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Motivating Cognitive Elaboration Through a Knowledge Diversity Manipulation during an Online Collaborative Problem-Solving Task

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Abstract: An experiment was conducted to determine how a knowledge diversity manipulation in an online synchronous collaborative dyad affects the frequency of explanations, particularly explanations that involve elaborating on one's thinking and learning during a problem-solving task. 196 undergraduates were recruited from an all-women's college to collaboratively solve a complex and ill-structured problem designed as a network design task. Thus, the study examined a cognitive diversity manipulation in a relatively homogeneous population. Effects of this cognitive manipulation were compared to the effects of a more social manipulation, which assigned specific task roles to individual dyad members to facilitate collaboration. Results show dyads with knowledge diversity tend to use more explanations to elaborate than dyads with without knowledge diversity, regardless of the social manipulation.

Introduction

What makes collaboration such an effective learning method? Several contemporary collaborative learning methods are designed to instigate explanation by enhancing knowledge diversity within the group (c.f., Doymus, 2007). The rationale often used here is that the information asymmetry instilled by knowledge diversity implicitly motivates students to engage in dialogue (e.g., "What information do you have?") and discourse (e.g., "I disagree."). Knowledge diversity can be engineered in a group by giving group members access to different pieces of the complete task or topic, but not to all (Moore & Corter, 2020); thus, distributing the information necessary to attain full understanding or to complete the task among all members. With distributed information or skills, no single member can complete the task or attain full understanding without verbal interactions and information exchange with their other group members. This has the benefit of encouraging meaningful communication among group members, but also can introduce confusion, and thus some risk of process loss. Additional confusion may arise if group members are not aware that knowledge or skills have been distributed among them. Task roles constitute another facet of knowledge diversity, but a more social one. Here, group members are explicitly assigned different responsibilities, each a necessary part of the work needed to complete a task. Assigned task roles tend to be more scripted and structured than distributed knowledge; yet both are designed to create circumstances in which all group members have a reason to communicate to exchange information and to listen to selectively process new information. Importantly, assigned task roles might also create a symmetry of status and responsibility that encourages participation from all members, because all group members have explicit responsibilities that are key to the accomplishment of the group's goal.

The Computer Support Collaborative Problem-Solving Task

The task was to design an optimal or shortest network connecting a set of points on a map. The participant is asked to design the shortest possible *road* network to connect the points, while simultaneously designing a minimal length tour or *route* connecting all the points (described as the route a supply truck will have to drive using the road network). The route must follow a path that visits all points exactly once, returning to the starting point. The mountains (see Figures 1 and 2, "Kalaktin Mountains") introduce the constraint that the route must travel around (not through) this feature on the map. The river (see Figures 1 and 2, "Grasotho River") – in combination with an explicit rule limiting river crossing to a single bridge – introduces another constraint, creating a bottleneck through which the network must pass. Thus, the complete design optimization task involves two distinct subtasks: attempting to design (a) a minimal-length road network and (b) a minimal route or tour using this same road network. These two subtasks can work at cross-purposes; simultaneously trying to optimize (minimize) the length of the road network and the length of the tour route is challenging and can present interesting (or frustrating) trade-offs.

Cognitive Elaboration

Communication was measured using automatically generated transcripts from the study Zoom sessions. Transcripts were checked for accuracy and human coded to identify instances of explanations. Utterances that raters identified as "explanations" involved stating or elaborating upon task directions (e.g., "We can only build one bridge," "If we make this our - A our base that means we will have to travel this twice."), one's thinking (e.g., "I'm just thinking about like our placement of the bridge," "I don't like that this is so far let me see if I can trace it."), or a proposed action (e.g., "It may make more sense to go from A to E and then to D does," "We're gonna yeah we're gonna have to do one point where we have to travel twice I guess."). Explanations generally involved efforts to coordinate one's understanding with the other member of the dyad and share ideas.

Transfer Learning

To establish a relationship between explanations and learning outcomes, and thus offer evidence that the explanations identified may be evidence of cognitive elaboration, a measure of individual learning was included in the analysis. This measure of learning relied on the frequency of transfer of two network design strategies to a set of five individual post-task activities. Transfer learning is the adoption of learning in one context followed by the application of that learning in another context (Woodworth & Thorndike, 1901). Each of the post-task activities are considered near transfer activities because (a) participants completed them immediately after the training and collaborative tasks and (b) the post-task activities benefit from network design knowledge and skills that are identical to those needed to design an efficient solution for the training and collaborative tasks.

Post-task activities were designed to benefit from (be minimized by) either one or both of two design features: Steiner points and loops (see Figure 3). The frequency with which these design features were transferred to the post-task questionnaire served as the measure of individual learning. A Steiner point, identified and discussed by Jakob Steiner in 1826, in its simplest form is an added node in a graph, which shortens one or more paths. Using a Steiner point on the "Relief Aid" task requires creating a new "intersection" node, not located at one of the villages on the map, from which roads could radiate or connect. Depending on its placement, this innovation enables shorter road or route networks. A loop is a path that circles through a set of points on the map, connecting all the points and returning to the start; in graph-theoretic terms, it is a cycle. The benefit of the loop innovation in this task is that it minimizes backtracking, shortening the route length, thus the total distance of the network. Loops often enable shorter routes or tours, although a loop cannot occur in a minimal road network, which must be a tree, i.e., a connected graph without cycles.

Figure 1.
Images of the collaborative spaces used in the computer supported collaborative problem-solving task. LEFT Map used for training and study manipulations. RIGHT Map used for participant collaboration.

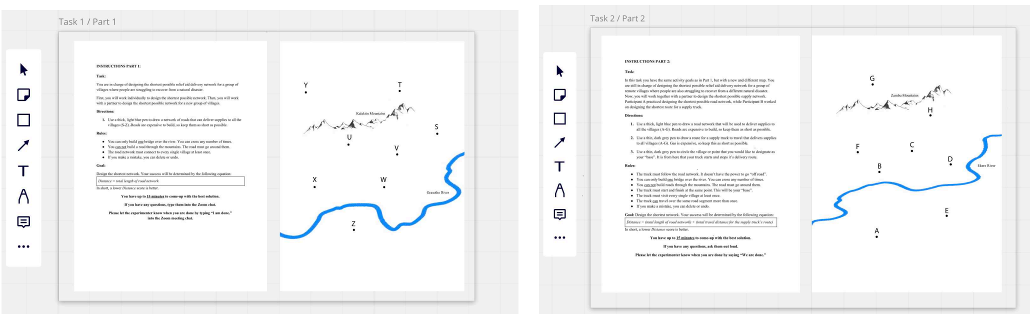


Figure 2.
Two example solutions for the problem of designing the minimal road network (indicated using a blue line) and route networks (directional route indicated by arrows drawn in grey). LEFT exhibits a solution that minimizes the road network length, while RIGHT exhibits a solution that achieves a relatively short route network by reducing the retracing of arcs, but at the expense of road network length.

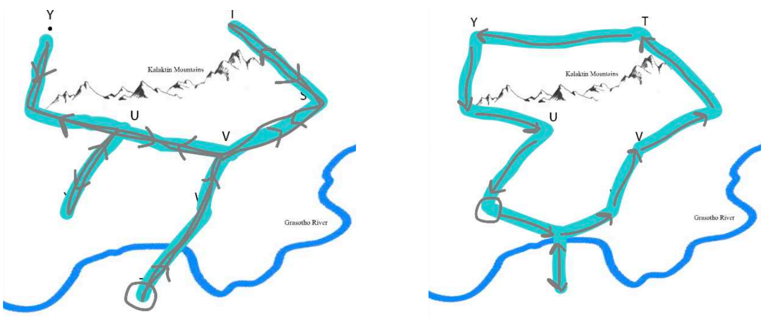
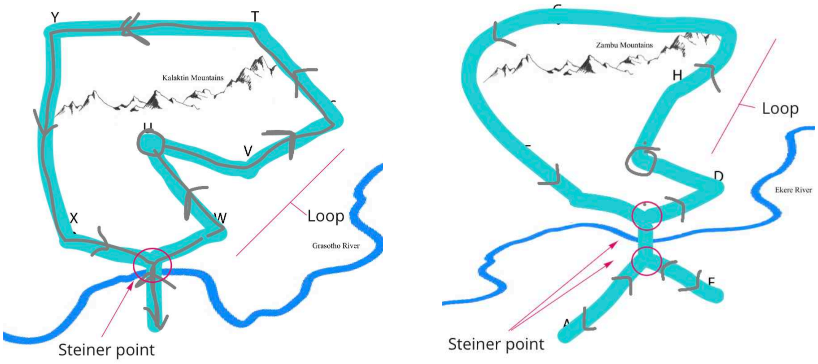


Figure 3.
Two example network design solutions exhibiting the network design strategies used to measure the frequency of transfer learning: Steiner points and loops. LEFT is a map from the training. RIGHT is a map from the collaboration



Research Questions and Method

The study was designed to address the research questions: 1) Does dyadic knowledge diversity affect the frequency of explanations? 2) Do assigned task roles affect the frequency of explanations? 3) Does knowledge diversity interact with assigned task roles in their effects on the frequency of explanations? These research questions were addressed using a two-by-two factorial design with four experimental conditions: Diverse Knowledge with and without Roles, and Shared Knowledge with and without Roles. The experimental procedure involved an individual pre-task or training task, the collaborative task followed by a post-task questionnaire. The manipulations were introduced using the pre-task as a short training task in which each member of a dyad in the knowledge diversity conditions received task directions that introduced them to different sub-tasks or components of the main problem-solving task. After completing the collaborative task, participants worked individually to complete a post-task questionnaire designed to assess transfer learning.

Study Conditions

Study conditions were designed to control and isolate the effects of knowledge diversity and assigned task toles on explanations associated with transfer learning. Participants with knowledge diversity and assigned task roles experienced a Jigsaw-like activity, in which they were given useful knowledge through a training task that differed from their partner's. Participants in this condition were also told which dyad member had prior experience with roads and which with routes. In this way, participants experienced a cognitive manipulation designed to induce knowledge diversity along with a social manipulation of explicitly assigned task roles. In the distributed experience *without* assigned task roles condition participants were *not* assigned task roles. In the joint experience with roles condition, participants experienced the same training task as their partner. Thus, they had shared prior experience from their training task before they collaborated. Task directions informed dyad members of their assigned task roles, explaining that one dyad member was responsible for building roads, and the other for planning routes. Because both participants had the same experience, they were being prompted to role-play, thus introducing a social manipulation. In the fourth condition, joint experience *without* assigned task roles, participants experienced the same training task, but were *not* told to act as if they have distinct roles.

Participants

Participants were recruited through a participant pool system managed by an all-women's college in the United States. Participant demographics reflected the population of the college. On average, participants (N=196) were 19.39 years of age (range, 18-45 years). Participants tended to be majority English speaking (69.2% English, 16.1% Other, 8.4% Chinese, 5.1% Spanish, 1.1% Korean) females (89.9%, female, 7.7% male, 2.2% non-binary, and <1% preferred not to answer), who had not yet earned their undergraduate degree (98.9% no degree yet, 1.1% undergraduate). Participants tended to be undeclared as to major (26% Undeclared, 22% Computational, 21% Humanities, 18% Psychology, 12% Science). While there is some variation in declared majors, this is a rather homogeneous population.

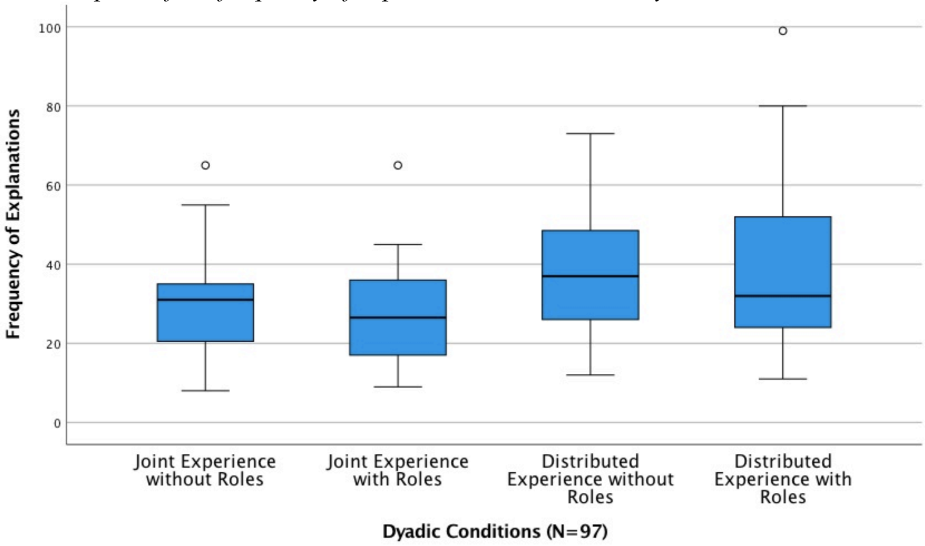
Results

Analysis found a positive correlation between the frequency of explanations that occurred during dyadic group work and transfer learning, $r = .258$, $p < .001$. This aligned with the literature on cognitive elaboration, which has established that the frequency of explanation and elaboration during discourse is positively associated with learning. Analysis of the research questions using a two-by-two factorial ANOVA of explanations revealed a main effect of distributed experience with on the frequency of explanations, $F(1, 98) = 8.142$, $p = .005$ (see Figure 4), with no effect of assigned task roles on explanations, $F(1, 98) = .160$, $p = .690$.

Table 2
Factorial (2x2) ANOVA results for explanations across four Dyadic conditions (JW, JR, DW, DR)

	df	SS	F	p
Main Effects				
Knowledge Diversity	1	3800.575	8.143	.005
Task Roles	1	74.472	.160	.690
Interaction				
Knowledge Diversity * Task Roles	1	254.095	.544	.462
Total	98	21741.16		

Figure 4.
Box plots of the frequency of explanations used in each dyadic condition.



Conclusion

The current study finds that group knowledge diversity can foster more explanations during collaborative dyadic problem-solving work in online settings than assigned task roles. The knowledge diversity examined in this study was induced using a training activity during a network design task, which predisposed members of a dyad to different solutions to the same problem, thus distributing problem-solving strategies among both members of the dyad and inducing knowledge diversity. Results show that dyadic knowledge diversity can be manipulated with a training task to positively affect explanations and learning outcomes. Generalizations from these findings are limited due to the relatively homogeneous sample population.

References

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