.

Table 1: Concept Maps Scoring Rubric.

Score	Description	Example
-1	Incorrect	levers are inclined planes
0	Ambiguous language (has, gives, uses, needs) in reference to concepts (MA, force, friction, distance)	screw has effort force
1	Fact, type of, is a, example, overgeneralization	third class is one of three kinds of lever
2	Definition, affects, intuitive language, increases, decreases	friction reduces MA
3	Scientific language, elaborate explanations, specify conditions for increase or decrease	levers increase the MA when the fulcrum is closer to the load

Individual and Group Concept Map Layout

We compared the map layout of both individual and group maps. We examined the chosen root word and structural organization (relational vs. hierarchical) between individual pre and post maps, and group maps. The chosen root word, or most central concept on a map, could be a machine or a physics concept. A relational concept map differs from a hierarchical map because relationships could be vertical as well as lateral, whereas in a hierarchical map relationships are primarily vertical.

Group Dialogue

We transcribed the audio of student dialogue that occurred during the collaborative concept mapping activity. Total audio data consisted of approximately 35 minutes of audio and seven pages of transcripts. We inductively developed a set of nine codes after a preliminary examination of transcripts to capture the convergent and divergent exchanges between group members as they talked about science to construct their group map (see Table 2). Our codes also align with the transactive knowledge convergence process described by Weinberger, Stegmann, and Fischer (2007). We coded the transcripts at the utterance level. Each utterance could be assigned multiple codes.

We examined percentages of group dialogue to understand both the patterns of overall interactions in each group and the contributions offered by individual students. We calculated percentages by dividing the number of utterances categorized into a particular code by the total number of utterances coded during the collaborative activity. Similarly, the percentages for types of individual talk were calculated by dividing the number of utterances coded into a category by the total number of coded utterances of a particular student. Two authors independently coded 70% of the transcripts and established an interrater reliability of approximately 83%. The first author subsequently coded the remaining transcripts.

Table 2: Coding Rubric for Examining Collaborative Concept Mapping Audio Data.

Code:	Description
Initiation of Ideas (II)	bringing up a new science idea
Simple Sharing (SS)	stating a science idea not taken up by other group members
Agreement of Ideas (AI)	explicit agreement between at least two group members
Contention of Ideas (CI)	explicit disagreement between group members in the form of questions or statements
Resolution of Disagreement (RD)	explicit consensus after a disagreement
Raising Questions (RQ)	asking group members questions about science concepts
Extending Ideas (EI)	refining or elaborating upon other group member's ideas
Restating Ideas (RI)	student restates idea or summarizes many group exchanges
Negotiation of Map Construction (NMC)	dialogue pertaining to what ideas to include on the map and how to position and connect them

Results

We report our findings based on three types of data: 1) individual and group map depth ratios, 2) individual and group map layout, and 3) individual contributions and group interactions, to understand if convergence of ideas occurred and how convergence was related to students' performance on the post individual concept maps.

Depth Ratio Comparisons between Individual and Group Concept Maps

In this section, we discuss concept map depth ratio scores on students' pre and post individual maps and group map scores. We also discuss learning gains made by students as seen in the difference between pre and post map depth ratio scores. We calculated learning gains by dividing the actual gain by the total possible gain from pre to post maps. As we discuss the depth ratio scores, it is important to understand what small differences in the ratios represent. The depth ratio gives an average score of all the propositions on a map. A depth ratio of 1.1 can be best understood as consisting of mostly propositions falling into a level one score (see Table 1). Since the depth ratio has a small range from negative one to three, small changes in scores are meaningful in terms of student learning gains and differences in scores.

In Group A, the pre individual map depth ratios suggested convergence in their, with a difference of only .09 between the highest and lowest scores in the group. Their collaborative map, with a depth ratio of 1.0, reflected a level of understanding similar to what students showed on their individual pre maps. We also found that Rose's depth ratio decreased on her post individual map and she exhibited no learning gain. Both Alex and Lincoln performed slightly better on their post individual maps, with learning gains of 21% and 13% respectively. Group A's average learning gain was 8.6%.

The difference in pre individual map scores in Group B was most divergent at 0.85. In contrast with Group A, their collaborative concept map showed a modest improvement in their depth of understanding (1.39) over their individual pre map scores. Unlike Group A, all students in Group B made substantial gains in their depth ratio scores on the post individual maps with learning gains ranging from 36% to 51%. The average learning gain for Group B at 41% was much higher than any other of the four groups.

The second most divergent group was Group C with a difference of .73 between students' pre individual depth ratio scores. Like Group B, Group C had a higher collaborative map depth ratio score at 1.4 than the other groups. Group C also had the second highest average learning gains at 16% out of all five groups, with all students in the group showing learning gains. Although their average learning gain is smaller than that of Group B's, it is twice the gain than that of Groups A, D, and E.

Overall, Group D and E had depth ratio differences and learning gains similar to those of Group A, including lower depth ratio scores on their collaborative concept maps (at .93 for Group D and .64 for Group E). Like Group A, Groups D and E were relatively more convergent on their pre individual map scores with a difference in scores of .32 and .28 respectively. The average learning gains of Group D at 6.6% and of Group E at 5.8% were slightly lower than that of Group A at 8.6%. Like Rose in Group A, Jesse in Group D exhibited no learning gain and Brian in Group E made a small learning gain.

Thus out of the five groups, Group A had the most convergent initial maps, and Group B had the most divergent map levels before the collaborative concept mapping activity. We therefore examined student dialogue in these two contrasting groups to better understand how students created a collaborative concept map, and how their collaboration affected their individual learning.

Table 3: Depth Ratio Scores and Percent Learning Gains of Students' Pre and Post Individual and Group Maps.

Group	Student	Pre Individual Map	Difference on Pre	Group Map	Post Individual Map	Percent Learning Gain or Loss: Individual Maps	Average Group Percent Learning Gain: Individual Maps
A	Alex	1.00			1.41	21%	
	Rose	1.09			.94	-8%	
	Lincoln	1.06	.09	1.0	1.35	13%	8.6%
B	Betty	0.44			1.29	36%	
	Keesha	1.08			1.77	37%	
	Jake	1.29	.85	1.39	1.60	51%	41%
C	Kristen	1.46			1.60	7%	
	Jerry	1.10			1.33	13%	
	Mary	1.08			1.39	15%	
	Collin	.73	.73	1.4	1.17	20%	16%
D	Naomi	1.12			1.30	10.5%	
	Jesse	1.29			1.16	-5.8%	
	Amy	1.00			1.24	10%	
	Armando	1.32	.32	.93	1.50	11.8%	6.6%
E	Allison	1.22			1.32	5.6%	
	Brian	1.05			1.10	0.03%	
	Gage	1.33	.28	.64	1.48	11.8%	5.8%

Map Layout Comparisons between Individual and Group Maps for Groups A and B

Examining contrasting cases shows potential for understanding how collaborative processes influence learning outcomes (Rummel & Hmelo-Silver, 2008). Alex, Rose and Lincoln were the students in the more convergent group, Group A. While Betty, Keesha, and Jake were the students in the more divergent group, Group B. In Group A, Alex drew the collaborative concept map and in Group B, Betty drew the group map.

Groups A and B present interesting contrasts in their group and individual map layouts (see Table 4). We first examined the root word choices on pre individual, collaborative, and post individual concept maps. We found that all students used a machine as a root word on their pre individual map. Group A chose a machine root word, whereas Group B used a physics concept. Rose and Lincoln in Group A continued to use a machine as a root word on their post individual map, but Alex chose a physics concept. In contrast, all students in Group B changed from using a machine root word to using a physics concept root word on their post map, consistent with what had taken place in the collaborative mapping activity.

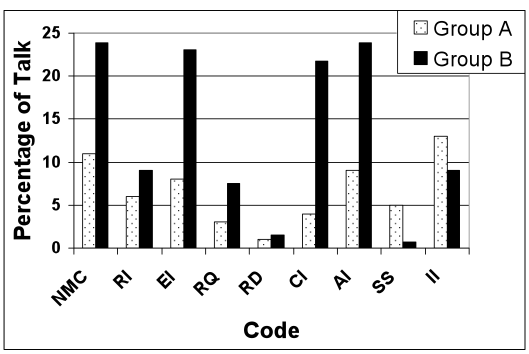
Second, we examined the structural organization of individual and group maps. Our analysis revealed that both groups drew relational group maps. Rose and Lincoln from Group A, and all students from Group B, had constructed hierarchical individual pre maps. Rose and Lincoln continued to draw a hierarchical map, but all students in Group B used a relational structure on the post individual map.

Table 4: Map Layout of Individual Students' in Group A and B's Pre and Post Individual and Group Maps.

		Root Word of Map: Machine (M) vs. Physics Concept (PC)			Map Structure: Hierarchical (H) vs. Relational (R)		
Group	Student	Pre	Group Map	Post	Pre	Group Map	Post
A	Alex	M		PC	R		R
A	Rose	M	M	M	H	R	H
A	Lincoln	M		M	H		H
B	Betty	M		PC	H		R
B	Keesha	M	PC	PC	H	R	R
B	Jake	M		PC	H		R

Patterns of Group Dialogue and Individual Contributions in Groups A and B

We analyzed group dialogue to further understand the convergence or divergence that may have occurred when students engaged in collaborative concept mapping. This analysis was done to a) examine if students' ideas converged through engaging in collaborative interactions, and b) to see how convergence or divergence during the collaborative concept map activity related to individual map construction. These findings will enable us to understand how aspects of group dialogue may possibly explain the changes between students' pre and post individual concept maps. First, we will report on general discourse patterns for each group and compare the two groups (see Figure 1). Subsequently, we will present a more detailed analysis of each individual's major contribution to the group dialogue (see Figure 2).



Code Legend	
NMC	Negotiation of Map construction
RI	Restating Ideas
EI	Extending Ideas
RQ	Raising Questions
RD	Resolution of Disagreements
CI	Contention of Ideas
AI	Agreement of Ideas
SS	Simple Sharing
II	Initiating Ideas

Figure 1. Collaborative Concept Map Dialogue in Groups A and B.

In Group A, the most prominent pattern was initiating ideas (12.5%), agreement of ideas (8.75%), and extending ideas (7.5%). The percentage of talk related to the negotiation of map construction, was 11.25%. In looking at individual contributions to the collaboration, Alex's main contributions were agreement of ideas (20.69%) and extending ideas (13.79%). Rose's major contributions were initiating ideas (25%) and negotiating map construction and restating ideas (16.7%). Lincoln made a limited contribution to concept related talk (12.5%). Overall, the percentage of science related talk in this group during the collaborative concept mapping activity was relatively low, because a good portion of Group A's utterances were off task or not applicable to the study.

In contrast, Group B engaged in relatively more science talk during the collaborative concept mapping activity than Group A. Their dialogue mainly involved agreement of ideas (23.9%), extending ideas (23.1%), and the contention of ideas (21.7%). The percentage of talk related to negotiation of map construction was 23.9%. When examining individual contributions to the discourse, we find that Betty's talk focused on the contention of ideas (25.6%) and extending ideas (25.6%). Similarly, Keesha engaged in the group discourse through agreement of ideas (32.5%) and contending ideas (20%). Jake's principal involvement in the group process was mainly extending ideas (31%), but he also emphasized the negotiation of map construction (29.1%).

We found clear differences between the two groups' patterns of talk. Group A focused less on science, whereas Group B was focused on negotiating science ideas and negotiating map construction. Furthermore, the individual contributions from students in the two groups were also different. In Group A, students engaged less with the collaborative concept mapping and engaged in more talk unrelated to the activity and science. Students in Group B talked more about science concepts and contributed in diverse ways to their group map. Finally, a large proportion of talk in Group B was spent in contending ideas, unlike in Group A.

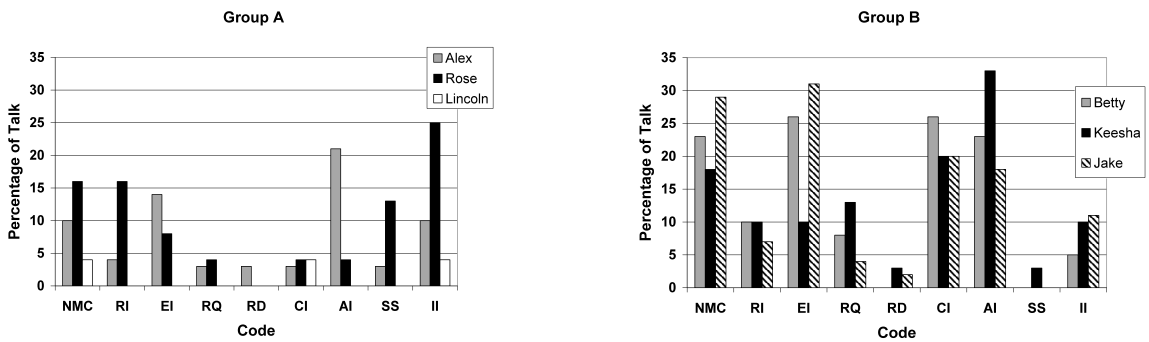


Figure 2. Individual Contribution to Collaborative Dialogue in Groups A and B.

Discussion

Our exploratory study contributes to the literature on concept mapping and collaborative learning because it examines group maps both as conscriptional *processes* and inscriptional *products*. Our study is consistent with Daley et al's. (2008) call for research to understand how groups construct knowledge, and how this knowledge construction aids in group performance. It also aligns with Basque and Lavoie's (2006) emphasis for further investigation of the relationship between collaborative learning and concept mapping, particularly the types of interactions that promote learning.

In investigating whether a collaborative concept map serves as a conscriptional device in the classroom, we found differences between both the product and the process of collaborative concept mapping in the two contrasting groups. Our results indicate that there was less convergence between students in Group A than in Group B during the collaborative process. Roth and Roychoudhury (1994), as well as van Boxtel, van der Linden, Roelofs, and Erkens (2002), claim that collaborative concept mapping promotes shared understanding among students. However, our findings show that whereas a collaborative concept map may act as a conscriptional device to facilitate convergence of ideas, not all groups benefit equally from this activity when used in the classroom.

Students in Group A had pre individual maps that initially showed convergence. The negotiation and contention of science ideas and map construction between these students during collaborative concept mapping was relatively lower than Group B, resulting in a less sophisticated group concept map product, as evidenced by a lower depth ratio score and simple machines root word choice. Derbentseva, Safayeni, and Cañas (as cited in Novak & Cañas, 2008) found that root word choice affects the quality of a concept map. A physics concept root word may promote the creation of propositions focused on *relationships,* resulting in more sophisticated maps. Having a simple machine as a root word may lead to shallower, fact-based links. Further, Alex drew the map and was the only student in the group who made a relational map on the pre and post individual map. Despite having made a relational group map, Rose and Lincoln created hierarchical individual post maps. Ruiz-Primo and Shavelson (1996) have emphasized that relational maps provide a richer representation than a hierarchy, indicating more sophisticated maps. Group A's group map may reflect Alex's thinking more than that of the whole group, which could explain the low convergence in map layouts on the individual post maps.

The dialogue in Group A provides further evidence of a low level of convergence. We found that students in Group A did not participate equally in this process. Alex and Rose engaged in some negotiation of the science concepts, but there was little convergence on science ideas between group members. For example, of the ideas that Rose initiated many were also categorized as simple sharing, because they were not extended by the group, indicating limited mutual engagement as they discussed the science. Furthermore, Lincoln made little contribution to the science discourse. Thus, our findings suggest low convergence of science ideas in Group A.

Conversely, there was more convergence of science ideas among students in Group B. They created a more sophisticated group map than Group A, as measured by a higher depth ratio score, a physics concept root word and a relational organization. Students converged on their post individual map layouts, because all of them changed from using a machine-based root word to using a physics concept root word, and from a hierarchical to a relational structure, consistent with their group map.

Group B's dialogue provides further evidence for convergence. Group B had about twice as much dialogue about negotiation of map construction as Group A. These students contributed in diverse ways to the dialogue, which was more varied and involved more contention and negotiation of science concepts than Group A. Perhaps this dialogue contributed to both the changes and convergence of the map layout on individual post maps.

Our findings suggest that the level of convergence achieved during collaborative concept mapping could have influenced students' performance on the post individual maps. The students in Group A engaged less in constructing a shared understanding of the science ideas. Unlike van Boxtel et al. (2002), we found that students who actively contributed to the discourse did not always exhibit high learning gains. The post map depth ratios showed that Alex and Lincoln had greater learning gains than Rose's, whose depth ratio decreased. While Rose did engage in the science discourse, many of her contributions were not taken up, perhaps resulting in her less sophisticated post individual map and negative learning gain. Thus, the divergence in the level of engagement of ideas during the collaborative mapping activity in Group A could have played a role in their learning, resulting in differences in individual map layouts and learning gains on their post maps.

In Group B, the higher level of convergence during collaboration might have contributed to post map learning gains for all students and to more sophisticated map layouts by all three students in the group. For example, all of the students in Group B changed their root word to a physics concept and changed to creating a relational post individual map after having worked on a relational group map, suggesting greater convergence and sophistication. The higher level of convergence in Group B could explain the substantial learning gains of all individual students in the group. We contend that the remarkable growth of these students collectively and individually can be understood in light of Stahl (2004) and Schwartz's (1999) argument. First, Stahl (2004) suggests that divergent ideas between group members have a significant impact on collaboration. Because Group B started with more divergent individual maps, each student brought divergent ideas to the collaboration. The students also negotiated their diverse perspectives to construct a shared understanding. Individuals construct novel understandings as they attempt to create shared meaning during collaboration (Schwartz, 1999). Students in Group B constructed a sophisticated individual understanding after their collaboration, as seen in their substantial individual learning gains. This notion is further substantiated by examining data from the other three groups. Like Group A, Groups D and E, who were initially more convergent, made the least learning gains out of the five groups and created less sophisticated group maps. Alternately, like Group B, Group C, the second most initially divergent group, had twice as much average learning gain and made a more sophisticated group map than the three more convergent groups. These trends lend further credence to the notion that initial divergence between group members is important for productive collaborations and positive individual outcomes.

These results have important implications for the classroom, because the role that collaborative concept mapping plays as a conscriptional and inscriptional activity becomes complex in a classroom setting. For example, in this study, students did not contribute equally to the group activity, unlike in the experimental studies of van Boxtel et al. (2002). Also, students made unequal gains in their post depth ratio scores, a finding that is consistent with Teasley and Fischer's (2008) argument that collaborative activities do not ensure equal learning gains for all students. One area of concern is that the overall depth ratios are relatively low on individual post maps for students in all five groups. This indicates that there is room for improvement in the depth of science talk and learning gains. Further, our results question the validity of using collaborative concept maps to assess group understanding, because they may not reflect the ideas of the whole group. Specifically, these findings speak to the importance of the teacher carefully structuring and facilitating students' collaborative concept mapping. For example, our examination of transcripts revealed that the teacher focused more on the procedural aspects of map construction, than on emphasizing deep conceptual connections. This may have affected students' engagement with their map construction. Perhaps map quality might improve if teachers explicitly emphasize the importance of making deep conceptual connections in student discourse related to their maps, help students to establish group collaboration norms, and promote metacognitive reflection. Finally, our study sheds light on forming groups for classroom collaborative activities. Our findings lend support for the effectiveness of heterogeneous group composition to promote negotiation of divergent perspectives towards a shared understanding.

Directions for Future Research

Future research could systematically investigate collaborative concept mapping with more groups in the classroom. Utilizing both audio and video to match student dialogue to the shared map referent may assist in this kind of analysis. Novak & Cañas, (2008) argue for presenting a *focus question* to facilitate richer map construction. Future research could explore both the effectiveness of focus questions in generating student negotiation towards shared knowledge construction and their impact during collaborative concept mapping. The growing interest in collaborative concept mapping and other collaborative activities in the classroom emphasizes the need for more research to understand the interactions occurring during collaboration and how these impact student learning.

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