Internalization of Physics Concepts and Relationships Based on Teacher Modeling of Collaborative Prompts

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Abstract: As students create shared artifacts, individuals and the social system co-evolve through dynamic processes in which individuals and groups shape each other. After collaboration, however, it is not always clear what students internalize from this interaction. Even when students are aware of group-work benefits, effective collaboration does not necessarily occur spontaneously within the group context. To address this potential issue, the teacher can facilitate collaboration by modeling how to foster elaborative group discussions. In this paper, we evaluate how teacher modeling of collaboration prompts may increase the quantity and quality of concepts that students internalize before, during, and after collaboration. We found that students who did not observe modeling increased the quantity of connection on their post concept maps. In contrast, students who did receive modeling increased both the quantity and quality of their connections. This suggests that modeling of prompts before collaboration can deepen the internalization of concepts.

Keywords: shared knowledge, collaboration skills, network analysis

Introduction

What happens to individual learning after working in a group? Building on Vygotsky's (1978) idea of internalization, social interactions shape individual learning and development, as "*interpersonal processes* [are] *transformed into an intrapersonal one*" (p. 57; emphasis in original). We base our study on a sociocultural framework that emphasizes that learning is a dynamic individual and collective practice that highlights the transformative nature of social interactions (Rogoff, 2008). As people create shared artifacts, both the individuals and the social system co-evolve through internalization and externalization (Cress, 2013). The individual shapes the group's understanding, and the group shapes each member's understanding.

While learning may be a social process, the degree of internalization depends on both the individual learner and the social context and interactions of the activity (Smagorinsky, 2012). Internalization, also referred to as appropriation by some researchers (Rogoff, 2008; Grossman, Smagorinsky, & Valencia, 1999), means to transform and take as one's own. One key factor that might affect the degree of internalization is the nature of the collaborative interactions. Research suggests that effective collaboration does not necessarily occur spontaneously within the group context (Barron, 2003). The classroom teacher can facilitate collaboration by modeling how to interact within groups and foster better group discussions (Mercer, 2000).

In this study, we examined how teacher modeling of effective collaboration affected students' understanding and internalization of physics concepts and the relationships between concepts. To examine the extent of internalization of ideas resulting from group discourse, we used concept mapping as a tool to organize and represent knowledge. Concept maps help connect ideas by describing the relationship between two concepts (Novak & Cañas, 2006). When students are working in a group, they "engage and interact with their environment to transform particular objects of activity to achieve an outcome, which is mediated by cognitive and physical artifacts" (Hmelo-Silver, Jordan, Liu, & Chernobilsky, 2011, p. 86). Collaboratively constructed concept maps can be used as an external artifact representing shared knowledge (Cress, 2013; Teasley & Fischer, 2008), and changing conceptual understanding (Roth & Roychoudhury, 1994). Our research question was: How does teacher modeling of collaborative learning through prompts for effective collaboration change students' internalization of physics concepts?

Methods

Students in two eighth grade science classrooms taught by the same teacher participated in this study. Students worked in groups of three to five, comprising 11 groups for a total of 42 students (22 female, 20 male). Students engaged in the CoMPASS design-based curriculum (Puntambekar, Stylianou, & Goldstein, 2007), which is an 8-week curriculum about work and energy using simple machines. Students worked in the same groups throughout the unit and had opportunities to practice developing individual concept maps.

Experimental design and procedure

This study used a 2 x 3 experimental design to examine the effects of teacher modeling of prompts on internalizing ideas from a group concept mapping activity. During the study, students in both conditions created concept maps before, during, and after collaboration for a total of 93 maps. Students either received modeling of prompts (6 groups, 27 students) or received no modeling (5 groups, 15 students). In the intervention, students received a list of four individual and four group prompts to support individual and collaborative thinking during the activity. The teacher then read several prompts to the class and explained what the prompt meant in her own words. An example individual prompt was "Justify your thinking about why the concepts or relationship between concepts you contribute are important," and a group level prompt "Ask other group members to justify, give evidence, or support their ideas." Further, the teacher demonstrated a hypothetical situation, such as "How could you help your group if someone says, 'I think we should start with lever'?" Finally, students practiced enacting these prompts in their small groups.

First, students spent 12 minutes creating an individual concept map about the physics ideas they had learned up until that point in the unit. Students in the teacher modeling condition received an additional seven minutes of instruction in how to support individual and collaborative thinking during the group activity time. Then, the teacher gave the students in both conditions identical directions to make their group maps; students were given 20 minutes to collaboratively create their map. The teacher instructed all students to think about deep connections between concepts and provided ideas for starting words and linking words. While working in their groups, students could access resources from previous activities in this unit. At the start of the next class period, students had fifteen minutes to create a final individual map. The entire activity took less than one hour.

Data sources and analysis

In each of the 93 concept maps, we extracted propositions that consisted of a concept – connection – concept set. For example, if a student connected two nodes, "levers" and "simple machines," with a line that had the words "type of" on top, then the proposition is "levers – type of – simple machine." To maintain these connections, the full proposition was chosen as the unit of analysis. We assigned each proposition two codes: a *concept profile* code and a *depth of relationship* code. *Concept profiles* scored the presence (1) or absence (0) of a connection between two concepts. For example, any connection between Friction and Work received a score of one. This isolated what concepts were added or left out of maps over time but did not examine the nature of connection between them. *Concept profile* codes were useful in assessing concept quantity and surface changes.

To extend beyond simply identifying what concepts students connected in their maps, we used a *depth of relationship* code to examine changes in the quality of relationships between concepts over time. Connections between concepts could be assigned a number from zero to four to indicate the depth of relationship between two concepts: absent or incorrect relationships (0), simple relationships (1), equations and definitions (2), simple directional relationships (3), and relationships that elaborate and specify the conditions for the relationship (4). We analyzed concepts as written to preserve the original language during coding, but we later converted concepts into a categorized and reduced format to permit network analysis of key concepts. Two researchers coded the concept maps for depth of relationship and achieved good inter-rater reliability with an overall agreement of 91.5%, weighted $\kappa = 0.885$; all discrepancies were resolved through discussion.

Our analysis explored the quantity and quality of propositions in maps created before, during, and after collaboration to assess internalization. Social network analysis (SNA) provides the opportunity to look at patterns of relationships to provide a more comprehensive picture of student understanding in CSCL contexts (Aviv, Erlich, & Ravid, 2003). In order to quantify the patterns of relationships between concepts while maintaining the networked nature of the maps we used the Epistemic Network Analysis (ENA; Shaffer et al., 2009) tool. This tool, based on SNA, transformed the propositions into co-occurrences and allowed us to build network graphs to study the quantitative relationships between maps. To condense the complexity of each concept map, ENA reduced the number of data dimensions to geometrically reproduce the internal structure of the data and then plotted that reduced map as a node in the space (x, y, z). The resulting dimensions, which explain the greatest variability between the maps, became the axes upon which the mean center (network score) of each map was projected (Shaffer, 2014). Therefore, each concept map became a node in this high-dimensional space and could be analyzed with other nodes from the same condition or time of map creation using a *t*-test. Because we used two separate coding schemes, we compared the concept maps in two loading spaces: one for the concept profiles (*Concept*) and one for the depth of relationships (*Depth*).

Results

Because ENA is a data reduction procedure, each dimension contrasts connections with extremes at each axis end showing primary differences. For each dimension, the first phrase denoted dimension loadings to the negative end of that axis and the second phrase characterized the positive loadings of that axis (see first column in Table 1). A dependent-samples *t*-test was performed to compare the mean network scores between pre and post maps for each ENA dimension for both conditions. This resulted in 12 comparisons that identified what connections accounted for the most difference within the sample, which are also listed in Table 1.

Table 1: Comparing mean network scores by condition over time

	Modeling				No Modeling			
Dimension Name and Description	Pre	Post	*t*	*df*	Pre	Post	*t*	*df*
Concept1: Simple Machine VS. Force & Mechanical Advantage	-0.153 (0.274)	0.005 (0.199)	-1.79	25	-0.027 (0.292)	0.135 (0.260)	-2.47*	13
Concept2: Lever Examples; Applied Force VS. Force	0.055 (0.169)	-0.124 (0.24)	3.40**	25	0.183 (0.187)	-0.064 (0.169)	4.10**	13
Concept3: Specific Machines VS. Mechanical Advantage, Work, & Force	-0.055 (0.139)	0.057 (0.237)	-2.12*	25	-0.091 (0.158)	0.063 (0.197)	2.34*	13
Depth1: Core physics concepts & Simple machines VS. Force & Specific machines	-0.152 (0.299)	-0.087 (0.276)	-0.76	25	0.142 (0.411)	0.119 (0.353)	-0.04	13
Depth2: Force & Simple machines VS. Force & Specific Machines	-0.076 (0.331)	0.093 (0.185)	-2.42*	25	-0.099 (0.231)	0.058 (0.170)	-1.92	13
Depth3: Force, Distance, & Work VS. Force & Specific and Simple Machine	0.044 (0.234)	-0.037 (0.208)	1.79	25	-0.061 (0.260)	0.023 (0.094)	-1.04	13

Note: Standard deviation of mean network score is shown in parenthesis; * $p < .05$, ** $p < .01$.

When comparing changes in *Concept1*, the No Modeling group included significantly more connections to Force and Mechanical Advantage after collaboration. While the Modeling group changed in the same direction, this was not significant. For *Concept2,* students in both conditions significantly internalized more concepts about Mechanical Advantage, Work, and Force but created fewer connections to specific machines. Students in both conditions added more concepts to Applied Force and fewer to Force and Simple Machines over time (*Concept3)*.

In comparing relationship depth, there was only one significant comparison among the six. Neither group of students changed over time when contrasting connections from core physics concepts and simple machines versus Force and Simple Machines (*Depth1*). However, for *Depth2* only the Modeling condition showed a significant difference indicating a shift from connecting Force to Simple Machines versus connecting to Specific Machines. Although there was no significant difference in *Depth3*, each group moved the opposite way of the other. The Modeling group shifted toward interconnecting Force, Distance, and Work; the No Modeling group shifted toward connecting to Force, Specific Machines, and Simple Machines.

Discussion

This study examined how individual learning may be affected by collaboration. Analyzing concept map networks using a network based analysis allowed investigation of the commonality and variance in underlying structures of sets of maps from each condition.

A key focus of collaborative learning is to improve students' individual learning outcomes; the extent of what each student learns, or internalizes, is therefore important to examine (Grossman et al., 1999; Smagorinsky, 2012). We found that students produced higher quantity and quality maps after collaboration; however, this finding had different implications across the two conditions. While students in the No Modeling condition seemed to show more evidence of internalization of connections between force and mechanical advantage (*Concept1*), this condition did not show differences when comparing changes in maps based on increasing the depth of their ideas. Though students added more concepts, these relationships failed to establish deeper connections such as directional relationships between concepts. Students in the Modeling condition showed both higher quantity *and* quality of conceptual relationships after working on their group maps. This suggests that the nature of the collaborative discourse that occurred while students worked on their group maps might have had an effect on internalization of the relations between science ideas.

Because individual physics knowledge was discussed and collaboratively combined to produce a group map, students processed ideas and accessed these collective ideas when constructing their final individual maps (Cress, 2013). The goal of collaboration was not just to create longer lists but to create deeper relationships between concepts, which was seen in maps for the Modeling condition but not in the maps for the No Modeling condition. This difference in condition supports the idea that when teachers model how to elaborate ideas and encourage the elaboration of others, students learn to understand when and how to apply these resources (Mercer, 2000). Student and group understanding underwent multiple and varied transformations during this activity, and each student may have internalized a different set of conceptual relationships. This supports Cress's (2013) assertion that the individual and group system co-evolved. Our study also supports identification of multiple levels of internalization or appropriation across individuals and groups (Smagorinsky, 2012).

The next step in this analysis will be to analyze each proposition in the concept maps in detail and to better understand how relationships between force, distance, work and mechanical advantage change over time and across groups. To support this analysis, we will use the discourse data recorded during collaboration to better understand what happened during collaboration to explain the differences in internalization.

This paper identifies ways in which students' ideas and understanding about physics concepts evolved over time and were affected by their group discussions. Only by analyzing concept maps before, during, and after collaboration could we observe the different ways students may have internalized different concepts during this short, one-hour activity. In summary, our results suggest that after receiving collaborative support for their group work, students improved the quantity and quality of internalized concepts.

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