Learning Through Collaboration: Designing Collaborative Activities to Promote Individual Learning

Katherine Strong Moore

Submitted in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy
under the Executive Committee
of the Graduate School of Arts and Sciences

COLUMBIA UNIVERSITY

2021

Abstract

Learning Through Collaboration: Designing Collaborative

Activities to Promote Individual Learning

Katherine Strong Moore

An experiment was designed and conducted to determine how knowledge diversity and assigned task roles for members in an online virtual collaborative group affects task performance and individual learning, and to explore the role of explanations as a mediating variable in these effects. The effects of knowledge diversity and assigned roles were examined in a collaborative network design-problem solving task, along with two control conditions to compare with individual work with and without self-explanations. Results show that explanations in dyadic discourse improve individual learning, and that groups with knowledge diversity tend to use more explanations than groups with assigned task roles. The results suggest that knowledge diversity and explanations are both important factors in determining how much individual learning occurs and how well it transfers from collaborative activities to similar, novel tasks.

Table of Contents

List of Charts & Graphs

Acknowledgments

First, I must acknowledge and thank my advisor, Professor James Corter. He has worked tirelessly with me since I started the Cognitive Science in Education program in 2013. His quick, concise, and insightful feedback has guided me through a Master's in Philosophy, three grant proposals, a published book chapter, and the COVID-19 pandemic. I can't thank him enough for his patience and confidence.

I would also like the acknowledge the incredibly hard work of the undergraduate research assistants involved in the pilot and the current study. On the pilot, these research assistants were Kyra Dawkins, Cyrus Hadavi, Sarah Jednak, Nick Kathios, Ali Keith, Leo Lv, Anuta Rathe, Amei Shank, and Nha-Uyen Pham. On the current study, the research assistants were Alisha Arshad, Brianna Hodges, Casey Qi, Eleanor Madeleine Lin, Hailey Madison Wetherill, Joshua Franklin Uhlfelder, Maya Sundar, Melody Jane Lu, Noah W Bell, Patrick Tong, Sonya Xu, and William Kieffer. A particular thank you to Neha Meta, Maya Sundar, Brianna Hodges, Eleanor Madeleine Lin, Noah W Bell, William Kieffer, Alisha Arshad, Casey Qi, and Hailey Madison Wetherill for continuing to work on the project in the Summer of 2021. The data processing for this project would have taken years without their diligent, careful, and incredibly hard work.

Lastly, I must thank my family for their support. My Mother, Cynthia, and my Father, Tod, for helping me transition into parenthood while continuing to gather data, conduct analysis, and write this dissertation. Thank you to Sterling for stepping in to take care of my daughter during the last month so I could finish, start and new job, and move to a new city safely. Most importantly, thank you to my life partner and best friend, Piete, whose steadfast and infinite love has powered me through the long days and even longer nights of work. This research could not have been completed without their guidance, confidence, and support. It takes a village!

Dedication

I gave birth to two babies during the COVID-19 pandemic: this dissertation and my beautiful daughter, Cassidy. This dissertation is dedicated to her, for being the most wonderful baby a graduate student and mama could ask for. Cassidy, without your naps this dissertation would not have been possible.

Chapter 1: Introduction

Peer collaboration has been identified as an effective educational approach to promote learning and discovery (e.g., Johnson & Johnson, 1999; Barron, 2003), exchange of original insights and critical thinking (Bos, 1937), resolution of differing perspectives through argumentation (Amigues, 1988), observations of alternative strategies (Azmitia, 1988), attention to explanations (Webb, 1985), greater transfer of learning (Brandon & Hollingshead, 1999), and social skills such as communication, presentation, problem-solving, leadership, delegation and organization (Cheng & Warren 2000). Recently, collaboration has been identified as a critical 21st-century skill for workplace success (Rios et al., 2020).

For these reasons, collaborative group work has become an increasingly common practice in K-12 classrooms, particularly those implementing STEM curricula, e.g., the Next Generation Science Standards (NGSS), and Project Based Learning (PBL). School districts, state departments of education, national research organizations, and curriculum specialists in the U.S. recommend (or even mandate) the use of peer-based learning (California State Department of Education, 1985, 1992; National Council of Teachers of Mathematics, 1989, 1991; National Research Council, 1989, 1995). The apparent success of this approach (see Johnson & Johnson, 1989) inspired Slavin (1999) to suggest that it is one of the greatest educational innovations of recent times.

What makes collaboration such an effective learning method? Prior evidence amply documents that groups tend to perform and innovate better than individuals. One possibility is that groups with knowledge diversity – a difference in perspectives or heuristics among group members that promotes different strategies and innovations during collaborative group work –

may have some advantages over less diverse groups and certainly over individuals (Moore & Corter, 2020). To clarify the effects of knowledge diversity, the current study attempts to separate the effects of a cognitive component (i.e., a training task that uses different subtasks to distribute experience of different solutions or insights among group members) and a social component (i.e., explicit assignment of nominal roles to distribute social responsibilities among group members).

To further explore why groups tend to perform and innovate better than individuals, this study investigates the mediating effects of cognitive elaboration, a mental sense-making activity that is presumed to occur automatically due to the cognitive demands of dialogue as one explains one's memories, actions or thinking aloud to another person. In an attempt to isolate the effects of this factor from other social and cognitive effects of group work, the study design adds a similar elaboration component (i.e., self-dialogue, also called "self-explanation") in one individual-work condition. In this condition, participants are prompted to explain their thinking aloud while working solo.

The subsequent sections explain the background and rationale for designing this study in greater detail. A problem statement and statement of specific aims are also included to clearly illustrate the issues the proposed study plans to address. These sections are followed by statements describing the scientific significance and broader impact of the results to contextualize the theoretical and practical relevance of these findings.

1.1 Background and Rationale

Collaborative group activities invariably involve some discussion and sharing of ideas. Discussion and discourse require summarization and articulation of ideas, and the planning of utterances to help another person understand. These linguistic processes require cognitive elaboration, invoked automatically in the process of explaining one's thinking either to oneself or to another person. Research has shown that when participants explain or elaborate, they are better able to make associations and retain information (Fisher & Craik, 1980; Baddeley, & Woodhead, 1982). More productive discussions and collaborations have been identified as those in which participants directly engage with another's thinking (Kuhn, 2015) and communicate to create a shared representation of the problem (Schwartz, 2015). Importantly, when explanations are offered during a collaborative learning activity, the speaker (and to some extent the listener) tends to experience positive individual learning outcomes (Webb, 1985; Voiklis & Corter, 2012). Interestingly, the creation of explanations has been shown to have beneficial effects on understanding and memory, even when they are generated only for oneself, as the cognitive literature on self-explanations demonstrates (e.g., Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, deLeeuw, Chiu, & Lavancher, 1994).

However, simply placing students in groups (expecting them to work together and communicate) does not necessarily lead to cognitive elaboration. Some individuals and groups may not have the needed social skills to interact productively. Some students will defer to the more able or more assertive students in the group, who may then take over the important roles in ways that benefit them at the expense of other group members. Similarly, other students will be inclined to leave the work to others while they exercise only token commitment to the task ("social loafing") (Latané et al. 1979). These potential issues highlight a need for social structures that encourage and facilitate explanations (and hopefully, cognitive elaboration), as opposed to trusting that they will simply occur on its own.

Additionally, when group members are actually engaged in explanation during collaborative group work, it is unclear whether all individual members benefit. Even engaged groups have been shown to fall prey to information processing limitations arising from cognitive and social processes, such as neglecting relevant information (Tindale, 1993) and premature commitment to one solution (known as "groupthink"), committing resources to failing projects (Smith, Tindale, & Steiner, 1998), production blocking by individuals (Diehl & Stroebe, 1987).

Perhaps because of these risks of "process loss" in groups, there is a growing consensus among researchers and educators that collaborative activities must be carefully designed and scripted to effectively promote learning (e.g., Barab et al. 2009; Dillenbourg & Betrancourt, 2006; Dow et al. 2011; Johnson & Johnson, 2009). Students learn because their interactions require particular cognitive activities (e.g., information summarization, explanation, disagreement, mutual regulation, and argumentation) that trigger learning (Cohen, 1994; Kuhn & Crowell, 2011; Voiklis & Corter, 2012; Kuhn, 2015, 2016). Several of these types of activities and educational interventions – ones that encourage these cognitive activities – are reviewed in detail in the subsequent section and structured literature review.

Results from this structured literature review suggest that many contemporary collaborative learning methods studied (and recommended) today are designed to instigate explanation by enhancing knowledge diversity within the group. 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."). In the classroom contexts examined in the literature review, knowledge diversity tends to be induced by forming ability heterogeneous groups or by introducing task roles as is the case in collaborative learning methods such as Reciprocal Peer Tutoring (RPT), Student Teams-Achievement Divisions (STAD), and Jigsaw. These collaborative learning methods tend to rely on two common aspects of collaborative activities to create knowledge diversity in a group; knowledge diversity and task roles.

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; 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. This is especially true if task roles have been assigned in the group, but the necessary information is not actually known by the designated "expert" (Tan, Sharan, & Lee, 2007). Additional confusion may arise if group members are not even aware that knowledge or skills have been distributed among them. This later obstacle may have occurred during the pilot study. For this reason (and because of its prevalence in contemporary collaborative learning methods), the proposed project includes a condition that explicitly alerts participants to their distributed knowledge (also referred to as knowledge diversity). This condition is referred to here as assigned task roles.

Task roles constitute another facet of knowledge diversity. Here, group members are explicitly assigned different responsibilities or scripted roles, 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 create social circumstances in which all group members have a reason to communicate in order to exchange information and to listen in order 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 structured literature review suggests that both distributed knowledge (also referred to as knowledge diversity) and task roles are valuable because they offer structure to collaborative learning activities and dialogue that increase positive effects on student achievement and learning; however, because they appear together frequently, their effects are confounded. This project attempts to tease these effects apart.

1.2 Problem Statement

Empirical classroom studies have implicated particular aspects of collaborative activities as beneficial – specifically, group knowledge diversity and assigned task roles. Documenting these positive effects have brought the field closer to understanding what makes collaboration an effective learning method. However, the problem is that many of the studies demonstrating these positive effects on individual learning are poorly controlled classroom studies (Moore & Corter, in press). Thus, the studies are not well positioned to 1) distinguish between the effects of these aspects nor 2) establish mediating mechanisms responsible for the success of these aspects. Laboratory studies are needed to independently manipulate and compare the main effects and possible interactions of these aspects.

1.3 Specific Aims

The current study tests the main effects of particular aspects of collaborative learning activities – group knowledge diversity and assigned task roles – on 1) explanations as a mediating variable and on 2) the outcome variables of task performance and individual learning. The study is designed to determine how the knowledge diversity of the members in a collaborative group affects the frequency of explanations and how explanations mediate the effects of knowledge diversity on task performance and individual learning.

If explanations prove to be a critical mediating variable for collaborative learning (as the literature suggests), then it may be valuable to determine whether it necessarily interacts with group work. To make this determination, the study includes individual work and individual work with self-explanations as two control conditions to compare against the effects of group work and isolate the effects of explanations on the outcome variables. In both control conditions, participants work independently, but in one control condition participants were prompted to explain their thinking aloud as they worked. With this addition, the study design can determine whether the positive effects of explanations are independent of group work.

1.4 Scientific Significance

The current study offers three findings, which affirm understandings prevalent in literature of group diversity and cooperative learning. First, the study affirms the known relationship between explanations and individual transfer learning; positively associating the frequency of explanations and individual learning. Second, the study affirms the known relationship between explanations and group performance; positively associating the frequency of explanations and group performance on a collaborative problem-solving task.

Third, the study finds that explanations mediate a relationship between group knowledge diversity and individual transfer learning. Literature on cooperative learning understands that groups composed of members with diverse knowledge (also referred to as group knowledge diversity) and assigned roles are more likely to learn than members of groups without these structures; however, this research leaves unresolved the question as to what aspects of this cooperative learning method influence individual learning outcomes. The current study addresses that question and finds that collaborative work in knowledge diverse groups can positively affect individual transfer learning through the frequency of explanations, regardless of whether task roles are assigned. Thus, the current study affirms an indirect relationship between group knowledge diversity and learning, which has informed the development of several cooperative learning methods, i.e., Jigsaw.

1.5 Broader Impact

These results support current understandings of the merits of group diversity, clarifying that diversity can positively affect individual transfer learning (a) when group knowledge diversity is introduced using a training task in an online setting to distribute the experience of solving discrete sub-tasks or components of the larger problem among members of the group, and (b) when explanations are offered during the collaborative conversation (i.e., spontaneously, in response to a question, or otherwise). Results from the current study can offer practitioners and educators additional assurance that cooperative learning methods that use engineered knowledge diversity (i.e., from a training task) (e.g., the Jigsaw method) to stimulate transfer learning outcomes are effective.

Chapter 2: Literature Review

This chapter provides a structured review of empirical research on collaborative learning methods conducted in the past thirty years, for the period 1990 – 2020. The aim is to offer readers a survey of relatively current practices (after the 1980's); essentially offering a summary of collaborative learning methods ranging from minimally to highly effective and highlighting "what works." The chapter begins with a brief consideration of the what, when, and how of collaborative learning methods. What exactly is "collaborative learning"? When and how is collaborative group work beneficial? The chapter summarizes relevant empirical literature with an eye towards providing some answers to these questions. For the "what" question, it describes some of the varied methods and activities that have been studied as collaborative or collaborative learning. For "how", it discusses specific outcome variables that can be improved by structured group work activities. For "when", it tries to clarify under what conditions beneficial effects of collaborative learning have been found.

To begin, the chapter addresses the "what" question with a focus on terminology used throughout this review. Clarity is needed to disambiguate commonly co-occurring terms such as "cooperation" and "collaboration", "achievement" and "learning", "group diversity", and "collaborative discourse". The following section attempts to describe how these terms are applied in the subsequent structured literature review (Section 2.2), by drawing connections between these terms and the literature and contextualizing them in the current study.

2.1 Terminology

Collaborative Learning

There is some disagreement in the literature as to the exact meaning of "collaborative learning". To some researchers, the term implies any group or partnered activity within an educational context, such as studying or sharing assignments (e.g., Dillenbourg, 1999). A similar term, "cooperative learning" may be defined as organized and managed group work, during which students work in small groups to achieve academic as well as affective and social goals. Hundreds of studies over the past three decades have associated cooperative learning and collaborative learning with gains in achievement, interpersonal skills, as well as attitudes towards school, self, and others (for literature reviews see Sharan, 1980; Johnson, Johnson, & Stanne, 2009; Slavin, 1992; Cohen, 1994). Importantly, cooperative learning may lead to gains in thinking skills (Johnson & Johnson, 1990; Qin, Johnson, & Johnson, 1995).

Some writers have drawn a distinction between cooperative learning and collaborative learning. Stodolsky (1984) makes such a distinction, proposing that "cooperative" be used to indicate that students are working together toward a common goal. Typically, the cooperative task is a complex problem that is broken down into parts and distributed among members to be mastered individually or in smaller teams. Aronson's et al. (1978) jigsaw puzzle is an illustration of this approach to group learning, wherein the cooperative task involves the exchange of partial solutions and their synthesis to generate a final solution. Thus, cooperating groups typically divide the common task into several subtasks and merge their results later.

In contrast, collaborating groups try to solve the learning task as a whole (Huber & Huber, 2008). According to Roschelle and Teasley (1995), collaborative learning demands joint efforts for coordinated learning activities based on students' understanding of collaboration as, "a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem" (p. 70). Thus, collaborative groups typically create social structures, roles, and responsibilities within the group necessary to complete the group task.

In cooperative activities, these structures tend to be implemented by an instructor, while collaborative groups tend to generate these structures without such support. However, this distinction is not consistent across the literature. According to some authors, cooperative learning is more appropriate for learning and processing foundational knowledge, such as learning facts and formulas, while collaborative learning is considered better suited for learning non-foundational higher order knowledge, which requires a critical approach to learning (Bruffee 1995; McWhaw & Schnackenberg, 2003).

Of course, both cooperative and collaborative approaches constitute a student-centric approach to learning, and many of the strategies for one can be adjusted slightly to align with the principals of the other (Jacobs, 2015). Thus, this dissertation does not make a distinction between these two terms; it preserves the term "cooperative learning" in the review of the literature (as this aligns with the authors' chosen language), and otherwise refers to both types of tasks as "collaborative learning" methods and interventions.

Achievement

Collaborative learning is widely acknowledged to have positive effects on achievement, but 'achievement' is a broad term that can encompass measures of long-term academic success (assessed over the course of several semesters), semesterly or quarterly achievement (measured by the subsequent marking periods grades), or a post-task assessment (administered immediately after the intervention). For the sake of contextualizing findings from the reviewed studies – and better addressing the "how" question – the type of achievement measured by each study is categorized into these three types of achievement, which are labeled in Table 1 as "long-term test", "course grade", and "post-task test" respectively.

Group Diversity

Groups theoretically have access to the knowledge and perspectives of all group members, unless the sharing of this knowledge is impeded by social factors or time constraints. Thus, it has been argued that diverse groups show performance advantages and are more likely to develop innovative solutions in a task, because their diversity affords the group a greater number of ideas, solutions, and perspectives to consider (Gabbert et al., 1986; Page, 2007, 2010). Diverse groups may also show learning advantages, because they expose individual members to a greater variety of concepts and solutions to learn. In both cases (performance or learning), the effects of diversity are due to cognitive differences, e.g., differing knowledge, perspectives, heuristics, or ideas; it is knowledge diversity (including ability differences) that has the clearest implications for learning.

Some collaborative learning methods, for example the Jigsaw method (Aronson, Blaney, Stephan, Sikes, & Snapp, 1978) described below, employ structured tasks or activities that create different specialized roles for members of the group. This has several benefits. First, the specialized roles can result in differences in perspectives and knowledge, thus promoting knowledge diversity. Second, asymmetries in knowledge create a need for communication, thus maximizing the probability of meaningful dialogue among group members (Voiklis & Corter, 2012; Brennan & Clark, 1996). Third, designating each member of the group as the resident expert in some aspect of the task or problem can overcome certain factors (e.g., shyness, status differences) that might otherwise keep some group members from contributing to the discussion.

Several of the reviewed studies attempt to introduce knowledge diversity with a prior experience or training task, either by creating processes that distribute information among group members or by assigning different roles to group members. To examine the effects of these types of knowledge diversity, the structured literature review highlights whether diversity is introduced using heterogeneous grouping of students (HG) based on ability, achievement, or demographics. It also highlights use of differentiated task roles (DR) as part of the collaborative learning method.

Collaborative Discourse

Distributed experience from a training task and assigned task roles are of interest in the current study, but they are two of many strategies designed to motivate collaborative discourse. Collaborative discourse is a social communication designed to exchange information for the purpose of accomplishing a shared goal. Collaborative discourse is believed to motivate students to probe each other's minds to some degree, per chance encountering new or reaffirming ideas, and thus increasing the likelihood an individual learns from the experience (cf. Azmitia, 1988; Bos, 1937; Brandon & Hollingshead, 1999; Johnson & Johnson, 1999).

Some of the methods examined here rely on a more advanced form of collaborative discourse, termed argumentation (Amigues, 1988) or argumentative discourse (Kuhn & Crowell, 2011; Kuhn, 2015, 2016). These collaborative learning methods motivate students to take on different perspectives and scrutinize each other's (and their own) positions. This scrutiny is valuable because it makes it more difficult to come to an agreement and reconcile opposition positions, which increases the need for particular types of communication, such as explanations, that focus on gaining an understanding of what the other person is saying.

Ultimately, educators aim to instigate collaborative discourse because it motivates students to pay attention to the explanations of others, and it is this attention that is believed to play an important role in consolidating knowledge (Webb, 1985). Thus, it is possible that collaborative discourse may be critical to any benefits collaborative learning activities afford students. While determining the importance of collaborative discourse is beyond the scope of this literature review, this project aims to examine specific aspects of collaborative discourse. The following chapter (Chapter 3: Method) explains how the current study examines explanation as a measure of "cognitive elaboration," (Webb, 1985) a key aspect of collaborative discourse. Here, the concepts of collaborative discourse and argumentative discourse have been referenced to describe and highlight a common aim of many of the following collaborative learning methods.

2.2 Structured Review of Collaborative Learning Methods

What follows is a systematic overview of contemporary (published 1990-2020) collaborative learning methods that have been evaluated in empirical studies of student collaborative work in authentic classroom settings, using the criterion of student achievement. Each method is presented with a brief definition and a summary of findings from relevant studies regarding effects on learning outcomes, i.e., achievement.

Selection criterion for the included studies were that studies had to compare differences in achievement or individual learning between a group of students participating in a collaborative learning activity and a comparison group (i.e., students working alone, students working with adults, students working in a traditional whole class instruction model) and be conducted in a classroom setting of students ranging from primary to undergraduate age. Additional screening criteria for the data and statistical analysis reported were also applied to ensure that all studies could yield an effect size estimate. In the end, a total of 76 studies on collaborative learning met the criteria for inclusion. All included studies were conducted since 1990, with 58 percent conducted since 2000, and 22 percent conducted within the past 10 years. Collectively, these studies include 15,299 students, with 29 percent from elementary schools, 18 percent from middle schools, 14 percent from high schools, and 38 percent from postsecondary and adult settings.

Studies identified by this structure review were synthesized into 12 specific cooperative learning methods, which are summarized in Table 1. These methods share the common goal of motivating of group discussion, and all attempt to evoke the common mechanism of cognitive elaboration or explaining one's thinking or reasoning to another person. However, the strategies for evoking these behaviors vary. In some methods, explanation is encouraged implicitly, via enhanced diversity of the group members, or explicitly, via scripted activities that create distributed experiences, assigned task roles, or scripted interactions. Again, the common purpose of these manipulations is to create group environments that evoke dialogue, advanced questioning, or the negotiation of meaning. Yet, these approaches have varying effects on individual achievement and learning. Evidence regarding the effectiveness of the methods is provided by the effect sizes summarized in Table 1.

Table 1 exhibits the twelve empirically evaluated cooperative learning methods (Column 1: Name of Method) with references to each study used to review and evaluate the method (Column 2: Empirical Study) along with a) the effect size (Column 3: Effect) of each method on individual learning, defined by Cohen's d, b) the subject or content area (Column 4: Content) in which the study was conducted, c) the type of achievement measure used to index individual learning (Column 5: Achievement), and d) the strategies(s) each method uses to impose structure on the group work (Column 6: Structure).

Methods listed in this table are ordered by their median observed effect size; the method with the greatest median effect size is listed first. Each type of collaborative learning method listed in Table 1 is described below to illustrate their implementation in the classroom studies. In these paragraphs, methods with mixed significant and non-significant results are marked with an asterisk, and those showing consistently significant effects are marked with a double asterisk.

Table 1. Twelve collaborative learning methods empirically evaluated in classroom-based studies since 1990.

Name of Method	Empirical Study	Effect	Content	PT	C	LT	HG	DR	PI	IG
Cooperative Roles	Acar & Tarhan (2008)	2.735	Chemistry	X			X	X		
	Acar & Tarhan (2007)	2.520	Chemistry	X			X	X		
	Kumar et al. (1998)	1.247	Mathematics	X				X	X	
	Aydin (2011)	0.740	Science Lab		X			X		
	Lee et al. (2002)	0.411	Social Studies		X		X	X	X	
Guided Reciprocal Peer Questioning	King (1991)	1.042	Mathematics	X					X	
	King et al. (1998)	0.988	Science			X		X	X	
	Souvignier & Kronenberger (2007)	0.322	Mathematics		X			X	X	
Cooperative Base Groups	Bayraktar (2011)	0.962	Gymnastics		X		X	X		
	Giraud (1997)	0.782	Statistics		X					
	Bunrasi (2012)	0.571	Algebra	X			X			
Student Teams-Achievement Divisions (STAD)	Kırık & Boz (2012)	1.357	Science	X			X			X
	Whicker & Nunnery (1997)	0.751	Pre-Calculus	X					X	X
	Jalilifar (2010)	0.680	English	X			X			X
	Nichols (1996)	0.188	Geometry		X		X			X
	Adesoji & Ibraheem (2009)	0.144	Chemistry	X			X			X
	Randolph (1992)	0.084	Biology		X					X
Team Assisted Individualization (TAI)	Tarim & Akdeniz (2008)	1.007	Mathematics		X		X			X
Cooperative Assessment	McCall (2017)	1.505	Biology	X						X
Jigsaw	Tarhan & Sesen (2012)	1.422	Chemistry	X			X		X	
	Şahin (2013)	1.329	Grammar	X			X			X
	Şahin (2010)	0.978	Education	X				X	X	
	Doymus (2007)	0.973	Chemistry	X					X	
	Şahin (2011)	0.865	Grammar	X			X		X	
	Lampe et al. (1996)	0.840	Social Studies	X				X		X
	Chu (2014)	0.495	Economics		X		X	X	X	X
	Webb (1992)	0.295	Psychology		X				X	
	Oakes et al. (2019)	0.273	Anatomy		X			X	X	
	Holliday (1995)	0.268	Geography	X			X	X	X	
	Shaaban (2006)	0.244	English	X				X	X	X
	Hänze & Berger (2007)	0.237	Physics		X				X	
Group Investigation	Shachar & Fischer (2004)	0.882	Chemistry		X				X	
	Tan et al. (2007)	0.154	Geography		X				X	
Reciprocal Peer Tutoring	Ortiz et al. (1996)	0.676	Social Studies	X			X		X	X
	Fuchs et al. (1999)	0.248	Reading	X			X	X	X	X
	Fuchs et al. (2000)	0.025	Reading	X			X	X		X

Voluntary Study Groups	Yetter et al. (2006)	0.143	Psychology	X						
	Overlock (1994)	0.104	Physics		X					
Problem-Based Learning	Bradley et al. (2002)	0.129	Chemistry		X		X	X		
Non-Voluntary Study Group	Baker (1995)	0.021	Comp. Science		X					

Achievement:
PT = Post-Task Test
C = Course Grade
LT = Long-Term Test

Structure:
HG = Heterogeneous Grouping of Students
DR = Differentiated Student Task Roles
PI = Prescribed Student Interactions
IG = Interdependent Goals & Rewards

*****Cooperative Roles***

A collection of studies on structured "cooperative scripts" has demonstrated that students working together learn better when assigned specific roles, such as being designated the "recaller" or the "listener" (Dansereau, 1988; O'Donnell, 1996; Newbern, Dansereau, Patterson, & Wallace, 1994). In this method, both group members read a section of text. The recaller then summarizes the information they just read while the listener corrects any errors, fills in any omitted material, and helps think of ways both students might recall the main ideas. The roles are switched for subsequent sections of the reading. Notably, Dansereau and colleagues found that the recaller learned more than the listener (O'Donnell & Dansereau, 1992).

*****Guided Reciprocal Peer Questioning***

This method was developed for structuring group interactions to promote higher order thinking and complex learning using a combination of a combination of thought-provoking questions (King, 1989, 1990, 1994, 2008; King et al., 1998), elaboration of content (Webb, 1989), argumentation (Kuhn, 1991), and modeling of cognition (Dansereau, 1988; King, 1994). During this process, students 1) ask questions that elicit explanations and inferences, 2) answer questions with relevant thoughtful responses, 3) build on each other's responses, and 4) assess and monitor each other's understanding. Direct instruction in these activities is generally needed.

For example, a teacher may model cognitive strategies (e.g., question generation, summarization, etc.), then gradually turn over responsibility to the students to carry on these activities with each other.

*****Cooperative Base Groups***

Cooperative base groups meet regularly (e.g., at the beginning and end of each day of training or class) to ensure that each student completed their homework and understood the material (e.g., Vasquez, Johnson, & Johnson, 1993). Base groups are typically responsible for designing study plans that ensure each member of the group completes their assignments and homework (submitting everything on time), learns the assigned material, studies, receives help and support when it is needed, and is prepared for upcoming exams.

*****Student Teams-Achievement Divisions (STAD)***

In STAD, small groups of learners with different levels of ability work together to accomplish a shared learning goal, then take a test individually to assess their learning. Research suggests that STAD can accelerate achievement, particularly in math classrooms (Huber, Bogatzki, & Winter, 1982). However, results in other contexts are mixed (Randolph, 1992; Nichols, 1996; Armstrong, 1998). Some studies have found accelerated achievement is possible if STAD is continuously used for the entire academic semester (Nichols, 1996). Other results suggest that courses using STAD may fail to convey the same amount of content conveyed in traditional lecture courses, thus students using STAD tend to tend to score lower course grade-based achievement tests.

****Cooperative Assessment***

In this method, students take a test as a group, which includes discussion and coming to consensus (McCall, 2017). In its simplest form, this method is merely an assessment scoring procedure. The rules of this scoring procedure stem from the opportunity to add up to 10 points to a student's individual grade if their score on the group assessment exceeds their individual score (Griffin, 1994). If their individual score turns out to be higher than the group's, they do not lose points. This method has not consistently yielded positive effects on individual achievement (Griffin, 1994). In a post-survey, one student astutely (and honestly) noted that they "slacked up" because they knew that their group contained individuals who tended to work hard. "Slacking up" or "social loafing" is a frequent concern for anyone who assigns cooperative group work to students (Karau & Williams, 1993). Social loafing can be expected to reduce the potential for individual learning gains from cooperative work.

*****Jigsaw***

In the "jigsaw" method (Aronson et al., 1978), students begin in home groups in which each member is given or finds unique information on a related topic. Students then leave their home groups and form "expert" groups with classmates who have or are finding information on the same sub-topic. The experts help each other understand their "piece of the jigsaw puzzle". Next, students return to their home groups, where they teach their pieces to each other (Jacobs, 2015). Several studies have found this method to have no impact on individual student achievement (Thompson & Pledger, 1998; Hänze & Berger, 2007). Studies that have found positive effects have done so by providing less experienced groups with support (Huber & Huber, 2008) and forming smaller groups (Slavin, 1995).

****Group Investigation***

Here, students take an active role in planning what they will study and how they do it. They form cooperative groups according to common interests. All group members participate in planning how to research their topic. They then divide the work among themselves and each group member carries out their part of the investigation. Finally, the group synthesizes and summarizes its work and presents these findings to the class (Miel, 1952; Joyce & Weil, 1972; Sharan & Sharan, 1976; Sharan, Ackerman & Hertz-Lazarowitz, 1979; Sharan & Sharan, 1990). Low or average-achieving students tend to show greater academic improvement from participating in this method than their high achieving peers (Lee, Ng, & Phang, 2002; Shachar, 2003; Shachar & Fischer, 2004). Specifically, low-achieving students provided better explanations, but their solutions to computational problems were not improved (Mevarech & Kramarski, 1997).

*****Reciprocal Peer Tutoring***

In this method, students are taught to tutor each other and alternate tutor–tutee roles. Dyads are then rewarded with opportunities to engage in special activities if the sum of the dyad's scores exceed a criterion (Fantuzzo, King, & Heller, 1992). In some studies, positive effects of this method were only observed after five weeks (Ortiz, Johnson & Johnson, 1996). During the first week, students working individually outperformed students using this method.

Voluntary Study Groups

Voluntary study groups are commonly found in postsecondary higher education settings (e.g., medical, law, etc.) in contexts where students must internalize and comprehend an extensive common body of information. Research has yielded negative or mixed results regarding the effect of voluntary study groups. In one study (Baker, 1995), minority and female students, but not others, who worked in study groups showed higher achievement than students from those groups who did not join a study group. This finding suggests that, at the university level, voluntary study groups may benefit some sub-populations but not others.

Problem-Based Learning*

Students are given a problem scenario, which they investigate and explain with a solution (Greenwald, 2000; Anderson, Mitchell & Osgood, 2005). Problem scenarios are purposefully vague in that they require students to discuss the cases fully in order to identify the information that they need to understand the problem. Effects of this method on individual academic achievement are mixed (Johnston, et al., 2000; Bradley et al., 2002). Bradley et al. note that group success can mask deficits in achievement of individuals. This warning can apply to research and application of other cooperative learning methods as well; thus, teachers considering using cooperative learning methods should carefully consider strategies with which to check the understanding of all individual group members before assuming that all members "get it".

Team Assisted Individualization

In this method, small groups of students are given learning materials to study. They then take a placement test to establish a baseline score. Teams are formed based on these scores to ensure heterogeneous grouping of skill level. The assigned group work usually includes generating a group or individual level summary of their learning. Then, students take an individual test. Team scores are awarded to groups based on the amount of improvement demonstrated by individual member's baseline scores and subsequent quiz scores. Importantly, this method has a greater effect on learning when the collective achievement of the entire group, as opposed to individual achievement, is recognized and rewarded (Cavanaugh, 1984).

Non-voluntary Study Groups

Non-voluntary study groups are formed, usually through random assignment, by course instructors (and researchers). Members of non-voluntary study groups are typically held accountable to a group product or test by their instructor, thus they experience a degree of motivation to work together as students would on a group project. The studies I reviewed suggest that this method does not accelerate individual achievement (Overlock, 1994; Yetter et al., 2006).

2.3 Synthesis of Structured Review

The top four methods described in the above section (and listed in Table 1), found a moderate to high effect size on achievement (the proxy for learning outcomes). These collaborative learning methods are Cooperative Roles, Guided Reciprocal Peer Questioning, Cooperative Base Groups, and Student Teams Achievement Division (STAD). What is it about these methods that makes them so effective? This section touches on a few basic tenets of collaborative learning practices to highlight some common structures that may explain why these particular cooperative learning methods are as effective as they are.

The majority of the moderate to highly effective studies applied a cooperative method using a heterogeneous grouping method. Heterogeneity was established by engineering group knowledge diversity (through roles or scripts) or by ability (through prior assessments of achievement). Each method assigns student task roles by design and prescribes student interactions to some degree. Interdependent goals and rewards linked the actions of individual group members to the achievement of the entire group. Each collaborative learning method applies these common structures in unique ways, which are briefly examined below.

Cooperative Roles, for example, structure the roles and responsibilities of each group member, ensuring that the work is distributed, and individual accountability is clear. This can be an effective tool for ensuring all group members engage in explaining their thinking to the group, because it requires alternating or shifting roles among group members so that everyone has a turn to talk. This is an example of differentiated roles, described above.

Guided Reciprocal Peer Questioning structures group member interactions, guiding them to explain their thinking with thought-provoking questions (King, 1994, 2008; King et al., 1998) and thinking aloud (King, 1994). During this process, students ask questions that elicit explanations and inferences, build on each other's responses, and assess each other's understanding. Direct instruction can enhance the effects of this method. For example, teachers can model cognitive strategies (e.g., question generation, summarization), then gradually turn over responsibility to the students to carry on these activities with each other.

Student Teams Achievement Division (STAD) involves establishing shared learning goals, usually with mixed ability groups, which can expose group members to a wide variety of ideas while uniting them in a common purpose. Students are placed in small groups of four to five (i.e., teams). The instructor presents a lesson, typically in the form of a lecture. Students then move into their teams to review the lesson content and to study collaboratively for a test. This test is then administered at the individual level. Importantly, although students receive individual grades, the instructor also calculates the average of each team's individual scores. If appropriate, the instructor also calculates how much each individual's score improved from the last test. Lastly, the instructor awards each team a certificate (or another kind of meaningful reward, e.g., at the college level this might be a certificate for one excused assignment) acknowledging the achievements of the group: the group average score, and the group average improvement score.

Cooperative Base Groups offer a social motivation for group cohesion. Groups meet regularly to ensure that each student completes their homework and understands the material. In some documented cases (e.g., Vasquez et al., 1993) members have also worked to improve the well-being of their group members in other ways, such as designing study plans that ensure each member of the group completes their assignments and homework on time, learns the material, studies, and receives help when it is needed. Cooperative Base Groups is an effective method because group members tend to take care of each other. This method uses minimal prescribed structures, yet tends to show positive effects after extended periods of time (i.e., a semester). Studies of other methods summarized in Table 1 – such as Team Assisted Individualization (TAI), Cooperative Assessment, and Group Investigation – have large to moderate positive effects on individual learning, but this review includes only one study of each method and generalizations cannot be made with confidence based on the results of a single study. Further study is needed before recommendations can be made.

The method of Cooperative Assessment is a collaborative test taking method in which the members of a group must reach consensus for each item on an assessment (McCall, 2017), in some variations, groups continue until they reach a correct answer (Vogler & Robinson, 2016). The effects of cooperative assessment are heavily influenced by students' awareness of the abilities of their group members. The awareness that there are "smart" or "hard-working" group members may inspire social loafing behavior, which negatively impacts individual learning (Griffin, 1994). In a post-survey (Karau & Williams, 1993), one student astutely (and honestly) noted that they "slacked up" because they knew that their group contained individuals who tended to work hard.

Group Investigation requires that students assign themselves roles, essentially distributing the work among group members so that each group member carries out their part of the investigation (Sharan & Sharan, 1990). This can overcome process loss behaviors such as competition and social loafing because tasks do not overlap, and task completion depends upon all group members doing their part. However, this method can also limit students' exposure to the entirety of the project. Students may lose sight of the "forest" among the "trees," learning only their part of the project and missing the bigger picture (or simply the other parts of the project). Teachers (both pre-service teachers and teacher educators) should be mindful of this effect.

Research suggests that heterogeneous grouping plays an important role in ensuring a diversity of perspectives and heuristics during Group Investigation. The difference in effect size (d) and significance between the Shachar & Fischer (2004) and Tan et al. (2007) studies, for example, suggests that students should not form self-affiliation groups. Shachar & Fischer (2004) ($d = .882$) randomly assigned students to groups, while Tan et al. (2007) ($d = .154$) let students compose groups according to interests and friendships. This difference in effectiveness might suggest that, although group investigation is designed to be relatively student driven, students benefit from teacher-led group assignments. This applies even at the college-level; teacher educators should model how to form groups and assign roles, and be explicit about their reasons for doing so, so that pre-service teachers learn how to do it for their own future K-12 classes.

Jigsaw and Reciprocal Peer Tutoring have been the subjects of extensive empirical research and, perhaps as a result, show a wide range of effects on individual learning, perhaps due to different levels of support or help given to students. For example, Huber and Huber (2008) found positive effects on learning when less experienced groups were given support and guidance. We also found that the effects of Jigsaw and Reciprocal Peer Tutoring tend to differ for students playing the roles of "expert" or "tutor" and those playing the role of "novice" or "tutee." In a study of high school physics students (Hänze & Berger, 2007), only the experts in the jigsaw (not the novices) demonstrated individual learning. This suggests that students might benefit from alternating roles, such that every member of the group has an opportunity to play the role of "expert" or "tutor."

A few of the methods that met the criteria for the review showed little to no effect on individual learning (or showed no significant difference between the effect of the method and traditional instruction). These methods are Problem-Based Learning, Voluntary and Non-Voluntary Study Groups. Why these methods have so little effect on individual learning remains unclear and may be due to in part to the fact that they do not have strong representation in the review.

2.4 Conclusions

The research literature examined here suggests that providing individuals with a wider variety of ideas and information to process (e.g., by manipulating group diversity) and with structures to support and guide social interactions to selectively process this information (e.g., structured task roles) may further foster individual achievement and learning. While collaborative group work is not the only means with which to accomplish this cognitive work of selectively processing a variety of novel ideas, it may be that structured social interactions provide an external mechanism better suited to aid learning processes than internal cognitive mechanisms alone. The research reviewed here suggests that several cooperative learning methods – ones that rely on a combination of the cognitive benefits afforded by knowledge diversity and social structure from task roles - have a greater effect on individual learning than traditional whole class instruction, which centers student attention on the teacher. These cooperative learning methods are discussed below.

Of the four structures identified in the structured literature review, heterogeneous grouping by perspective (also referred to in other chapters as knowledge diversity) tended to be used more frequently in studies that found the greatest effect sizes on achievement. There are several reasons why this might have happened. Heterogeneous grouping has been shown to improve the achievement of low-achieving students (Shachar, 2003) (a sub-population typically disadvantaged by the traditional model); it also teaches advanced discussion skills for all students (Webb et al., 1998). Interestingly, in its most effective applications (as reviewed here) heterogeneous grouping was applied alongside assigned task roles. For example, Cooperative Roles (e.g., Acar & Tarhan, 2008; $d = 2.735$) and the Jigsaw (e.g., Tarhan & Sesen, 2012; $d = 1.422$) methods give students the responsibility of explaining the reading or content to a peer, thus activating both cognitive and social mechanisms not exercised by traditional teaching..

Student Teams-Achievement Divisions (STAD) (e.g., Kırık & Boz, 2012; $d = 1.357$) and Team Assisted Individualization (TAI) (e.g., Tarim & Akdeniz, 2008; $d = 1.007$) group students heterogeneously by ability, assigning the role of “expert” to higher ability students and structuring student interactions such that experts have the assigned role and responsibility of a “supervisor”, guiding and checking low-ability student work. Guided Reciprocal Peer Questioning (GRPQ) (King, 1991; $d = 1.042$) relies on diverse ability grouping as well as highly structured roles that guide students through steps or processes of reading together. Each of these methods has been shown to offer significant improvements in individual achievement as compared to traditional teaching methods, and each of these methods uses a combination of heterogeneous grouping by knowledge and assigned task roles.

2.5 Connection to the Current Study

The results from this literature review suggest that methods that employ task roles, distributed experience (referred to as knowledge diversity), or a combination of both have positively impacted individual student learning. This combination is theoretically interesting as it may speak to a relationship between social structures and cognitive mechanisms. Several theoretical frameworks (e.g., social learning, distributed cognition) understand the cognitive work of learning as a process that involves external as well as internal mechanisms. The observed pattern from the literature review – of cognitive activities such as learning being better facilitated by seemingly social processes such as task roles and role play – offers an opportunity to examine this relationship in a controlled laboratory environment. Such a controlled setting may be better able to tease apart the effects of these frequently combined cooperative learning structures. It is for these reasons that the project aims to examine these two collaborative learning methods, ultimately to better understand the causal mechanisms that make collaborative group work an effective learning experience.

Chapter 3: Method

This research study is designed to distinguish between the effects of two aspects of collaborative activities: knowledge diversity (induced by varying experiences with a training task) and assigned team roles. This design is based on findings from the pilot study (Section 3.1) and the structured literature review (Section 2.2). Results from the pilot study left unresolved the question of whether assigned task roles interact with the effects of distributed experience with a training task on learning outcomes. Findings from the structured literature review suggest that task roles can make group diversity explicit, which alerts group members to the need to communicate. The literature review also suggested that communication that involves explanations may play a key role in the relationship between collaborative group work and positive individual learning outcomes.

This section begins with a review of the pilot study, including method, results, conclusions, and a section connecting findings to the current study. This is followed by a list of the current study's research questions, study design, operationalization of criterion variables, and a detailed description of the procedure of study implementation.

3.1 Pilot Study

The pilot study examined whether dyads with distributed experience from a training task demonstrated better performance or learning outcomes than individuals or dyads with joint experience from a training task. Findings confirmed that both group conditions led to superior performance compared to the individual condition but did not support the hypothesis that the distributed experience condition would have different effects on performance and learning than the joint condition. The design, method, and results from the pilot study are detailed below.

Specific Aims

The purpose of the pilot study was to examine whether the positive effects of knowledge diversity (i.e., diverse knowledge and perspectives) on group performance and individual learning could be produced via an experimental manipulation, namely a brief training task. In an attempt to induce diverse perspectives among participants, two component subtasks from a complex design task were assigned to different individual participants as a training task. After the differing training tasks, the two participants collaborated to solve the complex problem consisting of both subtasks.

The aim was to predispose participants to have different perspectives on how to solve the same problem. This "distributed" condition (DK) was compared to a second "joint" condition (KH), in which individual dyad members experienced the same training task, composed of both subtasks, before working together as a dyad. These dyad conditions were compared to a third individual condition (IND), in which individual participants were exposed to the training task, then worked as individuals on the main task without collaborating.

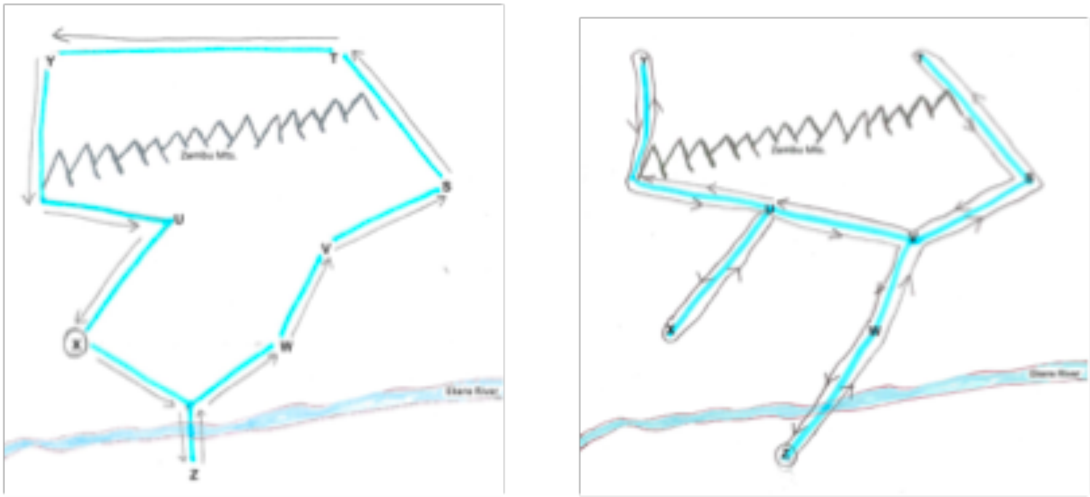
Research Questions

Relationships between these conditions were examined to answer the following research questions. Does group work facilitate the discovery and application of specific design insights to a different degree than individual work? Do these design insights transfer to novel contexts and tasks, such as a post-task questionnaire? When does the group recognize and adopt prior insights from individual participants? That is, when are insights "shareable", in the sense that an individual's insight will be successfully adopted by the group?

The Collaborative Task

Research questions were investigated in the context of a collaborative design optimization task, dubbed the "Relief Aid" game. This "game" is based on two simultaneous network design problems. The first network design problem participants faced is commonly referred to as the traveling salesman problem. The problem is to design the shortest route among a set of points on a map. The route must follow a path that visits all points exactly once, returning to the starting point. This task suited the purposes of the pilot because it permits a variety of possible solutions, affords space for diverse perspectives, and allows multiple design strategies.

A layer of complexity was added to the basic traveling salesman problem by imposing the additional task of designing a minimal-length road network upon which the delivery route must travel. This subtask, in isolation, corresponds to another formal problem in network theory, the problem of finding the minimal Steiner tree connecting a set of points. Thus, the task involved two distinct subtasks: attempting to design a minimal-length road network and a minimal route or tour using this same road network (see Figure 1). These two subtasks can work at cross-purposes, therefore 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. In essence, short road networks make the tour routes less efficient and short route networks often require lengthening the road networks underneath them.



A B

Figure 1. Two example solutions for the joint problem of designing the minimal road network (indicated using a blue marker) and route networks (directional route indicated by arrows) on a map in the plane. Panel A presents a solution that does a good job of minimizing the road network length. Panel B depicts a solution that achieves a relatively short route network by reducing the retracing of arcs, but at the expense of road network length.

Method

To address the research questions, participants (n = 104) were randomly assigned to one of three conditions: Dyadic Distributed Knowledge (induced by varying training tasks) (KD condition), Dyadic Shared Knowledge (induced by common training tasks) (KH condition), or Individual work (IN). Participants in the Individual condition worked as individuals on the joint design problem, simultaneously designing the shortest road network and the shortest tour, for two maps.

Map 1 was the pre-task or training task, and Map 2 was the main (criterion) task. In the Dyadic Shared Knowledge (KH) condition, participants worked as individuals to complete the joint design on the training task, and in dyads for the main task. In the Dyadic Distributed Knowledge (KD) condition, participants worked as dyads for the main task; but the two individuals had different training-task instructions and subtasks: one participant was directed to construct the shortest road network (only), and the other was asked (only) to construct the shortest tour or route connecting the points and returning to the starting point. Thus, when participants in the KD condition came together as a dyad to work on a second map, they found that they had different prior experience, and thus presumably different perspectives on the joint task.

After the dyad (or individual) completed the joint network design for the second map, all participants completed a questionnaire with specific transfer questions that prompted them to apply certain key design insights or innovations. In prior pilot studies, we have identified two design features, Steiner points and loops, as innovations that usually improve the network design by shortening total network length. 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 essentially created a new "intersection", not located at one of the points on the map, from which roads could radiate or connect. Depending on its placement, this innovation enables shorter road or route networks (Figure 2).

The second type of innovation identified is the use of loops. Loops often enable shorter routes or tours, though they cannot occur in a minimal road network. The loop innovation permits routes to avoid traveling back along previously traveled roads; thus, using the loop innovation can result in a much shorter tour (Figure 2).

These two target insights (use of a Steiner point and/or a loop) were identified on the pre-task (Map 1), criterion task (Map 2), and the post-task questionnaire. Individual learning and transfer of innovations was inferred using questions from the post-task questionnaire. If a participant used a loop or Steiner point on their criterion task and in answering the relevant post-test questions, it was counted as successful transfer of learning. Thus, we were able to compare application of insights and transfer of insights across the individual and dyadic conditions.

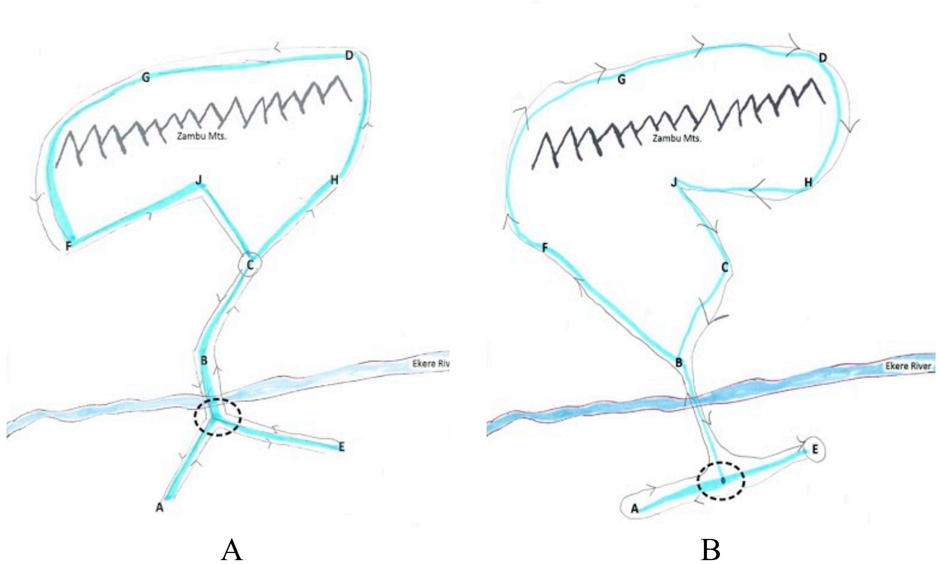


Figure 2. Submitted participant solutions for the main task in which participants worked together to design a network that included both a road and a route network using Map 2. Both figures show examples of solutions that used both a loop and a Steiner point, which is circled with a dotted line in each example.

Results

Dyads were more likely to adopt insights than individuals. Figure 3 shows the proportion of insights used across all three tasks in the stud - the pre-task (Map1), the task (Map2), and the post-task questionnaire – by condition.

Individuals show high and consistent use of loops in the pre-task and the main task (pre-task = 78%, main task = 78%), $\chi^2(1, N = 54) = .000$, $p = 1.000$. They show a lower frequency of application of the Steiner point (pre-task = 36%, main task = 42%), $\chi^2(1, N = 54) = .318$, $p = .573$. In the main task, loops are more often used by dyads (95%) as compared to individuals (78%), $\chi^2(1, N = 66) = 4.377$, $p = .036$. There is no significant difference in the frequency of use of Steiner points between dyads (51%) and individuals (42%), $\chi^2(1, N = 66) = .712$, $p = .399$.

This pattern suggests that dyads are more likely than individuals to adopt insights like the loop, but not the Steiner point.

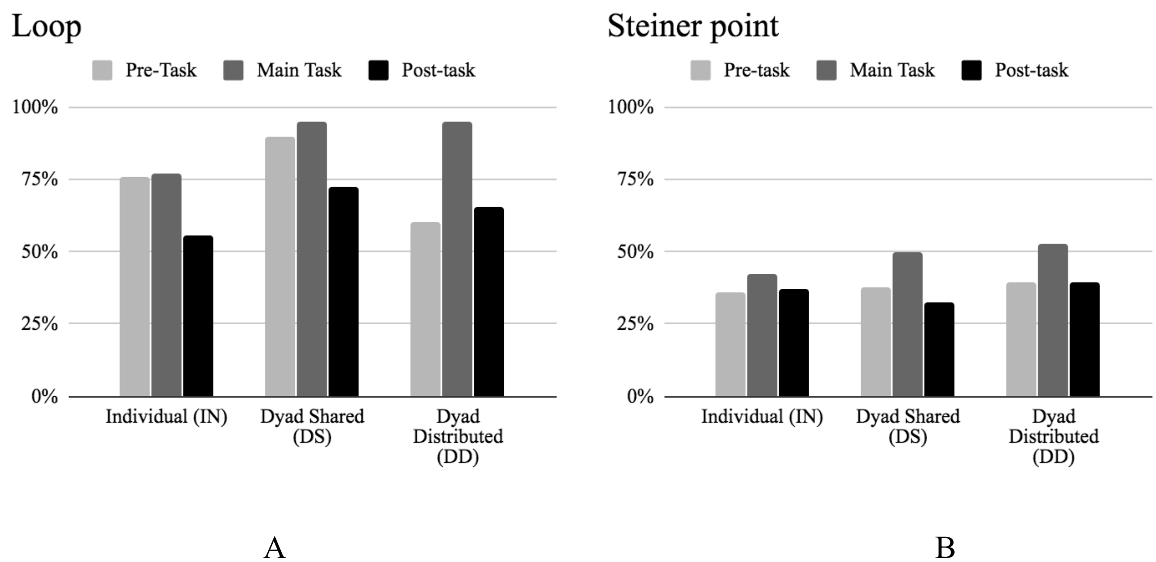


Figure 3. Figure A (left) shows the frequency with which a loop was used on the pre-task, main task, and post-task for all three conditions. Figure B (right) shows the frequency with which the Steiner point was used on the pre-task, main task, and post-task for all three conditions.

The data suggest that the loop insight was not only used more often than the Steiner point but was more shareable, or readily shared between dyad partners. Table 2 shows four contingency tables, exhibiting the frequency with which the loop insight and the Steiner point were adopted on the main task given their use on the pre-task. In the individual condition, all participants who used the loop in the pre-task also used it in the main task; six individuals used it in neither map. For dyads, if both partners created a loop on the pre-task, then the dyad invariably used a loop in the main task. Note that when one of the two partners had used a loop in the pre-task, the dyad created a loop 14 out of 15 times (93%). Thus, the loop design insight can be considered shareable.

Table 2. Use of loops and Steiner points across the two map tasks.

A. Use of Innovations by Individuals (Condition IND)

	Loop Use on Map2				Steiner Point Use on Map2		
Loop Use on Map1	Yes	No	Total	Steiner Point Use on Map1	Yes	No	Total
Yes	21	0	21 (78%)	Yes	8	1	9 (33%)
No	0	6	6 (22%)	No	3	15	18 (66%)
Total	21 (78%)	6 (22%)	27	Total	11 (41%)	16 (59%)	27

B. Use of Innovations by Dyads (Conditions KH & KD)

	Loop Use on Map2				Steiner Point Use on Map2		
Loop Use on Map1	Yes	No	Total	Steiner Point Use on Map1	Yes	No	Total
Both Participants	22	0	22 (56%)	Both Participants	5	2	7 (17%)
One Participant	14	1	15 (55%)	One Participant	12	4	16 (41%)
Neither Participant	1	1	2 (5%)	Neither Participant	3	13	16 (41%)
Total	37 (95%)	2 (5%)	39	Total	20 (52%)	19 (48%)	39

These data suggest that collaborative group work facilitates the discovery and adoption of shareable insights, like the loop. Does group work facilitate the transfer of insights to a different degree than individual work? Participants in the knowledge diversity condition, who were not predisposed towards adopting either of the insights, proved more likely to transfer these insights to a novel task than participants in the homogenous knowledge dyads, and participants in the individual condition. This finding, as well as others further detailing this relationship, are detailed below by condition.

Individuals. For the loop insight, there was no significant relationship between the main task and post-task, $R^2 = .239$, $p = .230$. Individuals were likely to repeatedly apply the loop on both Map 1 and Map 2, but unlikely to transfer it to a novel task. For the Steiner point insight, there was a strong relationship between the main task and the post-task, R^2 = .457, p = .017; suggesting that individuals more readily transfer insights, like the Steiner point, than the loop.

Knowledge homogenous dyads. There was no significant relationship between the main task and post-task for participant transfer of the loop insight (Participant A: R^2 = -.168, p = .478, Participant B: R^2 = -.115, p = .630) or the Steiner point in the homogenous dyads (Participant A: R^2 = .314, p = .177, Participant B: R^2 = .218, p = .355). Knowledge homogenous dyads do not transfer insights with greater frequency than individuals; instead, they appear to adopt both insights during the main task with greater frequency than individuals, but then fail to consistently transfer these insights to the post-task questionnaire. This finding contradicts expectations that collaborative group work has a universally positive effect on transfer. Here, results show that homogeneous knowledge groups (groups with the same training experience) transfer insights with no greater frequency than individuals.

Knowledge diverse dyads. For the loop insight, there was no significant relationship between the main task and the post-task for both participants in the knowledge diverse condition: Participant A (aka. Road designer), R^2 = -.102, p = .678, Participant B (aka. Route designer), R^2 = .224, p = .357. There was a relationship between the main task and the post-task for the Steiner point for both participants: Participant A, R2 = .506, p = .027, Participant B, R2 = .596, p = .007. This suggests that if participants in the knowledge diversity condition use the Steiner point on the main task, they were likely to transfer it on the post-task as well.

Discussion

What makes some insights more likely to be discovered and used by groups, and other insights less so? One possible explanation from this pilot is that in this task the loop insight may be more "shareable" (Freyd, 1983) than the Steiner point. The loop can shorten a route by a large visible margin, and this is easy to point out and justify to others. In contrast, using the Steiner point involves adding a new intersection node to the graphs, thus it may have seemed to some individuals and groups to be an invalid or illegal “move”. These types of interpretations and assumptions about the nature of the task might be factors that can inhibit the spread of innovations.

Conclusions

Dyads were more likely than individuals to adopt insights like the loop, but not the Steiner point. The knowledge diversity manipulation did not affect the dyad’s adoption of insights in the main task. Knowledge diverse dyads (KD) did not significantly differ in their adoption of insights from homogeneous knowledge dyads (KH) during the collaborative main task: loop, $\chi^2(1, N = 39) = .001$, $p = .970$, Steiner point, $\chi^2(1, N = 39) = .027$, p .869. This suggests that knowledge diversity may not affect dyadic innovation in network design problem-solving tasks. If the goal of the collaborative task is to improve the spread of insights, results suggest that for the network design task used in this pilot study, inducing differing perspectives through a training task is an ineffective method for attaining this goal. Another type of training task might have different effects on the outcome variables.

The knowledge diversity manipulation affects some the transfer of insights. Analysis comparing the use of insights on the main task and the post-task show significant relationships between the two tasks for both road and route designers using the Steiner point, but not for the loop. If a participant in the knowledge diverse condition used the Steiner point on the main task, they were likely to use it again on the post-task. This suggests the knowledge diversity condition may facilitate transfer of insights like the Steiner point.

Connection to Current Study

Results from the pilot study called into question the importance of knowledge diversity in collaborative learning activities. It seemed that what participants discussed (e.g., the type of insight discovered) had a greater effect on learning and transfer than their initial diversity of perspectives. This inspired research questions for the current study regarding communication as a mediating variable in the process of collaborative learning.

It seemed possible that results may have been due to a lack of awareness among group members about the knowledge diversity manipulation. In the knowledge diversity condition (KD), it was not made explicit to participants that they had different training tasks. During the collaborative process, some participants quickly discovered that they had different information than their partners, but for some, this revelation did not occur until well into their collaborative work. For others the discovery that their differing perspectives was due to the training task never happened. Instead, these participants expressed mild confusion, perhaps because they had less common ground than they believed.

This confusion in the KD condition may have caused unproductive and unnecessary process loss. Findings from the structured literature review (see Section 2.2) suggest that this process loss might have been lessened had the knowledge diversity been made more explicit. Several established methods for cooperative learning identified in the literature review (e.g., Jigsaw, Reciprocal Peer Tutoring) attempt to induce knowledge diversity with explicitly assigned task roles. This connection between the pilot and the structured literature review informed the hypotheses and research questions of the current study, both of which are detailed below.

3.2 Hypotheses

The current study is designed to test if including explicitly assigned task roles in the collaborative process has a different effect on learning outcomes than knowledge diversity alone or if perhaps there is an interaction between the two. It may be that a combination of assigned roles and knowledge diversity has a different effect on the outcome variables than these two manipulations do when implemented independently. Specifically, assigning task roles might make knowledge diversity explicit, thus avoiding some of the group confusion and process loss observed in the pilot, and improving the effects on learning outcomes.

> H1: There is an interaction between knowledge diversity and assigned task roles that positively affects group task performance and individual learning outcomes.

Also, as mentioned at the beginning of this chapter, the current study investigates the mediating role of explanations between the study conditions and the outcome variables: performance and learning. The structured literature review suggested that cognitive elaboration may play an important role in cooperative learning outcomes.

> H2: Explanations mediate the relationship between the study conditions and the outcome variables, group task performance and individual learning.

Because the current study uses “explanation” as a proxy for cognitive elaboration, the relevant hypothesis and research questions focus on explanations as the mediating variable in the study. These relationships are detailed in the research questions below.

3.3 Research Questions

Effects of Group vs. Individual on Outcome Variables

1. Do dyads outperform individuals on the given problem-solving task?
2. Do individuals who have worked in dyads show greater learning (i.e., more frequent transfer of conceptual insights from the given problem-solving task to items on a post-task questionnaire) than individuals who have not worked in a dyad?

Main Effects of Distributed Training Experience vs. Joint Training Experience on Outcome Variables

3. Does distributed experience (induced by dyad participants receiving different training tasks, both subtasks of a larger, complete task) lead to different outcomes in terms of (a) performance and (b) individual learning outcomes, compared to joint experience (i.e., both participants receive the same training tasks).
4. Does distributed experience affect group discourse, especially aspects of discourse that signal productive work and/or explanation?

Main Effects of Assigned Task Roles vs. No Assigned Task Roles on Outcome Variables

5. Do assigned task roles influence (a) performance and (b) individual learning outcomes, compared to groups working without assigned roles?
6. Do assigned task roles affect group discourse, especially discourse variables that signal productive work and explanation?

Interactions of Distributed Experience and Role Differentiation on Outcome Variables

7. Do distributed experience and assigned task roles interact in affecting (a) performance and (b) individual learning outcomes?
8. Do distributed experience and assigned task roles interact in their effects on group discourse, especially aspects of discourse that signal productive work and/or explanation?

Effects of Self-Explanations in Individual Work

9. Does the elicitation of self-explanations by individuals lead to better task performance compared to individuals who do not self-explain?
10. Does the elicitation of self-explanations lead to greater learning (i.e., more frequent transfer of conceptual insights from the given problem-solving task to a post-test) compared to individuals who do not self-explain?

Effects of Mediating Variable (Explanations) on Outcome Variables

11. How are the explanations (a sign of cognitive elaboration) that occur during dyadic group work associated with (a) task performance and (b) individual learning?
12. How do the self-explanations (also a sign of cognitive elaboration) that occur during individual self-explanation affect (a) task performance and (b) individual learning?
13. How do the explanations that occur during dyadic group work differ from the self-explanations used by individuals?

3.4 Study Design

The research questions are addressed using a two-by-two factorial design with two added control conditions. The four main conditions are Diverse Knowledge with and without Roles, Shared Knowledge with and without Roles, and the control conditions are Individual work with Self-Explanation and Individual work *without* Self-Explanation (See Table 3). As in the pilot study, the experimental procedure involves three stages: a pre-task, a main task, and a post-task questionnaire.

Conditions are introduced using the pre-task as a short training task in which the two members of a dyad in the Diverse Knowledge conditions receive task directions that introduce them to different sub-tasks or components of the main problem-solving task. Because performance on each sub-task benefits from a strategy that is also beneficial in the main task, the different training tasks introduce dyad members to equally valuable, but different perspectives on how to solve the problem in the main task.

Afterwards, participants work individually to complete a post-task questionnaire designed to assess transfer learning. All work on the main task was video recorded, transcribed, and coded to identify nine speech acts associated with collaborative learning activity, including explanations.

Table 3. Study Conditions
Italicized text represents each of the six proposed study conditions.

	Dyadic Work Conditions		Individual Work Conditions	
	Differentiated Roles	Non-Differentiated Roles		
Distributed Experience	*Distributed Experience with Roles*	*Distributed Experience without Roles*		
Joint Experience	*Joint Experience with Roles*	*Joint Experience without Roles*	*With Self-Explanation*	*No Self-Explanation*

The Collaborative Task

The collaborative task used for the current study is the same as the pilot study task (see Section 3.1). It is a relatively "ill-structured" task, which means that it lacks a single, correct answer, but still allows for some answers to be measurably superior to others. Like many ill-structured tasks, the collaborative task presents a degree of uncertainty about which strategies, rules, or principles are necessary for the solution. It is designed to create circumstances in which participants must make judgments about the problem and defend these judgments by expressing personal opinions, presenting alternative perspectives, or describing prior knowledge. Yet, they must do this without feedback to guide and inform them as to the quality or correctness of their decisions or strategies. Thus, the collaborative task requires some degree of collective induction.

Collective induction is the cooperative search for a general rule or principle that can account for a set of observations (Laughlin, 1999). It is of particularly appropriate for the purposes of the current study as collective induction is commonly used in experimental research to compare the problem-solving performance of groups to individuals (c.f., Laughlin & Shippy, 1983; Larson Jr, 2013). Inductive tasks can also be completed by both groups and individuals; they not necessarily favor skills typical to groups to a greater degree than individuals and vice versa) (c.f., Laughlin et al., 1991). Inductive tasks also both demonstrable (incorrect or poor solutions can be identified) and aesthetic (solutions are evaluated based on judgement, but there is no demonstrably correct answer) (Klayman & Ha; 1987). These features afford the collaborative task to serve a study that compares groups to individuals and seeks to motivate collaborative discourse and self-explanations.

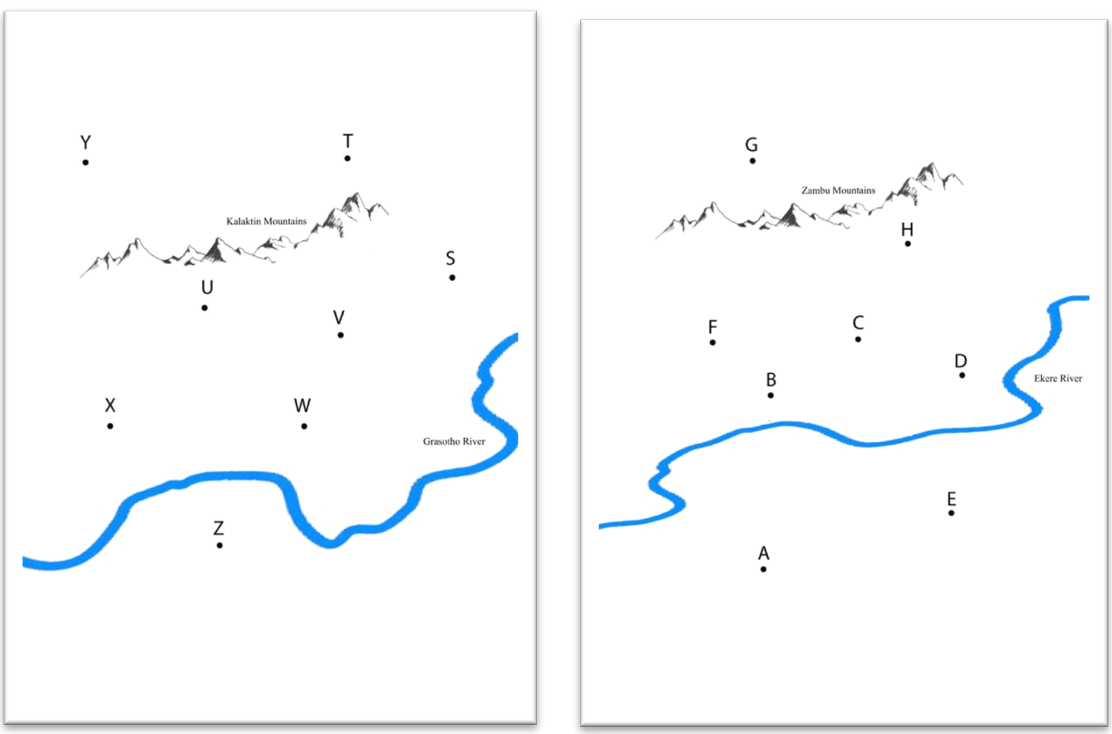
Research on the role of the task on group decision making and collaborative problem-solving processes is extensive, and beyond the scope of the current study. Relevant research is cited here merely to highlight prior research in social psychology recommending a task designed for inductive reasoning because it affords space for diverse perspectives, multiple design strategies, and decision-making processes that promote discourse. A task thusly designed is well suited for the interests of the study, particularly regarding the specific aims of the study to examine the knowledge diversity and explanations.

In the pilot and the current study, the task was to design an optimal network for connecting a set of points on a map. It adds a layer of complexity to the basic traveling salesman problem by imposing the additional task of designing a minimal-length road network upon which the delivery route must travel. 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; therefore, 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. The subtasks could potentially introduce two types of conflicts regarding the network design: 1) short road networks make the tour routes less efficient because they require the truck traveling the route to re-trace each edge of the network and 2) short route networks often require lengthening the road networks underneath them in order to complete the circular path of the loop. This potential conflict may motivate negotiation, explanation, and argumentation. This affords the current study the opportunity to examine the effects of these communication behaviors on performance and learning.

The design optimization task is composed of two sub-components or subtasks. The problem solver is confronted with a map with the location of ten villages plotted. The participant is asked to design the shortest possible road network to connect the points, while simultaneously designing a minimal length tour on all the points (described as the route a supply truck will have to drive using the road network). The latter subtask is a constrained or non-Euclidean version of the traveling salesman problem. The basic problem is to design the shortest route among a set of points on a map. The route must follow a path that visits all points exactly once, returning to the starting point. The mountains (see Figure 1a and 1b, “Zambu Mts.”) introduce the constraint that the route must travel around (not through) this feature on the map. The river (see Figure 1a and 1b, “Ekere 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.

Because the route requires a return to the starting point, while navigating an obstacle and a bottleneck, a degree of planning is required. An immediately apparent solution is to use a tree or lattice network design to connect all the points on the map; this is a perfectly acceptable design solution for the participant assigned the subtask of designing a road network. Their task rules stipulate only that they must use road segments sparingly to design the most efficient (minimal) road network possible. However, a lattice or branching tree network would force a route network to back-track along each branch as it endeavors to reach each village and return to its base. Realizing the inefficiency of the lattice network in the context of this task benefits from the kind of abstract thinking involved in future planning or “planning ahead.” Such abstract design-thinking is arguably less evident and potentially more challenging than the road network design; thus, the route network subtask not only increases the complexity of the task, but it also potentially requires a greater degree of cognitive work than the road network design.

Participants attempted two examples of this design problem. Map 1 is the training task; this is always done individually. Map 2 is the main or criterion task; this is done either in a dyadic condition or in an individual-work condition. During the main task (Map 2), dyads collaborate to design both the road and the route, while individuals work alone (those in the self-explanation condition explain their thinking aloud while working alone).



A **B**

Figure 4. (A) The first map (Map 1) given to participants as a training task. (B) The second map (Map 2) given to participants as a collaborative task or as another individual task, depending on assigned condition.

Notice that both Map 1 and Map 2 (see Figure 4) include the two obstacles described: a mountain range and a river. The instructions state that the network must go around the mountains (it cannot pass through) and the network must cross the river at only one point (there can be only one bridge). These obstacles created an implicit need for efficient innovations that could minimize the number of road links in the network and the amount of "back-tracking" or re-tracing necessary to complete the trip.

As described in the pilot study, two insights that are of interest: the Steiner point and the loop. Briefly, a Steiner point is an added node in a graph, which shortens one or more paths. A loop is a path that connects a set of points on the map and returns to the start. When used together, these design insights significantly shorten the length of the total network. Both maps shown in Figure 5 use both a Steiner point and a loop; they are also the minimal-length (i.e., optimal) designs submitted for each type of map. Figure 5 highlights examples of the loop and Steiner point.

Figure 5a. Map 1 completed as the training task (map from pilot).

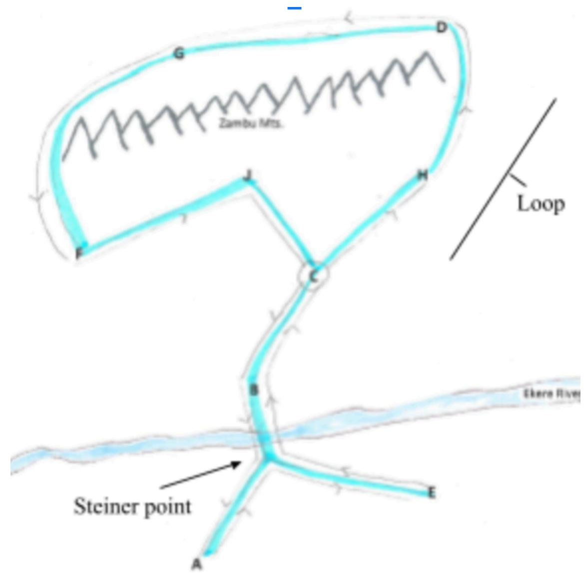


Figure 5b. Map 2 completed as the main task (map from pilot).

Because the study is designed to examine whether (and how) insights gleaned during collaborative group work are transferred, participants are not explicitly instructed about these insights. If a participant had the insight to use a Steiner point or a loop, it emerged through discovery learning. Discovery learning plays an important role in the manipulation, which is designed to create instances where participants might learn an insight *from* the collaborative process, as opposed learning from instruction, which is not of interest in the current project.

Of course, because participants were not explicitly introduced to these insights, they may not have realized their utility and, thus, they may not have applied them in their network designs. This possibility is briefly examined in the Results (Chapter 4). Also taken into consideration is whether participants apply or adopt the inappropriate design strategy of the spanning tree in their final solution. For this task, a spanning tree network tends to increase the total length of the network (because it increases the tour length), thus negatively impacting performance.

Conditions

Study conditions are designed to control and isolate the effects of knowledge diversity and explanations on performance and transfer learning (a complete list of these six conditions can be seen in Table 3). The study design uses two control conditions to isolate the effects of explanation – essentially separating this type of utterance from the social context of the various dyadic conditions. Participants in these two control conditions, first work alone on the training task as a joint design problem, simultaneously designing the shortest road network and the shortest tour using Map 1 (shown completed in Figure 1a and 1b). Then, they are given a new different map, Map 2 (shown completed in Figure 2a and 2b), also known as the main task. Here, they (again) work alone on a joint design problem.

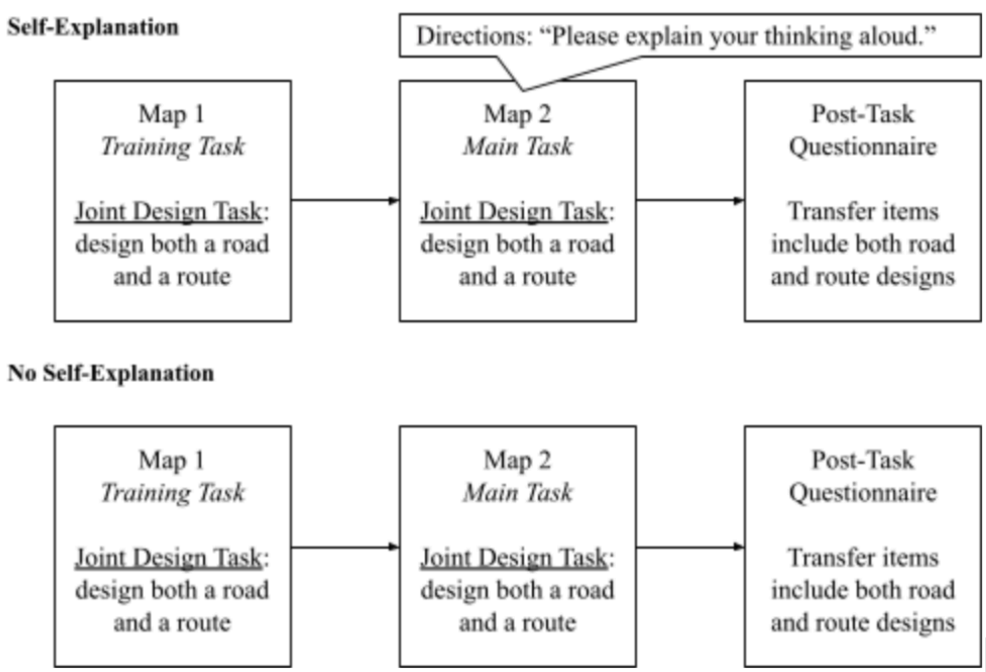


Figure 6. Progression of activities experienced by participants in the Self-Explanation and No Self-Explanation conditions. Conditions are identical but for directions in Self-Explanation Condition.

Participants in the Self-Explanation condition are prompted by the task directions to self-explain, "During this task, please say what you are thinking aloud as you work. Use elaborate explanations when you can. For example, you might explain your thinking, your choices, or why you changed your mind." Participants in the No Self-Explanation condition do not receive these directions (See Appendix B to view the directions and materials for these conditions). Figure 6 illustrates the progression of tasks for both individual conditions.

The study uses four dyadic conditions to examine the effects of knowledge diversity (from a training task) and assigned task roles on performance and transfer learning: Distributed Experience with Roles (DR), Distributed Experience without Roles (DW), Joint Experience with Roles (JR), Joint Experience without Roles (JW).

The Distributed Experience with Roles condition (DR) is designed to be a simplified version of the collaborative learning methods found to be most effective in the structured literature review. Participants in this condition experienced a Jigsaw-like effect, in which they were given knowledge that differed from their group members, but which was essential to communicate for the sake of successfully completing the second task. They also experienced a peer tutoring effect (e.g., Guided Reciprocal Peer Tutoring), in which they were told which group members would take the lead in drawing roads or routes during the collaborative activity. The task directions (which were both written and spoken) stated, "Participant A practiced designing the shortest possible road network, while Participant B worked on designing the shortest route for a supply truck."

Participants in the DR condition, first, worked alone on the training task (Map 1) as a distributed design problem, with two different subtasks. One member of the dyad (Participant A) received directions prompting them to design the shortest road network. The other member received directions prompting them to design the shortest tour route. Then, they came together to work collaboratively as a dyad during the second main task (Map 2). Here, they worked together on the same design problem, the solution to which required the unique knowledge that each participant (may have) learned during their training task (See Appendix B to view the directions and materials for this condition). After submitting their final network design solution, each participant will individually complete a post-task questionnaire prompting them to transfer the knowledge they (may have) learned from their individual and collaborative work. Figure 7 illustrates the progression of activities participants in this condition experienced.

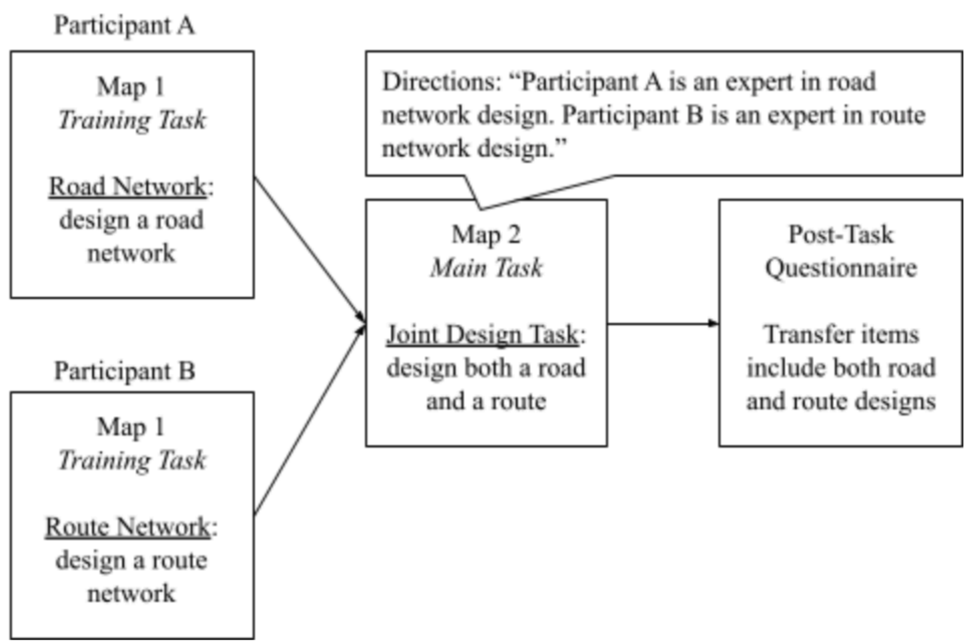


Figure 7. Progression of activities experienced by participants in the Distributed Experience with Roles condition (DR).

The DR condition is designed to make participants' distributed training experiences explicit. If the manipulation worked, participants in this condition were aware for their knowledge diversity and may have thus been motivated to explain their training task directions, their understanding, or their perspectives to a greater degree than participants who were not aware of this diversity (or participants who were not exposed to this manipulation). Whether this manipulation achieved the intended effects is examined in the Appendix A (Section A.2), yet this manipulation essentially introduces cognitive diversity along with the social manipulation of task roles.

Participants in the other three dyad conditions experienced different variations of the DR condition. These variations are illustrated in Figures 8 -10 and described below.

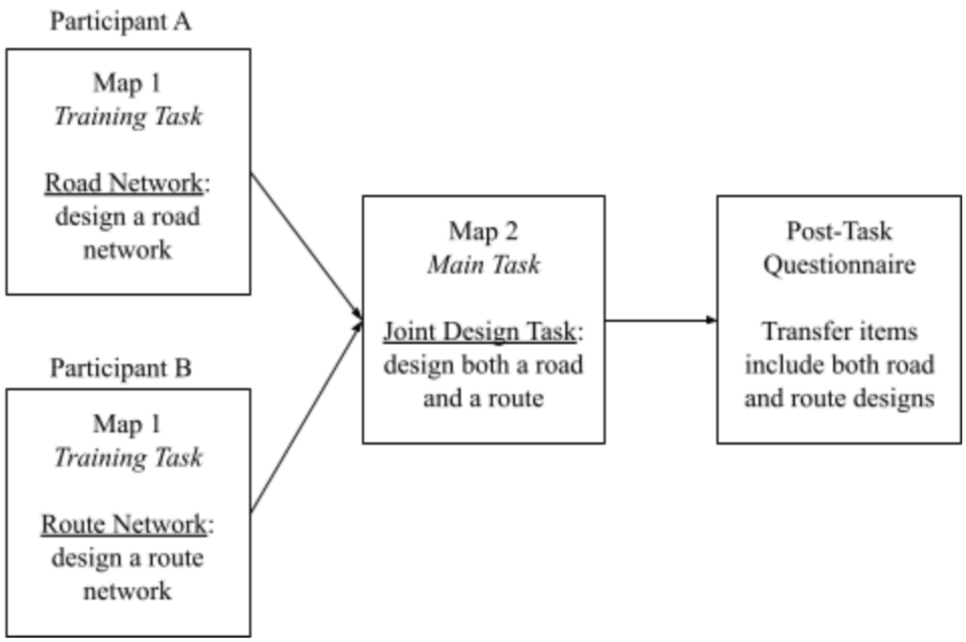


Figure 8. Progression of activities experienced by participants in the Distributed Experience without Roles condition (DW).

In the Distributed Experience *without* Roles condition (DW), the progression of tasks and the experiences of participants is almost identical to those of participants in the DR condition, but for the fact that participants in the former condition are not told they are experts in a particular subtask (see Figure 8). In this condition, it is possible that participants may discover that they have different training experiences through discovery learning, but it is not a guarantee.

Thus, participants experience a cognitive manipulation designed to induce knowledge diversity without a social manipulation of explicitly assigned task roles.

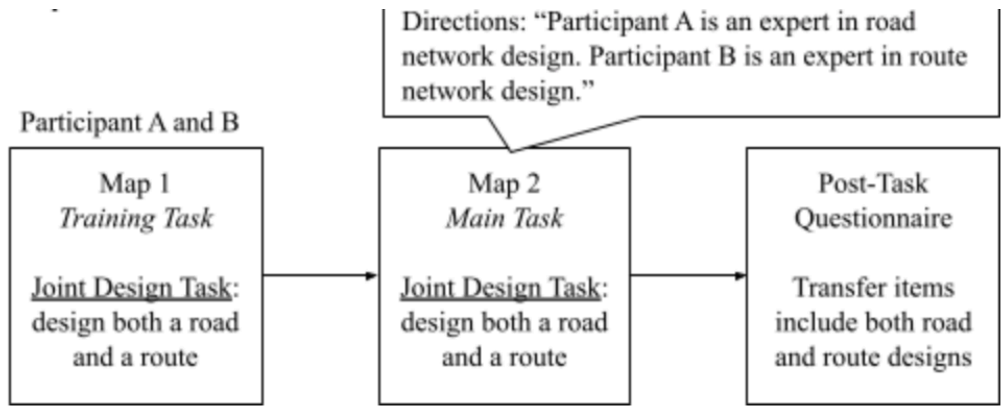


Figure 9. Progression of activities experienced by participants in the Joint Experience with Roles (JR).

In the Joint Experience with Roles condition JR), participants experience the same training task subtask as their partner (i.e., road or route). This results in a shared prior experience (or training experience) before they collaborate on the main task, Map 2. Here, both the training task and the main task involve designing both a road network and a route or tour, thus participants experience both subtasks as part of their training. Participants in the JR condition work alone on the training task (Map 1) as a joint design problem. Then, they come together to work collaboratively as a dyad on the main task (Map 2), which is also a joint design problem. At this point, each participant is told (in their shared directions) that they are to play the role experts in different areas, with the "primary responsibility" of either building roads or planning routes. Then, after submitting their final network design solution, each participant individually completes the post-task questionnaire.

Note that the roles are differentiated in this condition; one participant is told that they are responsible for the road network design and their partner is told they are responsible for the tour route design. Because both participants have experienced the same training task, they have access to the same information. Essentially, both participants will be prompted to role-play as experts when they are not, thus introducing a strictly social (not cognitive) manipulation.

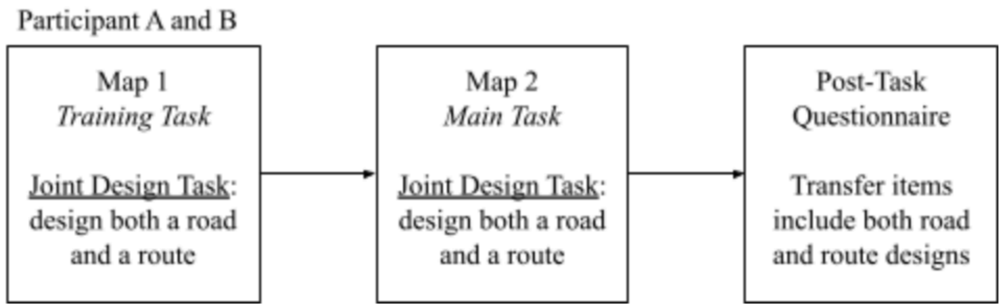


Figure 10. Progression of activities experienced by participants in the Joint Experience without Roles condition (JW).

In the fourth dyadic condition, Joint Experience without Roles (JW), roles are not assigned, and participants are not told they have differing training experiences. Otherwise, the JW condition is designed to be identical to the JR condition. Participants in this JW condition, first, work alone on the training task (Map 1) as a joint design problem. They then work collaboratively as a dyad on the main task (Map 2), which is also a joint design problem. Participants are *not* told they are experts or to act as if they have distinct roles during this collaborative task; thus introducing a cognitive manipulation, in which both participants share the same training experience, without the social manipulation. Then, after submitting their final network design solution, each participant individually completes the post-task questionnaire.

3.5 Procedure

This section offers a detailed description of the processes with which the study was implemented with a focus on recruitment, random assignment to condition, data collection, and data processing. The project progressed in four stages over the course of one year (September

2020 – April 2021), beginning with approval from Teachers College's Institutional Review Board (IRB) in the Summer of 2020 (Protocol #20-359). For the sake of efficiency, these stages were concurrent. Stage 1, Recruitment, was ongoing throughout the academic year. Participants could sign up to participate at any time through an online scheduler. Stage 2, the implementation of the experiment (referred to here as the "study sessions"), occurred periodically throughout each day of each week of the 2020-2021 academic year. Stage 3, data collection, occurred during each study session. Stage 4, data processing, began the Spring of 2021.

Stage 1 – Recruitment

Participants were recruited from the Barnard College participant pool through the Barnard Psychology Research Participation System[1]. Participants were awarded two course credits for participation (see Appendix B for images online recruitment materials). Any Barnard student interested in participating could use the Research Participation System to choose from a list of available timeslots: 10:00am, 12:00pm, 2:00pm, and 4:00pm EST every Monday, Wednesday, and Friday over the upcoming two weeks. Timeslots were limited to two participants only. Once two people signed-up for a time slot, it was automatically removed from the list of available timeslots. If only one person signed up for a time slot, the study session was assigned to the Individual with Self-Explanation condition and run accordingly (see discussion of this re-assignment process in the Limitations, Chapter 5).

Random assignment was conducted in advance by randomly assigning time slots to condition. This involved creating an empty participant database that listed all available timeslots. Using the standard number generator provided with Excel and Google Spreadsheets to call numbers from an index of the study conditions, a study condition was assigned to each timeslot

[1] barnard.sona-systems.com/Default.aspx?ReturnUrl=%2f

in the database. As participants signed up for time slots, their information was automatically associated with the condition randomly assigned to that timeslot (see Results, Chapter 4, Section 4.1, for detailed analysis of the effects of random assignment across conditions).

Once participants signed-up for a timeslot, their information was added to the participant database. They were then sent a confirmation email that included a Zoom meeting link to the study session, a copy of the Consent Form, and Participants Rights. (See Appendix B to view these materials). Participants were also sent a Google Calendar invitation. On the morning of a scheduled session, participants received a reminder email with the Zoom meeting link. If a participant failed to attend their scheduled study session, the session was either re-assigned to the Individual with Self-Explanation condition or rescheduled depending on the attending participant's availability (again see Limitations, Chapter 5, for critical examination of this process).

Stage 2 – Implementation of the Experiment

Participants arrived in each study session by way of a Zoom link. Upon arrival they were greeted by the principal researcher on the project, Katherine Moore, who welcomed them, briefly described the purpose of the study, and what they could expect to occur during the study session.

Once introductions were complete, the researcher shared screen and played a three-minute training video which showed a smaller, simplified version of the criterion maps used later in the session. In the video, the smaller map was used to model how to use the digital tools (i.e., the pen) and interact with the online interface (i.e., select objects, undo, zoom in and out) of the Miro board. Miro boards are collaborative, online, whiteboards that allow users to draw on the same digital document simultaneously. Participants did not need to log in or enter any identifying information to access the Miro boards in this study.

Once training was complete, each participant received a private message through the Zoom chat with a link to a second two-minute video in which the task directions were displayed and read aloud. Private messages allowed participants to receive different, condition specific task directions, which facilitated the distributed knowledge experimental manipulations (DR and DW) using differing training experiences.

Once finished viewing the directions video, participants used another link (again sent privately through the Zoom chat) to the collaborative Miro board for the first task, Task 1 / Map 1. During this task each participant had their own Miro boards, and kept their computer cameras off, and their computer microphones muted. This prevented any participant interaction during the first task. Participants had fifteen-minutes to complete the first task. If one participant finished before the other, they were asked to wait until the other participant had finished.

When both participants were finished (or when fifteen-minutes had passed), their access to their Miro boards was terminated. The directions video for the second task was then played on the researchers shared screen for the participants to watch together. Afterwards, participants were invited to ask questions, and were then sent a link to a second collaborative Miro board, which hosted Map 2. Here, participants in the dyadic conditions met the other member of the dyad for the first time; this often led to a brief exchange of introductions before participants began working on the problem-solving task. Participants in the individual condition with self-explanation found a second map and began narrating their thoughts and activities. Participants in individual condition without explanation found a second map and began working without experiencing social interaction. Participants had fifteen-minutes to complete the second task.

During Task 2, participants occasionally had questions regarding the directions, particularly regarding what was allowed (e.g., “Can we connect the lines here?”). These questions came from participants in all conditions, and typically occurred as participants considered the merit of using a Steiner point. The researchers answers to these questions were kept as brief as possible, typically consisting of a simple yes or no.

Despite including several opportunities in this procedure to offer clarity, a few participants misunderstood the directions. Worthy of note are misunderstandings that violated the rule limiting the number of bridges to one. If participants drew multiple bridges across the river on the Map 1 or Map 2, their map was removed from the analysis of performance (which relies on network length). However, these maps were not removed from the study because they offered an opportunity to study relationships between these mistakes or misunderstandings, the conditions, communication processes, and learning outcomes.

Once Task 2 was complete, participant access to their second Miro boards was terminated (just as in Task 1). Participants were then sent a third, private, individual link to Task 3. Task 3 consisted of five smaller network design puzzles, each with their own small paragraph of directions. Task 3 did not include a directions video; however, the researcher remained quietly present as each participant worked on this task, monitoring their work and using the chat to answer any questions that arose.

Once participants completed Task 3, they clicked on a link on their Miro board that took them to the post-task questionnaire hosted on Qualtrics. Participants typically left the Zoom meeting to complete the questionnaire. Once it had been confirmed that all portions of the study had were complete, participants were awarded to course two credits and sent a thank you email (see Appendix B for links to the videos, study session scripts, maps, and the post-task questionnaire).

At the end of each study session, the following procedure was followed: (1) participant access to study session materials was removed, (2) Zoom meeting video, audio, and automatically generated transcript were downloaded from Cloud storage and saved to a secure external hard dive, (3) study materials hosted on Miro (i.e., maps) and Qualtrics (i.e., post-task questionnaire) were also downloaded and saved to the same external hard drive, (4) all files were catalogued, (5) participants from that session were awarded two credits through the Barnard Psychology Research Participation System, (6) a thank you email was sent to session participants.

Stage 3 – Data Collection

Data collection occurred during each study session. During this period, participants were video, and audio recorded. Afterwards, products from their work (i.e., maps and questionnaires) were automatically saved. Gathering the data itself involved (a) recording all Zoom meetings (both audio and video), (b) automatically transcribing all Zoom meetings, (c) downloading a copy of all maps from each of the three problem-solving tasks conducted in Miro, (d) downloading the individual post-task questionnaires from Qualtrics, and downloading a csv file of all participant responses to the post-task questionnaire from Qualtrics. All files were catalogued with the study session date. Files documenting individual work were labeled with the participant identifier, A or B. All files were stored on a secure external hard drive and backed up on the encrypted Cloud based server managed by Teachers College.

The data gathered from each participant are (a) a .pdf file of the pre-task activity sheet, (b) a .pdf files of the collaborative task activity sheet, (c) a .pdf file of the post-task activity sheet, (d) a .pdf file of the post-task questionnaire (e) a .mp4 file of the video recorded collaborative conversation, (f) a .m4a file of just the audio from the conversation, (g) a .vtt file of the automatically generated transcript of the collaborative conversation recorded in the .m4a audio file. Video recording includes two perspectives: shared-screen view (i.e., the map) and the participants' computer camera view. While the focus of all video analysis centers on recordings from the shared screen view, participant faces were captured incidentally.

Stage 4 – Data Processing

Once data from a study session had been collected and catalogued, it was processed by a team of ten research assistants. Data processing involved (a) checking automatically generated transcripts for clarity, (b) human coding transcripts using the code scheme (see Table 7), (c) reviewing all maps to identify insights, (d) scoring post-task questionnaires to evaluate the accuracy of participant transfer of insights, (e) measuring all maps to determine performance, and (f) reviewing post-task questionnaires to determine dyad demographic diversity. Each of these data processing procedures is briefly described below.

Research assistants reviewed and corrected automatically generated transcripts from each study session. They then coded all utterances in each transcript using the code scheme used in the pilot study (See Table 7). To prepare for this work, research assistants participated in a one and half hour training session, in which the principal researcher described each speech act in the code scheme, showed short videos from the pilot study exhibiting each speech act, and then led a collaborative coding activity in which all research assistants practiced coding a sample transcript with a tool designed to highlight coding patterns. After the activity, the team examined correlations and outliers in coding choices and discussed misconceptions and clarifying questions. After the training, research assistants met weekly with the principle researcher to engage in consensus exercises. During these exercises, the team coded an excerpt of a new transcript together, reviewed coding choices, and discussed patterns and inconsistencies. As a result of this work, research assistants coded all 137 transcripts gathered during this study, twice. They maintained an interrater reliability of .886 and an average KAPPA of .489, which suggests a moderate agreement (Cohen, 1960) among raters on average (see Table 4 for details). It has been argued (c.f., McHugh, 2012) that Cohen's 1960 interpretation of the KAPPA score is too lenient and that any KAPPA below .6 indicates "inadequate agreement among the raters" (p. 4).

Weak agreement may be the result of the low prevalence of several speech acts in the discourse, rater bias, or non-independent ratings (e.g., speech act codes frequently applied together) (Sim & Wright, 2005) all of which are likely to have occurred in this dataset. A thorough examination of rater agreement is beyond the scope of the current study; thus, the study proceeds with the understandings that if the research were to continue, a) raters would need to be retrained, b) analysis would require multivariate procedures to determine whether speech act overlap indicates a latent variable, which would suggest that some speech acts in the current code scheme should be simplified or collapsed into a composite speech act, c) operationalizations of this set of speech acts would need to be validated to clarify their meaning and the linguistic constructs they represent.

Table 4. KAPPA scores averaged by speech act with Cohen (1960) and McHugh 2012) interpretations of agreement indicated by score

Speech Act	KAPPA	Cohen	McHugh
Explain	.464	moderate	weak
Propose	.430	moderate	weak
Question for Consideration	.519	moderate	weak
Question for Information	.487	moderate	weak
Response to Agree	.635	substantial	moderate
Response to Modify	.307	fair	minimal
Social Facilitation	.603	substantial	moderate
Coordinate Joint Attention	.501	moderate	weak
Interruption	.342	fair	minimal

Research assistants also divided into smaller teams to focus on processing different portions of the data. A small team took on the job of searching through all 448 maps to identify insights, i.e., the loop and Steiner point. Another team took on the job of scoring all post-task questionnaire items designed to measure participant understanding of the task. This team was given a small set of correct and incorrect sample responses (i.e., showing understanding and misunderstanding) as a guide. Findings are reported in Results (Chapter 4, Section 4.1).

The research assistants also measured all 448 maps gathered from the study, using a tool developed by the researcher and her advisor. The tool is a spreadsheet designed to take input identifying each link in a network and generate as output the total sum of the network. The tool called from a library of 178 pre-measured links (including all Steiner points used in the pilot and current study) between nodes on both Map 1 and Map 2. Data entry using this tool involved entering a code of numbers into a matrix (instead of measuring the length of each segment in each network).

Lastly, post-task questionnaires were processed by the researcher to generate descriptive statistics of participant demographics. The post-task questionnaire asked participants for their gender (female, male, non-binary), age, education (undergraduate, graduate), major, and native language. Because entries for major and native language were variable, responses were categorized into a set. Majors were binned into five commonly occurring categories: Computational, Humanities, Science, Psychology, and Undeclared. Native language was binned into five commonly occurring categories: English, Chinese, Korean, Spanish, and Other.

3.6 Criterion Variables

The research questions and study design focus on three outcome variables: task performance, transfer learning, and communication or speech acts (with specific interest in explanations). This section operationalizes each variable.

Task Performance

Criterion task performance was measured using the Map 2 dual-network solution, Road network length + Route network length = Total network length. The objective performance criterion (to be minimized) is the total summed length of both the road and the route networks (measured in cm, using Adobe Illustrator SC3 Line and Measure tools). Shorter total network length is an indicator of performance gains, and successful collaborations or individual work across all six experiment conditions (see Figures 1, 2, and 5 for sample solutions, see Figure 4 for blank versions of Map 1 and Map 2 for the current study).

Transfer Learning

Learning was measured as the frequency of transfer of two network design features to a set of individual post-task activities. This sub-section includes operationalizations of the terms (a) frequency of transfer, (b) design features, and (c) the post-task activities, beginning with the later and ending with the former.

The post-task activities, used to measure the transfer of network design features, were completed after the first two network design tasks (Map 1 and Map 2). Each task required a network design solution similar to those experienced in Map 1 and Map 2. Tasks were designed to benefit from (be minimized by) either one or both of the design features: Steiner points and loops. This allowed for the identification of incorrect transfer or transfer error. The design features are briefly described below.

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.

The learning criterion was measured as the frequency with which participants applied these design features to the novel network design puzzles in their post-task activities. Application of learned knowledge or skills in a novel context is a kind of "transfer learning." Transfer learning is the adoption of learning in one context followed by the application of that learning in another context (Woodworth & Thorndike, 1901). A more common operational definition describes transfer learning as the process of past experiences affecting learning and performance in novel situations (Ellis, 1995). Each of the five post-task activities are considered near transfer activities because (a) participants completed them immediately after the first and second network design activities and (b) the post-task activities benefit from network design knowledge and skills that are identical to those from the main task. Table 5 summarizes the characteristics of each task. (See Appendix B to view each post-task activity).

Table 5. Descriptive Summary of the Five Post-Task Activities and Measures of Transfer Learning

Post-task Item	Excerpt from Directions	Network Design Feature Transferred
Q1	"Draw the shortest possible network of irrigation canals."	Steiner Point
Q2	"Draw the shortest possible way Elliot should travel to get to all the stops and get back to work quickly."	Loop
Q3	"Draw the shortest bus route possible connecting all the houses in the town to the school."	Loop
Q4	"Draw a cost-efficient network connecting the power plant to the homes."	Steiner point
Q5	"Draw the shortest network of tunnels Hannah's ants can dig to get to each of the 4 cubes."	Steiner point and Loop

Table 5 shows that some post-items were designed to measure the transfer of the Steiner point and others were designed to measure the transfer of the loop (Q5 measures the transfer of both). If a design feature was transferred to an item that it benefitted (e.g., a Steiner point was transferred to Q1) it was considered one count of successful transfer. Importantly, if a design feature was transferred to an item that it did *not* benefit (e.g., a loop was transferred to Q1), it was counted as incorrect transfer and a transfer error. Table 6 summarizes correct and incorrect design features transfer for each item of the post-task activities (Q1-Q5).

In the analysis, these indicators of transfer learning are combined into two composite variables designed to indicate the total frequency with which either design feature was successfully transferred, Total Transfer Success, and unsuccessfully transferred, Total Transfer Error. These composite transfer learning variables are summarized in Table 7.

Table 6. Types of successful and unsuccessful transfer learning for each post-task activity item

	Post-Task Item Design	
Post-task Activity	Successful Transfer if feature applied	Transfer Error if feature applied
Q1	Steiner point	Loop
Q2	Loop	Steiner point
Q3	Loop	Steiner point
Q4	Steiner point	Loop
Q5	Steiner point & Loop	Neither Steiner point nor Loop

Table 7. Indicators of Transfer Learning and Mistakes

Indicator Type	Indicator Variables	Relevant items from post-task
Total Transfer Success	Successful Transfer of Loop	Q2, Q3, Q5 with Loop
	Successful Transfer of Steiner point	Q1, Q4, Q5 with Steiner point
Total Transfer Error	Loop Transfer Error	Q1, Q4 with Loop
	Steiner point Transfer Error	Q2, Q3 with Steiner point

Communication

Communication was measured using automatically generated transcripts of the study sessions. Zoom automatically time stamps and transcribes the audio file. This process automatically parses transcripts into utterances by speaker turn taking (see Section 5.5 for further details on this limitation of the study). Each turn is a segment of speaker-continuous speech. Transcripts were then human coded to identify specific types of utterances or meaningful phrases, referred to here as “speech acts” (see Procedure, Section 3.4 for details on the coding process). This code scheme of speech acts is operationalized in Table 8. The references column cites studies in which these speech acts were developed.

Table 8. Summary description of each speech act in the code scheme

Speech Act	Description	Examples
Explain (E)	An utterance that signals verbal consideration of an idea, thinking aloud, or a response to explain an action or a thought, state the task rules, or describe prior knowledge.	"… then I went back up, but I don't know." "I was thinking if there is a way to cut this…" "The other thing we could do is go up this way…" "If you do it this way for A and B it's shorter."
Propose (P)	An utterance to suggest a task-related action be taken, such as adding or removing a link to the network, or adding a design insight (i.e., loop or Steiner point)	"What if we start at E?" "Ok. We can try on this map." "And maybe we can go from J to C directly." "So we can measure… let's see…"
Question for Consideration (Qc)	An utterance posed as a question to encourage a participant to consider something for the purpose of learning their opinion, getting their permission, or gaining consent	"What about this part?" "Like this?" "Right?" "What do you think?"
Question for Information (Qi)	An utterance posed as a question to solicit information or seek clarification on a previously mentioned, written, or drawn piece of information.	"Are we working on this map?" "There's only one bridge?" "How did you get your solution?" "Where did you put your base?"
Response Agree (Ra)	A response to any type of previous statement that expresses agreement. This includes affirmative memes like, "yeah" "ok" "uh-huh". [Note: Tone matters.]	"Ok" "Yeah, that's right." "I think maybe that's a good idea" "Yeah… yeah."
Response Modify (Rm)	A response to any type of previous statement that suggests modifications to the statement, augments the statement by suggesting an addition, amendment, or alternative. This can include a counter proposal.	"Yeah, I don't know about that. I think…" "I guess the other think you could do is…" "But, if you do it this way… it's shorter." "Or what if it went like this…"
Coordination of Joint Attention (J)	Any utterance or sound meant to direct a partner's attention. This may include directing a partner's attention to an area on the map, an area in the directions, or another object. In a virtual setting	"Maybe something like this…" "We could go this way…" "Go A to E from here." "… the other thing you could do is go this way."

	this can be done with the physical movement of a cursor on the screen or an utterance such as “there” or “here, here, then here”.	
Social Facilitation (S)	An attempt to address, manage, or grow a social relationship with a participant. This includes telling a joke, expressing an emotion, sharing a piece of personable information, or performing a social service, such as introducing oneself, inquiring as to a person's health, saying "bless you" after a person sneezes, or offering a compliment	“What’s your name?” “Thank you.” “I don’t know why I did that.” “This kind of looks like a dinosaur.”
Interruption (N)	An utterance that interrupts the speaker. It should have the immediate effect of cutting off the former speaker's utterance, such that they are not able to complete their utterance. Note: This does not include speaking after a pause or speaking after another speaker has trailed off.	“… plus this, plus, this” “And then…” “Right, or you could do like…” “Yeah.”

The subsequent paragraphs operationalize each speech act summarized in Table 7, and then briefly describe prior research that has developed and examined collaborative discourse using these speech acts. Because explanations play an important role in the specific aims and design of the current study, it receives slightly more attention in these descriptions.

Explain. Utterances that were labeled as “explain” (E) involved stating or elaborating upon information from the participant’s short- and long-term memory. Statements were uttered facts, beliefs, or perspectives. Elaboration was uttered interpretations, embellishment, or connection of information to other topics of discussion, specific utterances in the conversation, or material. In the context of the collaborative task in the current study, elaboration tended to involve describing interpretations of the task directions, listing a series of proposed steps for the purpose of clarifying a proposal, answering questions, and spontaneously stating one's thoughts out loud.

The act of explaining has been examined in a great number of empirical studies. In the context of the current study the act of "explaining" most closely aligns with the prior research of Merlin Wittrock (1986), Noreen Webb (1989), and Chi et al. (1989). Each of their definitions of the term are briefly described and contextualized in the current study below.

The act of explaining one's memories or prior knowledge for the purpose of connecting it to the current work at hand parallels Wittrock's research and generative theory of learning (1989). According to Wittrock, learning occurs when people draw associations between the present topics or material and their prior knowledge. The generation of these connections are where learning occurs. In the context of the current study, raters used Wittrock's version of explanations to identify utterances connecting the training task to the main task, and utterances describing one's personal experience (e.g., with network design, maps, truck routes, etc.).

Noreen Webb (1989) offers two levels of explanations, which are described as low- and high-level elaboration. Low level elaboration includes an answer to a question, such as a statement without explanation. High-level elaboration includes an explanation or justification of an answer. Webb's research finds that high-level elaboration to a question or a peer's request for help is positively associated with achievement (for the speaker). In the context of the current study, raters used Webb's version of explanations to identify utterances that responded to elaborate or answer a question with a description or justification. These were often accompanied by the respond to modify speech act if the explanation was a response that corrected or adjusted what the speaker's partner had just said or done.

Self-explanation was also assigned the code "explain." Self-explanations, as described by Chi et al. (1989) are spontaneously generated explanations to oneself as one studies "worked-out examples." In the case of Chi et al.'s research, these worked out examples came in the form of text describing scientific information with a few model examples, which participants read and then summarized aloud solo. In the context of the current study these worked-out examples were the training task and the main task. As participants in the Individual with Self-Explanation (IE) condition completed the second task (when directions prompted them to use self-explanation), they would explain their thinking by reflecting on their performance, evaluating their progress, and describing the options or new courses of action they were considering.

In summary, raters identified a wide variety of utterances as "explain", ranging from connections to prior knowledge, to detailed explanations or justifications in response to questions, to spontaneous statements (either to a partner or to oneself). The following paragraphs describe the other eight speech acts raters used to code participant utterances.

Propose. Utterances that were recorded as "propose" (P) involved suggesting, introducing, directing, or insisting on a course of action. In the context of the task, proposals tended to involve suggesting a particular sequence of links in a network, offers to draw the network, or hints that the partner should draw the network. Proposals were frequently posed grammatically as a question, e.g., "Shall I draw?" Depending on the conversational context and tone, such an utterance would be coded as a question *and* as a proposal because the pragmatic affect was that the partner would signal a "Yes" and the speaker would begin to draw.

In an empirical study of collaborative triads, Barron (2003) found that proposals (and partner responsiveness to those proposals) explained group achievement on problem-solving tasks to a greater degree than prior achievement of group members or the frequency of correct ideas generated. In this research, Barron briefly explains that a proposal is a solution to the study tasks. In the context of the current study, raters used Barron's version of proposals to identify utterances that described solutions to the network design problem. Raters also identified utterances as proposals if a participant suggested a course of action related to a non-task related problem, i.e., technical issues, misread or misunderstood directions.

Question for Consideration. Utterances that were recorded as "questions for consideration" (Qc) involved asking one's partner for their opinion, their reflection, or their consent. In the context of the task, these questions tended to seek guidance, feedback, or direction from the partner. Questions for consideration tended to arise alongside proposals and explanations, as if participants did not want to take action without their partner's consent or understanding.

Barron (2003) used the similar, but non-identical code of "discuss" in her empirical research to identify when an utterance would facilitate further discussion. Responses labeled as discussion included questioning a proposal, challenging it with new information, or requesting more time for discussion. Discuss was one of three speech acts in Barron's code scheme, which also included accept and reject. Upon examining these three types of responses as they emerged during collaborative discourse on a problem-solving task, Barron found that successful triads were more likely to respond to peer proposals with discuss (and accept) than unsuccessful groups.

Because of the frequency of "discuss" type utterances in the current study, it was decided to split Barron's code into two speech acts; question for consideration was one of them. The other was response modify, which is detailed in a subsequent paragraph. Splitting Barron's “discuss “code allowed the current study to better illustrate bi-directional responses involved in the exchange of ideas (Barron’s study used a uni-directional focus on responses only).

Question for Information. Utterances that were recorded as “questions for information” (Qi) involved asking one’s partner for information that it was assumed they knew. In the context of the task, these questions tended to seek information from the partner, such as their name, a description of the directions on their first task, or whether they knew what time it was. Questions for information tended to evoke brief statements from partners, which tended to offer an answer and occasionally provide a brief explanation.

Including this type of question in the code scheme allowed raters to distinguish between questions that aligned with Barron’s (2003) term “discuss” (which was found to encourage proposals and thus achievement) from those that did not align with this term. Questions that did not foster discussion tended to prompt responses that aligned with Webb’s (1989) term for low elaboration; these are answers that were brief, direct, and with minimal explanation. While questions for information certainly evoked informative responses from the speaker’s partner, they did not tend to spark discussion.

Response Agree. Utterances that were recorded as “affirmative response” (Ra) involved a positive or affirmative reply to a partner’s utterance. In the context of the task, these responses tended to be a simple “Yes” or noise clearly indicating agreement. Less regularly, a response to agree was more ambivalent, i.e., “Sure” or “It doesn’t matter.” Responses to agree tended to accept a partner’s proposal or encourage or affirm a perspective uttered by the speaker’s partner.

Barron’s (2003) research found that responses of agreement, specifically responses that accepted another group member’s proposal were more frequently used by triads who were successful on a collaborative problem-solving task, than by unsuccessful triads. The speech act used in the current study is an imperfect adoption of Barron's version, because Ra in the current study includes responses that accepted any idea, not just a proposal.

Response Modify. Utterances that were recorded as "response modify" (Rm) involved a reply that involved an addition, modification, or enhancement to the previous speaker's statement. In the context of the task, these responses tended to responses to proposals and involved corrections, and clarifications. Responses to modify tended be followed by discussion, but not consistently. They occasionally led to a pause in the conversation, i.e., silence, or a long pause before a topic change.

Of the speech acts included in the code scheme, response to modify is the closest to Barron's (2003) term "discuss" because it tended to occur as a series or exchange of Rm's. In the current study, raters used an almost verbatim description of Barron's (2003) term "discuss" to identify Rm. The two studies descriptions of discuss and Rm overlap in that they are "responses that acknowledge proposals," but do not "accept them outright." Both terms also include "restatements that signal evaluation." Where the terms slightly diverge is that "discuss" could include questions, whereas in the current study questions were labeled as either Qc or Qi.

Additionally, in the current study, Rm involved short exchanges, occurring over three or four pairs of turns. These exchanges tended to terminate in a P (e.g., a new, modified proposal), Qc (e.g., an attempt to clarify a misunderstanding), or a Ra (e.g., an agreement to proceed with the modification).

Importantly, Barron's reported relationships between responses to accept and discuss proposals were only found significant when the two categories were merged. Future research using the code scheme from the current study might consider following Barron's analysis and merging Qc, Qi, Ra, and Rm into a single code, which Barron labels "engagement."

Coordination of Joint Attention. Utterances that were recorded as “coordination of joint attention” (J) involved statements that directed the listener’s attention to a physical location on the shared map. Coordination tended to coincide with a gesture using the cursor on the screen, e.g., circling a point, moving the cursor back and forth between two points to indicate the location of a potential new line segment on the map. The most common utterance raters labeled as J was counting, i.e., “one, two, three”. Participants used counting to model their solution for their partner (i.e., tracing the pattern of nodes traveled in a sequence), which meant J often occurred in tandem with P, and Rm.

The work of Roschelle and Teasley (1995) justifies the attention paid to this speech act. They use it in a general sense to refer to coordinated cognitive activities involved in collaborative work. In their research, Roschelle and Teasley describe coordinated joint attention as a coordination of meaning through language and action to introduce, monitor, and repair a shared understanding. These definitions make clear that coordinated joint attention is a cognitive phenomenon that happens at the level of the collaborative session. Roschelle and Teasley include coordinating efforts such as deictic actions and attention to physical space; this is where the current study’s use of the term overlaps.

In the current study the raters used “coordination of joint action” (J) to identify deictic actions in which a speaker calls the hearers attention to a specific aspect of the task environment. Thus, coordinating joint attention is identified in the current study as a micro-action. While Roschelle and Teasley use the term to describe what goes on in a collaborative session, the current study uses the term to identify a type of utterance.

Social Facilitation. Utterances that were recorded as “social facilitation” (S) involved utterances that had an off-task but socially relevant effect on the conversation. Social facilitation involved introductions, jokes, pleasantries and off-task remarks that expressed humility, fatigue, and other emotions. Social facilitation tended to emerge during moments of confusion, conflict, challenges, or long pauses. Social facilitation was not included in the current study because of an overlap with other code schemes in cooperative learning research (as with the other speech acts in the current study); instead, social facilitation was developed during the pilot in response to a need to include off-task, but social relevant behaviors in the analysis. It was believed that social facilitation may ameliorate the collaborative process and may thus have positive effects on performance or learning outcomes.

Interruption. Utterances that were recorded as “interruption” (N) involved any type of utterance that cut-off or disrupted the speaker. This speech act could include either negative interruption (i.e., designed to disrupt the speaker’s utterance), positive interruption (i.e., interjects to help in a constructive way), or overlaps (i.e., synergy or several minds thinking together, e.g., finishing another’s sentence to demonstrate agreement or understanding). This speech act could be applied with any other speech act, as any speech act could be an interruption. Like social facilitation, it was included in the code scheme not because of an overlap in the code schemes of other research in the cooperative learning literature (although research in interruptions is quite extensive, c.f., Gillies, 2008; Haller et al., 2000; Reski & Aswad 2018). Instead, interruptions were included in the study because of their frequency in the pilot. Anecdotal observation suggested that participants were more likely to interrupt each other when they agreed with each other. It was speculated that interruptions might be evidence of synergy (although research in non-collaborative contexts suggests the opposite, Lee & Duffy, 2015; Zickerick et al., 2020).

Chapter 4: Results

This chapter presents, first, an analysis of participant demographics, variables, and manipulations to establish the overall efficacy of random assignment and study implementation. These analyses are followed by presentation of the results addressing the research questions, which examine the relationship between two types of group diversity and collaborative communication. The research questions also look at the relationship between collaborative communication and two outcome variables: task performance and transfer learning. These relationships are compared to the effects of two control conditions designed to isolate the effects of communication processes on the outcome variables.

Analysis of the research questions regarding the criterion variables was accomplished using a two-by-two factorial design, with two added control conditions. It was conducted using an analysis of variance (ANOVA) followed by a series of planned contrast tests. The results are presented in an analysis of each criterion variable (Section 4.3), then by research question (Section 4.4). Implications are discussed in Chapter 5.

4.1 Participant Demographics

Participants were recruited from the Barnard College Psychology Research Participation System. This recruitment system is managed by Barnard College's Admissions Office. The resulting participant pool is comprised almost entirely of undergraduate females, averaged 20 years of age. Barnard offers students a variety of majors, roughly distributed across topics of Humanities, Sciences, Psychology, and Computation. Students are required to declare a major by the middle of the second year. Participants in the current study reflect the demographics of this larger population.

On average, participants (N=273) were 19.39 years of age (range, 18-45 years). Participants (see Table 9) were typically 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 (see Table 9).

In spite of the random assignment to conditions, there was a significant difference in the distribution of declared majors across conditions, X^2 (20, N = 273) = 40.405, p = .004, with an overrepresentation of computational majors in the DR condition. Computational majors comprised 22% of all majors in the study, but they comprised 33% of the DR condition (see Appendix A, Figure A for details of this imbalance). Because computational majors included topics relevant to the performance task (e.g., Mathematics and Architecture), computational majors might have had an advantage over other participants on the collaborative problem-solving task; however, analysis found no evidence of this (see Appendix A, Tables A and B for details). All other recorded participant demographic characteristics do not differ across conditions (See Appendix A for all relevant tables and figures).

Table 9. Demographic characteristics of full sample with distributions (n, %) across study conditions (N=273)

	IW		IE		JW		JR		DW		DR		Full Sample	
	N=38		N=39		N=46		N=44		N=46		N=60		N=273	
	n	%	*N*	%	*N*	%	*n*	%	*N*	%	*n*	%	*n*	%
Gender														
Female	35	13	35	13	43	16	40	15	40	15	51	19	244	89
Male	3	1	2	1	3	1	2	1	4	1	7	3	21	8
Non-binary	0	0	1	<1	0	0	1	<1	2	1	2	1	6	2
No answer	0	0	1	<1	0	0	1	<1	0	0	0	0	2	1
Education														
Undergraduate	38	14	38	14	46	17	44	16	46	17	58	21	270	99
Graduate	0	0	1	<1	0	0	0	0	0	0	2	1	3	1
Major														
Computational	6	16	6	15	7	17	12	27	10	22	20	33	61	22
Humanities	15	40	9	23	5	11	10	23	7	15	10	17	56	21
Psychology	4	11	9	23	15	32	8	18	6	13	9	15	51	19
Science	8	21	2	5	7	15	2	5	11	24	4	7	34	12
Undeclared	5	13	13	33	12	26	12	27	12	26	17	28	71	26
Native Language														
Chinese	2	8	1	4	3	13	6	26	4	17	7	30	23	8
English	30	16	31	16	34	18	26	14	29	15	39	21	189	69
Korean	0	0	1	33	0	0	1	33	0	0	1	33	3	1
Spanish	0	0	3	21	3	21	3	21	4	29	1	7	14	5
Other	6	14	3	7	6	17	8	18	9	21	12	27	44	16

4.2 Descriptive Statistics

This section offers descriptive statistics summarizing the main mediating and outcome variables: i.e., performance, communication, and transfer learning. See Appendix A, for analysis of the comprehension check, and Appendix A, Table F and Figure C for manipulation checks of the two interventions, knowledge diversity and assigned task roles).

Task Performance Criterion

Task performance, as measured by total network length, is independent of transfer learning; these two outcome variables are uncorrelated, $r = .01$, $p = .928$. Furthermore, task performance does not correlate with any of the speech acts. These results suggest that task performance is independent of the mediating variables, speech acts, and the other outcome variable, transfer learning.

Only one of the target design features, the loop, was found to shorten the total network length and thus improve task performance (see Table 10 for means and standard deviations).

Table 10. Comparison of performance (total network length) with and without use of the target design features, Loop and Steiner point

Design Feature	Network Length with Design Feature		Network Length *without* Design Feature		*t*(271)	*p*	*d*
	M	*SD*	*M*	*SD*			
Steiner point	133.98	5.54	133.69	12.30	-.262	.794	-.029
Loop	132.31	7.02	138.15	15.01	3.137*	.002	.602

* Equal variance not assumed

Discourse Characteristics

At the group level, dyads spent an average of 9.5 minutes (SD = 4.162) on the collaborative task (range, 2.36 - 19.41 minutes), but the distribution was bimodal, with a cluster of conversations centered at about 5 minutes length and another more dispersed cluster at about 12 minutes (see Appendix A, Figure D). The number of turns taken averaged 67.0 turns per conversation (SD= 38.75) with a positively skewed distribution (range, 6 – 205 turns per conversation). The number of words spoken during the conversation showed a similar pattern (*M* = 602.08, SD= 382.498, range 45 words – 2,246 words) (see Appendix A, Figures E and F and Table G).

Table 11 displays the discourse characteristics by study conditions (in which participants spoke). There are not significant differences between conditions. On average, participants in the knowledge distributed conditions (DW and DR) spent more time speaking, used a greater number of turns, and a greater number of words than participants in the joint or shared knowledge conditions (JW and JR) and participants in the self-explanation condition (IE).

Table 11. Discourse characteristics by condition

Study Conditions in which participants spoke	Total Time Spent Speaking (min)		Number of Turns Taken		Number of Words Spoken	
	M	*SD*	*M*	*SD*	*M*	*SD*
Self-Explanation (IE)	7.19	3.70	40.26	27.07	372.92	234.00
Joint without Roles (JW)	9.19	4.16	94.74	39.43	861.04	475.70
Joint with Roles (JR)	9.84	3.87	95.09	39.78	843.82	384.57
Distributed without Roles (DW)	11.43	3.45	120.26	37.34	1061.00	339.36
Distributed with Roles (DR)	10.78	3.65	111.00	40.78	1006.77	447.91

Communication Criterion

The frequency of explanations, the speech act of primary interest in the current study, correlates with the frequency of each of the other speech acts (see Table 12). In fact, almost all speech acts in this study correlate with each other. There are a couple possible explanations for these relationships. One explanation may be that these high correlations arose from covariation in the length of many of the dialogues. This would mean that the frequency of speech acts would be explained by the length of the conversation rather than by the study condition in which they occurred. To test this possibility a principal component analysis (PCA) of the proportion of speech acts was conducted, but found a high frequency of negative eigen values, suggesting an ill-structured matrix possibly due to the great deal of overlap in the application of the speech acts.

A second explanation for these high correlations may be the presence of one or more latent variables, perhaps merely the total number of utterances (see Appendix A, Table H for cosine similarity matrix).

Table 12. Pearson correlation matrix of all speech acts.

Speech Acts	1.	2.	3.	4.	5.	6.	7.	8.
1. Explanation	--							
2. Propose	.589**	--						
3. Question Consideration	.448**	.741**	--					
4. Question Information	.468**	.720**	.817**	--				
5. Response Agree	.387**	.668**	.738**	.611**	--			
6. Response Modify	.423**	.724**	.799**	.849**	.577**	--		
7. Social Facilitation	.466**	.548**	.642**	570**	.673**	.562**	--	
8. Coordinate Joint Attention	.449**	.501**	.395**	.261**	.503**	.184*	.369**	--
9. Interruptions	.285**	.230**	.115*	.112*	.321**	.027	.281**	.467**

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

Principal component analysis (PCA) reveals two components (see Appendix A, Figure G for a scree plot and Table I for the principal components loadings matrix). The first component is dominated by *explanation* and *coordinating joint attention*. Prior research associates both with cognitive elaboration (Chi et al., 198; Roschelle & Teasley, 1995; Webb, 1989), and work by Roschelle & Teasley (1995) suggests that these two terms should be linked. The second component is dominated by *response modify*, *social facilitation*, and *response agree*. Each of these speech acts have a social effect of continuing the conversation, either by engaging in discussion of modifications, expressing socially positive behaviors, or by agreeable responses.

Because Component 1 correlates with transfer learning, $r = .173$, $p = .015$, this may be a more general indicator of what Webb (1989) and O'Donnell and Dansereau (1992) refer to as "cognitive elaboration". And it may be that component 2 represents behaviors important to facilitating the collaborative process (i.e., motivating discourse); this factor is not directly associated with transfer learning outcomes, $r = -.092$, $p = .200$.

Learning Criterion

As mentioned in the previous section describing the criterion variables (Section 3.5), post-task activities were designed to measure the frequency of application of two design features (the loop and the Steiner point), as the criterion measure of transfer learning. Application of the loop on items Q2, Q3, and Q5 and of the Steiner point on items Q1, Q4, and Q5 is considered "successful transfer" (again, see Section 3.5 for details); conversely application of the loop on Q1 and Q4, and the Steiner point on Q2 and Q3 is considered inappropriate use or "transfer error". These composite measures of transfer were designed to allow analysis to consider how the conditions and mediating variables may have facilitated misunderstandings (as well as transfer learning). See Appendix A for item analysis (Figure H).

4.3 Main Analysis

This section details the main findings from the analyses aimed at answering the research questions. The section is organized into three subsections to structure findings concerning task performance, transfer learning, and explanations (see Appendix A, Table J for the correlation matrix for each of the mediating and outcome variables).

Task Performance

This subsection presents the research questions relevant to task performance listed with the corresponding analysis for each question. Table 13 displays the descriptive statistics for task performance variables for dyadic (N=98) and individual conditions (N=77). Table 14 presents the two-by-two ANOVA of task performance for the dyadic conditions only.

Table 13. Descriptive statistics (M, *SD*) for task performance outcome variables across all study conditions (N=175)

Outcome Variables	All Study Conditions												Full Sample	
	IW		IE		JW		JR		DW		DR		Full Sample	
	N=38		N=39		N=46		N=44		N=46		N=60		N=273	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Total Length	134.1	10.9	134.9	10.32	136.0	11.1	133.3	12.30	132.1	5.2	131.9	7.9	133.8	9.9
Road Length	54.1	6.0	53.1	7.7	58.7	4.9	54.3	5.9	57.3	7.5	52.5	6.7	54.6	6.8
Route Length	80.1	10.3	81.8	10.5	77.3	11.6	79.0	11.4	74.9	9.4	79.4	9.2	79.2	10.4

Table 14. Factorial (2x2) ANOVA results for task performance across four dyadic conditions (JW, JR, DW, DR)

Performance (Total Network Length)	*df*	*SS*	*MS*	*F*	*p*
Main Effects					
Knowledge Diversity	1	164.520	164.520	1.864	.450
Task Roles	1	50.798	50.798	.576	.175
Interaction					
Knowledge Diversity * Task Roles	1	34.266	34.266	.388	.535
Total	97	8548.099			

RQ1. Do dyads outperform individuals on the given problem-solving task? Dyads do not outperform individuals on the network design problem-solving task. There is no significant difference in length of the total network submitted for Map 2 between dyads and individuals, $t(173) = .838$, $p = .403$, $d = 9.923$.

RQ3a. Does distributed experience induced by a training task have a different effect on performance than joint experience? Findings from the two-by-two factorial ANOVA (as seen in Table 14) show no effect of distributed experience from a training task (also referred to as knowledge diversity) on performance, $F(1, 97) = 1.864$, $p = .450$.

RQ5a. Do assigned task roles influence performance and compared to groups working without assigned roles? Findings from the two-by-two factorial ANOVA (as seen in Table 14) show no effect of assigned task roles on performance, $F(1, 97) = .576$, $p = .175$.

RQ7a. Do distributed experience and assigned task roles interact in affecting performance? Findings from the two-by-two factorial ANOVA (as seen in Table 14) show no interaction between distributed experience (knowledge diversity) and assigned roles in regards to performance, $F(1, 97) = .388$, $p = .535$.

Transfer Learning

This subsection presents the research questions relevant to individual learning (as measured by transfer learning) listed with the corresponding analysis for each question. Table 15 displays the descriptive statistics for the transfer learning variables for individuals from all conditions (N=273). These transfer learning variables include both successful transfer and transfer error. They also include use of the design features, the loop and Steiner point; note that descriptive statistics show that use of the loop in the network design improves task performance (but the Steiner point does not). In Table 15, the variable "Loop Error" refers to errors specific to loop transfer, and "Point Error" refers to errors specific to Steiner point transfer. Table 16 presents the two-by-two ANOVA of transfer learning for dyadic conditions only.

This analysis examines the individuals within each dyad; essentially, opening the dyads to examine the individual behaviors within. This type of analysis risks disassociating individual group members from the context and ecology of their group; interpretations from these data attempt to preserve an understanding of these individuals and their learning as the product of collaborative group work (as opposed to individualized experiences).

Table 15. Descriptive statistics (M, *SD*) for transfer learning outcome variables across all study conditions (N=273)

Outcome Variables	All Study Conditions													
	IW N=38		IE N=39		JW N=46		JR N=44		DW N=46		DR N=60		Full Sample N=273	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Total Transfer	3.24	1.34	2.92	1.38	3.09	1.09	3.16	1.31	3.37	1.39	3.05	1.29	3.14	1.30
Loop Transfer	2.18	.90	2.00	.86	2.17	.61	2.09	.80	2.20	.78	2.07	.63	2.12	.75
Point Transfer	1.05	.93	.92	1.01	.91	.91	1.07	.93	1.17	1.08	.98	1.03	1.02	.98
Transfer Error	.89	.73	.82	.76	.70	.76	.89	.75	.89	.88	.65	.71	.79	.76
Loop Error	.63	.71	.67	.66	.59	.62	.66	.75	.57	.72	.58	.67	.61	.68
Point Error	.26	.60	.15	.36	.11	.38	.23	.52	.33	.60	.07	.25	.18	.47

Table 16. Factorial (2x2) ANOVA results for transfer learning across four dyadic conditions (JW, JR, DW, DR)

Transfer Learning (Total Transfer Success)	*df*	*SS*	*MS*	*F*	*p*
Main Effects					
Knowledge Diversity	1	.36	.36	.223	.637
Task Roles	1	.74	.74	.453	.502
Interaction					
Knowledge Diversity * Task Roles	1	1.85	1.85	1.135	.288
Total	195	316.10			

RQ2. Do individuals who have worked in dyads show greater learning than individuals who have not worked in a dyad? Individuals who worked in a dyad do not show a greater frequency of transfer learning than individuals who did not work in dyads. This is evidenced by the fact that there is no significant difference in total transfer success between

dyads and individuals, $t(271) = -.459$, $p = .647$, $d = 1.299$. There is also no significant difference in total transfer error between dyads and individuals, $t(5) = -.441$, $p = .677$, $d = .742$.

RQ3b. Does distributed experience induced by a training task have a different effect on individual learning outcomes than joint experience? Findings from the two-by-two factorial ANOVA (as seen in Table 16) show no effect of distributed experience from a training task on learning outcomes, $F(1, 195) = .223$, $p = .637$.

RQ5b. Do assigned task roles influence individual learning outcomes, compared to groups working without assigned roles? Findings from the two-by-two factorial ANOVA of transfer learning (as seen in Table 16) show no effect of assigned task roles on learning outcomes, $F(1, 195) = .453$, $p = .502$.

RQ7b. Do distributed experience and assigned task roles interact in affecting individual learning outcomes? Findings from the ANOVAs of performance and learning (as seen in Table 16) show no interaction between distributed experience (knowledge diversity) and assigned roles in regards to learning outcomes, $F(1, 195) = 1.135$, $p = .288$.

Explanations

Because this study focuses on explanations as reflecting cognitive elaboration, and thus as a mediating variable between the study conditions and the outcome variables, several research questions were designed to examine the relationship between explanations and the outcome variables of group performance and individual learning. These questions are presented in this subsection and listed with the corresponding analysis for each research question.

The presentation begins with analysis of explanations summed across both participants within the dyad (N=98) and individual conditions with verbalization (N=39). This analysis treats all explanations uttered during a dyad’s work as complementary and “additive.” This approach is based on the assumption that the explanation affects the shared understanding of the task, regardless of who uttered the explanation.

Table 17 displays descriptive statistics for the frequency of explanations – as well as the eight other speech acts – across all study conditions with verbalization (see Appendix A, Table J for correlation matrix). Table 17 also presents results from one-way ANOVAs comparing each speech act across all dyadic conditions. Table 18 presents the two-by-two factorial ANOVA of the total frequency of explanations uttered during dyadic discourse. Figure 11 displays boxplots of the distributions of the frequency of explanations uttered within each dyad.

Table 17. Descriptive statistics (M, *SD*) for all speech act variables across all study conditions (N=137)

	Study Conditions with Verbalization											
	IE N=39		JW N=23		JR N=22		DW N=23		DR N=30			
Speech Act Variables	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*(3,98)	*p*
Explain	27.97	20.51	29.26	14.78	27.77	13.65	38.57	16.81	43.57	31.59	3.126	.029
Propose	4.82	5.30	13.04	8.64	10.50	8.33	10.70	8.08	15.10	22.09	.624	.601
Question Consider	.03	0.16	6.70	4.96	5.68	4.34	8.39	4.92	9.97	17.28	.851	.469
Question Information	.26	.75	3.35	2.42	3.55	2.50	3.43	2.45	6.63	16.78	.779	.509
Response Agree	.05	.32	13.96	7.91	13.09	7.91	17.17	6.82	15.67	15.26	.680	.567
Response Modify	.49	1.21	1.48	3.09	0.91	1.41	0.87	1.39	3.23	11.55	.760	.519
Social Facilitation	1.72	2.70	7.48	7.76	7.55	6.36	10.78	6.75	9.57	10.57	.888	.451
Joint Attention	.97	2.63	13.83	11.22	14.91	12.99	19.65	13.87	18.4	15.92	.956	.417
Interruptions	.00	.00	1.00	1.73	1.18	1.967	1.57	3.203	1.47	2.64	.262	.853

Table 18. Factorial (2x2) ANOVA results for explanations across four Dyadic conditions (JW, JR, DW, DR)

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

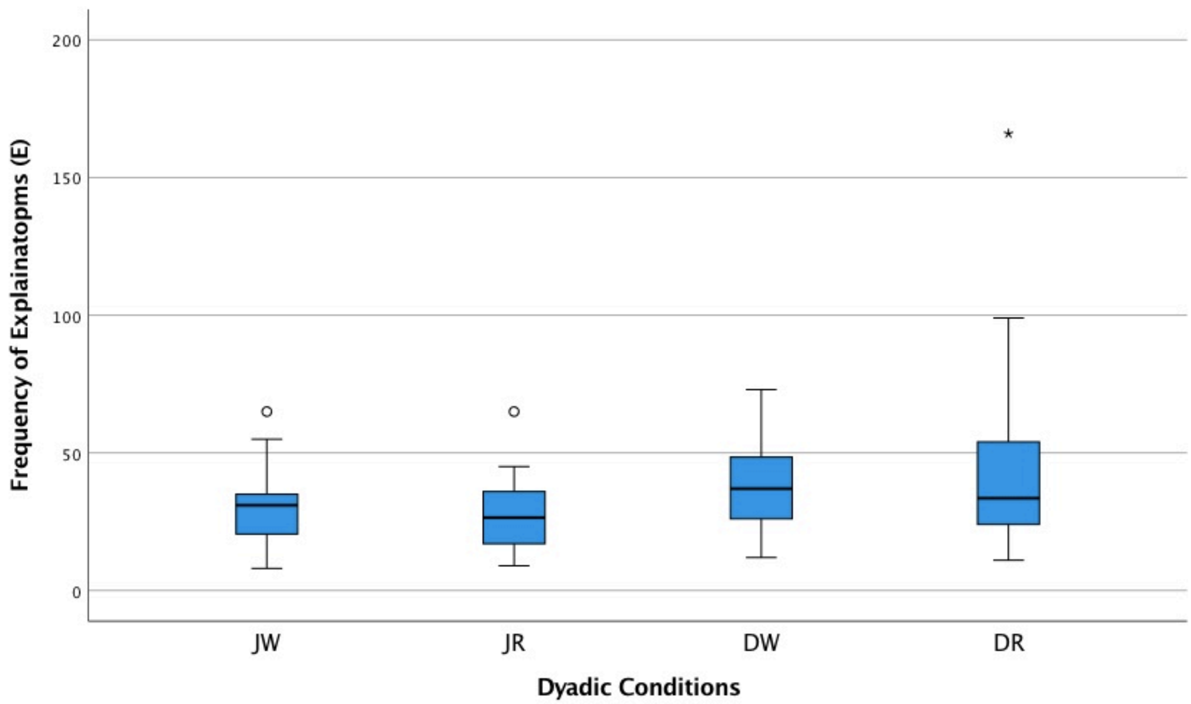


Figure 11. Box plots of the frequency of explanations used in each dyadic condition.

RQ4. Does distributed experience affect group discourse, especially explanations?

Findings from the two-by-two factorial ANOVA of explanations (as seen in Table 18) show a significant effect of distributed experience with a training task (knowledge diversity) on the frequency of explanations, $F(1, 98) = 8.142$, $p = .005$ (see Figure 11 for Box plots of the distributions illustrating this main effect). See Appendix A, Tables K, L, M, and N for effects of distributed experience from a training task (knowledge diversity) on more general discourse characteristics, i.e., time spent collaborating, turns taken, and words spoken.

RQ6. Do assigned task roles affect group discourse, especially explanations? Findings from the two-by-two factorial ANOVA of explanations (as seen in Table 18) show no effect of assigned task roles on explanations, $F(1, 98) = .160$, $p = .690$. See Appendix A, Tables K, L, M, and N for effects of assigned task roles on discourse characteristics.

RQ8. Do distributed experience and assigned task roles interact in their effects on group discourse, especially explanations? Findings from the two-by-two factorial ANOVA of explanations (as seen in Table 18) show no interaction between distributed experience (knowledge diversity) and assigned task roles on explanations, $F(1, 98) = .544$, $p = .462$. See Appendix A, Tables K, L, M, and N for effects of this interaction on discourse characteristics.

RQ11a. How are the explanations that occur during dyadic group work associated with task performance? Explanations that occur during dyadic group work have a weak association with task performance that is approaching significance, $r = -.157$, $p = .066$ (N=98). Recall that in the current study, a negative correlation with network length is an indicator of a positive relationship with task performance, because the aim of the problem-solving task is to minimize the total length of the network. See Appendix A, Table O for the correlation matrix of task performance variables with all speech acts that occur during dyadic group work.

RQ11b. How are the explanations that occur during dyadic group work associated with individual learning? Explanations that occur during dyadic group work have a positive correlation with transfer learning, $r = .258$, $p < .001$. Because the measure of transfer learning is a post-task questionnaire taken by individuals, this analysis is conducted at the level of individual members of the dyads (N=273).

Analysis at the level of the individual is appropriate for the purposes of addressing this research question because it aligns with prior work in cooperative learning research, particularly work by Webb (1989), O'Donnell and Dansereau (1992), and Barron (2003) who independently examine the phenomenon of explanations or cognitive elaboration during cooperative group work and find that positive effects on learning outcomes are specific to the speaker (not the listener). In other words, it is the person in the group who explains who shows significant learning gains, not the person who listens. Thus, while dyadic discourse is most obviously measured with the dyad as the unit of analysis, cognitive elaboration is best measured with the individual as the unit of analysis, so as to be sensitive to differential affects between dyad members.

On a related note, when analysis is conducted at the level of the individual, all but one of the findings reported above persist. Knowledge diversity continues to affect the frequency of explanations $F(1, 196) = 12.579$, $p < .001$ (as in RQ4). Assigned task roles do not affect the frequency of explanations, $F(1, 196) = .000$, $p = .994$ (as in RQ6), and knowledge diversity and assigned task roles do not interact to affect the frequency of explanations, $F(1, 196) = .217$, $p = .642$ (as in RQ8). See Appendix A, Table P for all two-by-two factorial ANOVAs. The one finding at the individual level that differs from the other findings reported above is that explanations at the individual level do not correlate with task performance, $r = -.052$, $p = .429$ (finding differs from RQ11a). See Appendix A, Table Q for the relevant correlation matrix. This difference suggests that explanations help both the speaker and the listener in the dyad.

Several other analyses were conducted at the individual level to address a final set of research questions, which examine the effects of self-explanation in the individual-work control conditions on the outcome variables and compare these to the effects of explanations used by individuals in a dyad. Because one of the specific aims of the current study is to better understand the effects of cognitive elaboration, and prior research has established that this effect occurs primarily for the speaker, the analyses addressing the next set of research questions is conducted at the level of the individual to compare the two individual conditions (N=77). These analyses are reported in the subsequent sections along with the corresponding research questions. Table 19 reports relevant *t*-tests comparing task performance and transfer learning between individuals who used self-explanations and individuals who did not.

Table 19. Contrast *t*-tests comparing the two individual conditions by performance on the network design task (Map 2) and transfer learning (N=77).

Criterion Variable	Individuals using Self-Explanation		Individuals not using Self-Explanation		*t*(75)	*p*
	M	*SD*	*M*	*SD*		
Performance						
Total Network Length	134.87	7.98	134.13	10.94	.118	.906
Transfer Learning						
Total Transfer Success	2.92	1.38	3.23	1.34	1.009	.316

RQ9. Does the elicitation of self-explanations by individuals lead to better task performance compared to individuals who do not self-explain? The elicitation of self-explanations does not lead to better task performance than participants who did not use self-explanation, $t(75) = .118$, $p = .906$ (as seen in Table 19).

RQ10. Does the elicitation of self-explanations lead to greater learning compared to individuals who do not self-explain? Self-explanation does not lead to a higher frequency of transfer learning as compared to individuals who do not self-explain, $t(75) = 1.009$, $p = .316$ (as seen in Table 19).

RQ12a. How do the explanations that occur during individual self-explanation affect task performance? Explanations that occur during individual self-explanation are not associated with task performance, $r = -.006$, $p = .970$. See Appendix A, Table Q for the relevant correlation matrix.

RQ12b. How do the explanations that occur during individual self-explanation affect individual learning? Explanations that occur during individual self-explanation are not associated with transfer learning, $r = .189$, $p = .250$. See Appendix A, Table Q for the relevant correlation matrix.

RQ13. How do explanations that occur during dyadic group work differ from the explanations that occur during individual self-explanation? To address this research question, the analysis compares the frequency of self-explanations from individuals (N=39) to explanations offered during dyadic discourse (N=98). Here, dyadic discourse is a composite of all dyadic conditions (Dyadic discourse = JW, JR, DW, and DR). See Table 20 for means and standard deviations.

Multivariate analysis is an ideal approach for addressing this research question because explanations co-occurred with almost every speech act. Raters frequently applied multiple speech act codes to the same utterance, creating frequent overlap. Thus, the quality or meaning of an explanation is in part defined by the context of the overlapping speech acts. Analysis for RQ13 uses the other speech acts to measure this context in an attempt to compare the quality of explanations across conditions.

A Hoteling's T-test reveals that the frequencies of speech acts differ between individuals and dyads, $T^2(9, 127) = 1.541$, $p < .001$ (see Table 20 for one-way ANOVA tests of between subject effects for each speech act). Figure 12 illustrates differences in the distribution of each speech act for individuals and dyads (Recall that dyadic discourse combines speech acts from two participants).

Factor loadings from a principal component analysis (PCA) of the speech acts uttered during self-explanations suggest that self-explanations are related to *proposals*; while factor loadings for another PCA of the speech acts uttered during dyadic discourse suggest explanations from dyadic discourse are related to *questions*, *responses*, and *social facilitation* as well as *proposals*. See Table 21 for component matrices from both analyses. Note that Table 21 shows the speech act of *social facilitation* occurs during individual self-explanation, which was operationalized to include telling a joke, expressing an emotion, or sharing a piece of personable information. Raters coded these utterances as "social facilitation" they occurred, regardless of condition (see Section 3.6 for details on the speech act *social facilitation*). See Appendix A for details on this analysis including tests of assumptions. See Figures J and K for scree plots.

Note that the PCA of dyadic discourse treats the dyad as the unit of analysis, which allows it to examine group discourse patterns to better understand social effects of group work on communication. This differs from the PCA reported in Section 4.2 (and Appendix A, Table I), which examines speech acts at the level of the individual; thus, it is able to draw associations between latent variables and learning outcomes.

Table 20. Descriptive statistics (M, *SD*) for all speech act variables between individual and dyadic all study conditions with verbalization

	Individuals using Self-Explanation		Dyadic Discourse				
Speech Act Variables	*M*	*SD*	*M*	*SD*	*F(1,137)*	*p*	η^2
Explain	27.97	20.51	35.49	22.30	3.312	.071	.024
Propose	4.82	5.30	12.55	14.02	11.180	.001	.076
Question Consider	.03	.16	7.87	10.36	22.255	<.001	.142
Questions Information	.26	.75	4.42	9.51	7.424	.007	.052
Response Agree	.05	.32	15.04	10.50	79.073	<.001	.369
Response Modify	.49	1.21	1.74	6.63	1.378	.242	.010
Social Facilitation	1.72	2.70	8.91	8.25	28.333	<.001	.173
Joint Attention	.97	2.63	16.84	13.79	50.664	<.001	.273
Interruptions	.00	.00	1.32	2.44	11.267	.001	.077

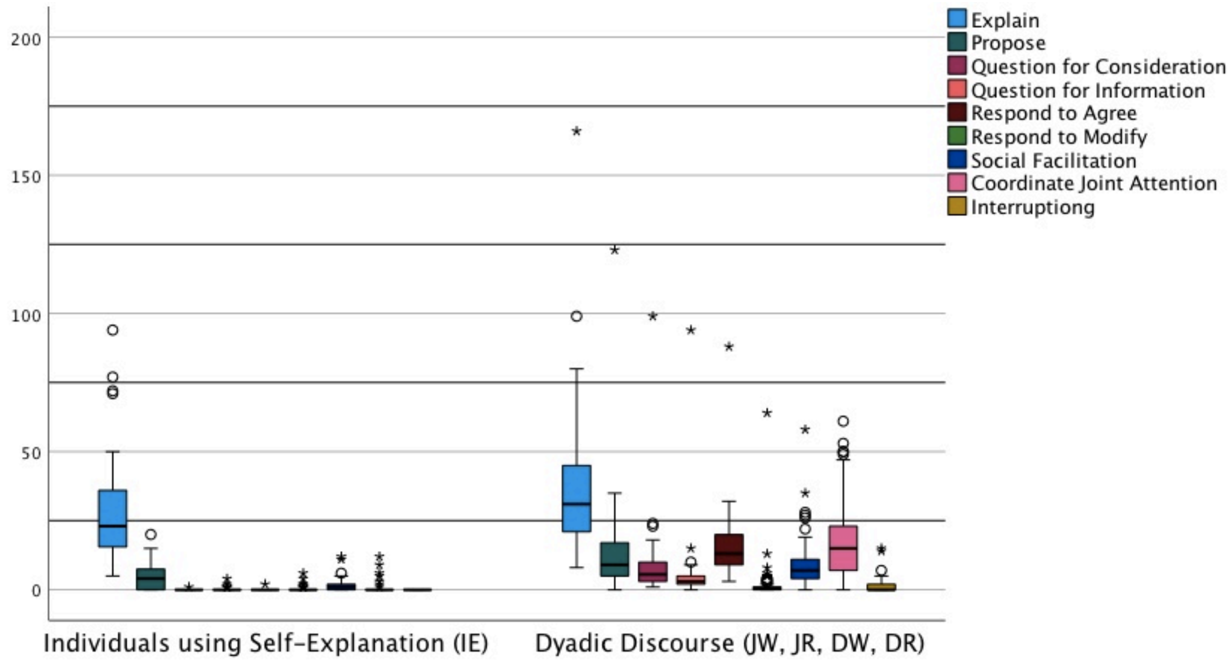


Figure 12. Box plots showing the frequency of each speech act by either the individual condition with self-explanations (left) or individuals in dyadic conditions (right).

Table 21. Principal component matrix for all speech acts uttered by individuals using self-explanation and within dyadic discourse, with Varimax and Kaiser normalization

	Individuals using Self-Explanation Components		Dyadic Discourse Components	
Speech Acts	1.	2.	1.	2.
1. Explain	.906	.017	.665	.516
2. Propose	.830	.046	.877	.268
3.Question Consideration	--	--	.953	.020
4. Question Information	--	--	.940	-.004
5. Response Agree	.443	.858	.843	.262
6. Response Modify	--	--	.961	-.035
7. Social Facilitation	.721	-.600	.751	.165
8. Joint Attention	--	--	.170	.838
9. Interruptions	--	--	-.024	.828

Chapter 5: Discussion

The current study addresses the question of whether two strategies of effective cooperative learning activities – ensuring group knowledge diversity and assigning task roles – positively affect group task performance or individual learning outcomes from a collaborative problem-solving task. The current analyses offer three main findings. First, group knowledge diversity – introduced through a training task – tends to positively affect the frequency of explanations during dyadic discourse regardless of the assignment of task roles (see Section 5.1 for details). Second, explanations uttered during dyadic discourse are positively associated with learning outcomes and, to a lesser degree, with group task performance (see Section 5.2). Third, frequency of self-explanation is not associated with performance or learning outcomes (see Section 5.3). Section 5.4 offers a summative discussion of these concepts, examining how they might be related to social discourse variables not associated with learning outcomes. This chapter unpacks these findings, contextualizes them within the literature, and connects them to a larger theoretical discussion. This is followed by a brief discussion of implications, limitations, and future directions.

5.1 Knowledge diversity

The current study enhanced knowledge diversity in a dyad by way of a training task. Results from the comprehension and manipulation checks suggest that this manipulation was effective in predisposing members of a dyad to adopt different perspectives on how to solve a network design task. Participants who experienced a different training task than their partner were more likely to use explanations during their collaborative discourse than participants who instead experienced the same training task. This relationship between group knowledge diversity and explanations persisted regardless of whether the group's knowledge diversity was made explicit through the assignment of task roles.

Why did this happen? Why might the cognitive manipulation of knowledge diversity have motivated explanations to a greater degree than the social manipulation of assigned task roles. On reason may be that, in the context of the collaborative network design task, the implementation of the social manipulation may not have had the desired effect. Instead of making the dyad's knowledge diversity explicit, it may have simply distributed task responsibilities among group members. In other words, instead of informing dyad members that they had different perspectives, the task roles may have informed dyad members that they had different jobs. Role assignments may have been interpreted as action-based roles (i.e., the road builder's task was to *build* roads), rather than roles designed to spark explanations (i.e., the road builder may not have seen a need to *explain* how to build a road). Thus, the method may explain the differential effects of the manipulation.

A second reason may be that the cognitive manipulation created an authentic need for explanation and information exchange. The need may have arisen as participants attempted to understand the problem, and realized they had different perspectives. The work to coordinate a shared understanding would have required explanations as well. The authentic need explanations may also have arisen as participants attempted to agree upon a single solution, and realized they actually disagreed. The work to reconcile their disagreement would have required information exchange and explanations. Both possibilities suggest ways that the cognitive manipulation may have created a need for knowledge coordination or a reconciliation of conflicting ideas, which would have motivated group members to share and discuss their ideas.

This second reason is consistent with the literature on group diversity (c.f. Hong & Page, 2004; Jeppesen & Lakhani, 2010; Page, 2007, 2010, 2014; Surowiecki, 2005), which demonstrates (both theoretically and empirically) that group diversity increases the frequency of proposed novel solutions, which can increase the frequency of innovation and thus group performance. Diverse groups tend to out-innovate and thus out-perform homogeneous groups, even expert homogenous groups, a phenomenon described by Surowiecki (2005) in the *Wisdom of Crowds*.

Page (2014) depicts diversity as offering different experiences that afford the group different perspectives. In this context, diversity leads to increased probability of a correct solution (also see Jeppesen & Lakhani, 2010). Diverse groups outperform high ability groups because high ability groups tend towards homogeneous or similar solutions, which increases their error / failure rate relative to a (large) diverse body of non-experts (Hong & Page, 2004). Importantly, this enhanced success for diverse groups hinges on their ability to communicate and exchange information. Thus, positive effects of group diversity on performance are mediated by information exchange (Homan et al., 2007).

Results from the current study are consistent with this literature, and demonstrate that group knowledge diversity positively affects the frequency of explanations (the mediating variable) to a greater degree than groups with homogeneous knowledge. Interestingly, these results were achieved with a knowledge diversity manipulation, and did not stem from the prior knowledge diversity of group members. This sets the current study apart from the literature to some degree, because it shows that the benefits of group diversity (and the "wisdom of crowds") is not inherent to a group's composition but may instead be a phenomenon that can be catalyzed by an intervention or experience (i.e., a training task). Further research is needed to generalize this finding beyond a network design problem-solving task. Practical implications are discussed in Section 5.5.

Importantly, the current study does not find a direct relationship between this knowledge diversity manipulation and task performance or learning outcomes. Rather, the effects of diversity are mediated through explanation. This is briefly discussed here before moving to the next section, which examines the mediating variable, *explanations*.

Regarding learning outcomes, research in education and social psychology (see Section 1.1) establishes group knowledge diversity as a *desideratum* or strategy (one of many, c.f. Dillenbourg & Betrancourt, 2006; Johnson & Johnson, 2009) to promote discourse and explanations as a mediating variable for learning outcomes (Cohen, 1994; Kuhn & Crowell, 2011; Kuhn, 2015, 2016; Voiklis & Corter, 2012). Certain group characteristics are helpful because they foster interactions that require cognitive activities that trigger learning. This supports the finding from the current study that knowledge diversity directly affects explanations, not learning outcomes.

Regarding task performance, the current study found no evidence of a direct relationship between knowledge diversity and task performance, which was surprising given the literature, but not unprecedented. Some previous research examining group knowledge diversity as manipulated by a training task also found no effects on task performance (c.f., Harrison et al., 2002; Sauer et al., 2006). However, Harrison et al. (2002) found that positive effects of cognitive and psychological diversity on performance emerge as time passes (i.e., several weeks). The current study limited collaborative group work to fifteen minutes. As another example, Sauer et al., (2006) find that knowledge diversity positively affects performance only for more complex tasks (e.g., participants manage a multiple-task computerized environment wherein the cabin air system in a space craft undergoes a series of complex fault scenarios).

This prior research suggests that the intervention in the current study may have needed more time (i.e., >15 minutes) for participants to experience the benefits of their knowledge diversity on their task performance. It may also be that the performance task used in the current study lacked the level of complexity needed for knowledge diverse group performance advantages to emerge.

5.2 Explanations

The current study finds that explanations are positively associated with learning outcomes, and to a lesser degree with group task performance (see Section 3.6 for the operationalization of the *explanations* speech act). This finding suggests that explanations observed in the current study may be associated with cognitive elaboration. Cognitive elaboration is a mental sense-making activity presumed to occur as a result of cognitive demands of dialogue as one explains one's memories, actions or thoughts to another person (see Section 1.1 for details describing *cognitive elaboration*).

However, the current study found a relationship between explanations and learning only in dyadic conditions. In other words, explanations were only associated with transfer learning when they were uttered in a group setting. This is not perfectly consistent with the literature on cognitive elaboration, which is understood to occur during self-explanation as well as during group discourse (Lombrozo, 2006). Thus, to better understand the quality of the explanations observed in the current study and their effects on transfer learning, this section discusses differences between explanations uttered during dyadic discourse and explanations uttered during self-explanation.

Factor analysis of the speech acts that occurred during dyadic discourse offers the insight that explanations co-occurring with efforts to coordinate joint attention were also positively associated with learning outcomes (see Section 3.6 for details describing coordination of joint attention, see Section 4.2 for the factor analysis). This finding suggests that explanations associated with learning may have involved efforts to draw another's attention to a shared space and perhaps coordinate another's understanding with one's own. While this cognitive work can fall under the definition of cognitive elaboration, this section seeks an alternative term to better parse different effects of dyadic discourse and self-explanation on learning.

A potentially useful term for describing the work of explaining to coordinate attention and understanding comes from Roschelle and Teasley (1995), who describe coordination of knowledge or "knowledge coordination" as an exchange of meaning through language to introduce, monitor, and repair a shared understanding (also Kuhn, 2015; Schober & Clark, 1989; Wilkes-Gibbs & Clark, 1992). Knowledge coordination is described in several other studies examining collaborative discourse as a probing of another's mind, which increases exposure to new ideas and thus positively affects learning outcomes (cf. Azmitia, 1988; Bos, 1937; Brandon & Hollingshead, 1999; Johnson & Johnson, 1999). Attention to the mind of another has long been understood to play an important role in consolidating knowledge (Webb, 1985). And the effectiveness of this coordination process as an educational tool has been well documented in the literature on peer tutoring (Devin-Sheehan et al., 1976; Fantuzzo et al., 1992; Ortiz et al., 1996), which the current study found to be one of the more effective cooperative learning methods (see Section 2.2).

Another useful term, from information processing theory, is the "co-construction of knowledge." Co-construction happens when individuals collaboratively build knowledge and develop strategies that no group member had in advance of the problem-solving task (Webb, 2009). It is a process of sharing, seeking clarity, offering corrections, drawing connections, and building on each other's ideas and perspectives (Hogan et al., 2000; Schwartz, 1995). Barron (2003) concisely describes co-construction as the coordination of ideas and proposals.

Both the "coordination" and "co-construction" of knowledge serve as useful terms to describe a potential difference in the quality of explanations uttered during dyadic discourse as compared to self-explanations uttered by individuals in the current study. The subsequent section examines findings specific to self-explanations to better understand other factors that made self-explanations observed in the current study unique.

5.3 Self-explanation

The current study found that self-explanations – offered spontaneously during individual problem-solving work done in solo – did not have a relationship with performance or learning outcomes. This finding was surprising given the literature on self-explanations. Prior research has shown that students who use self-explanation show greater learning gains than peers who do not use self-explanation (Chi et al., 1994; Roy & Chi, 2005). Some research has even shown that self-explanation facilitates transfer learning (Rittle-Johnson, 2006), including in *online* learning environments (Aleven & Koedinger, 2002) such as used in the current study. This section discusses four possible explanations for the current study's null findings regarding self-explanation.

First, findings from the current study may differ from prior research on self-explanation because of differing definitions of the term. For example, in a review of the literature on explanations, Lombrozo (2006) describes self-explanations as explaining novel information to oneself. Yet, other reviews of self-explanations describe them as the integration of new information with prior knowledge to oneself (Chi et al., 1994), and as inferences about causal connections (Siegler, 2002). These definitions differ both from each other and from the self-explanations observed in the current study.

In the current study, self-explanations were identified using the same criteria as was used to identify explanations in dyadic discourse (see Section 3.6); however, a close examination of the language used in utterances identified as self-explanations finds a pattern of meta-cognitive language. Participants' self-explanations tended to reflect on their performance, evaluate their progress, and describe the options or new courses of action they were considering. These characteristics of self-explanations from the current study are not reflected in the cited literature and may be the reason findings from prior research were not replicated in the current study.

Alternatively, it may be that findings from the current study are better aligned with research that found self-explanations are not positively associated with learning outcomes. Rittle-Johnson (2006) argues that a "careful review" of the literature on self-explanation reveals that self-explanation does not consistently improve learning. The author highlights two unpublished studies that found no benefit for eliciting self-explanations in a problem-solving task (Earley, 1999; Rittle-Johnson & Russo, 1999).

Indeed, Kuhn and Katz (2009) find students using *no* explanations outperformed peers using self-explanations. Kuhn and Katz suggest that in their study, self-explanation may have overemphasized students' prior knowledge and reinforced previously held misunderstandings, which may have distracted students from the challenging work of reading and interpreting new information. They write, "when children repeatedly explain their pre-existing theories, as they did in the [self-]explanations condition, they may become more committed to them." Similarly, in her review of explanations, Lombrozo (2006) also warns against this shortcoming of self-explanations. She writes,

> "Because explanations embody prior beliefs, they have an undisputed danger: when generated from true beliefs, explanations provide an invaluable source of constraint; when generated from false beliefs, explanations can perpetuate inaccuracy."

Of course, these reported dangers of self-explanations are not universal and have been shown to be avoidable. For example, students can be prompted to explain only correct information (c.f., Rittle-Johnson, 2006). Thus, a third reason that the current study may have found no effects of self-explanation on performance or learning may be that it did not use recommended strategies for avoiding the dangers of self-explanation. Participants were not prompted to explain only correct information, and it is possible that participants using self-explanations may have reinforced their misunderstandings of the task directions through their self-explanation. In the current study, most misunderstandings observed during data collection were left unaddressed, without correction (regardless of condition). Only misunderstandings of the task directions that were immediately apparent from the network design were addressed, and then only through a written comment posted in the online chat window, which not all participants noticed.

The previous section (see Section 5.2) explores a fourth possible reason as to why self-explanations in the current study had no relationship with task performance or learning outcomes. It may be that the context in which self-explanations were uttered in the current study did not require the cognitive activity needed to trigger transfer learning. A brief review of relevant literature presented in Section 5.2, suggests that coordination or co-construction of knowledge may play an important role in facilitating transfer learning. This review suggests that taking the thoughts of another person into account might help facilitate transfer learning.

Interestingly, there is prior research that compares self-explanations that take the thoughts of others into account against self-explanations that do not. In an empirical study of young math students, Siegler (2002) investigates these two different types of self-explanations. In one condition, students are given a correct answer by the experimenter, then prompted to use self-explanation to answer the question, “How do you think I knew that?” This was contrasted with another condition in which students were given the correct answer, then prompted to use self-explanation to answer the question, “Why do you think that is correct?” Note that the former condition prompts students to consider the mental space of another, while the later condition does not. Siegler reports that students in the former condition – prompted to explain the reasoning of another person – showed the greatest transfer learning.

Siegler’s findings support the current supposition under discussion that explanations are associated with learning outcomes because they coordinate knowledge across multiple minds. Siegler’s findings show that self-explanations can facilitate learning outcomes when they are structured to coordinate one’s understanding with another person’s understanding. These findings offer an example of knowledge coordination – behavior common to dyadic discourse - occurring during individual self-explanation. Siegler even argues that this method shares some of the advantages of didactic approaches.

This idea offers some clarity regarding the question of how dyadic discourse differs from self-explanations, because it shows that individuals can engage in cognitive behaviors typical of dyads, i.e., knowledge coordination. Thus, a comparison between dyads and individuals may not effectively distinguish the features of interest in explanations (i.e., features associated with transfer learning), because these features may have occurred in both dyadic discourse and self-explanations (according to Siegler). Thus, a follow-up question for discussion is: What discourse features (of either dyads or individuals) enable knowledge coordination (or the co-construction of knowledge)? This question is addressed in the following section.

5.4 Social Discourse

This section attempts to bring together the three main findings from the current study to better understand the observed effects of group knowledge diversity on explanations and transfer learning. It may be that group knowledge diversity created a social context with need for the kind of explanations that enable the coordination or co-construction of shared knowledge, which facilitated cognitive processes facilitating transfer learning. But what discourse features enable or constitute knowledge coordination? In an effort to examine results that speak to this question (and supposition), this section focuses on results from a principal component analysis (PCA) of the speech acts uttered by individuals during dyadic discourse (see Section 4.2, subsection *Communication Criterion*).

In the current study, explanations uttered during dyadic discourse were highly correlated with certain other types of speech acts. PCA revealed two components (see Appendix A, Figure G for a scree plot and Table I for the principal components loadings matrix); one component heavily loaded on *explanation* and *coordinating joint attention*, which correlated with transfer learning. The other component was dominated by *response modify*, *social facilitation*, and *response agree*, none of which correlated with transfer learning. However, each of these three speech acts involves, to some degree, perpetuating a discussion or engaging with the partner. The first factor is referred to here as knowledge coordination or co-construction. The second factor is discussed as “social discourse.”

This relationship between social discourse and knowledge coordination (where social discourse co-occurs with knowledge coordination, but does not directly affect learning outcomes), may be best described by a contemporary theory of distributed cognition, which considers social roles, context, and group culture as major components of a larger cognitive process. Until recently, research using distributed cognition theory has concentrated on mental capabilities (at the level of the individual) for the purpose of developing a theory of the architecture of cognition (Anderson, 2013; Newell, 1994). These analyses centered on types of task analysis, and few focused on environmental or social resources used to organize behavior (Van Der Veer et al., 1996). This work initially sidelined relevant research in social process, e.g., from anthropology and ethnographic research, which centered culture and context in studies of group behavior. These fields have since been acknowledged as playing critical roles in systemic information exchange in groups (Anderson et al., 1993), and contemporary theories of distributed cognition now center them as important components of group cognition.

One key role of social processes in group work is the organizing or structuring of interactions and cognitive work. This has been referred to as the "cognitive ecology" of a group (Perry, 2003). Cognitive ecology is the environmental, social, cultural, and historical elements of the context of the group that motivate and influence group interactions. The work to organize these elements, also referred to as proactive *structuring* or a *coordination* around the task, plays a central role in coordinating the actions of individuals within a group.

It may be this proactive structuring or coordination that was observed in the current study in the form of social discourse. While prior research has shown that knowledge coordination can occur in self-explanations, it may be that the social discourse that more naturally occurs (i.e., without prompting from an experimenter, c.f. Siegler, 2002) during group work fosters this coordination as well. Findings from the structured literature review support this interpretation, offering several effective methods for structuring social discourse to better facilitate explanations and transfer learning. And the current empirical study found that of these structures, knowledge diversity may best situate a group's social discourse and "cognitive ecology" to encourage explanations that coordinate or co-construct knowledge and facilitate transfer learning. Theoretical implications of this supposition and practical implications of the findings from the current study are further discussed in the following section.

5.5 Implications

The current study shows that group knowledge diversity can be manipulated with a training task to promote certain speech acts associated with transfer learning gains (i.e., explanations, coordinated join attention). This section briefly discusses the theoretical and practical implications of these findings.

Theoretical Implications

The group knowledge diversity manipulation may have introduced what is referred to in distributed cognition theory as a "cognitive ecology" that may have better facilitated communication associated with cognitive activity (e.g., cognitive elaboration or knowledge coordination) and learning gains. This theory may explain the differential effects of knowledge diversity and task roles on explanations. Task roles were a social manipulation, which assigned certain responsibilities to groups members, but was not designed to affect knowledge. Conversely the knowledge diversity manipulation was a cognitive manipulation, which exposed members of a group to different (yet equally important) aspects of a network design task. Thus, the knowledge diversity manipulation created a need for information exchange, and a reason for coordinating shared knowledge within the group. Yet, while the knowledge diversity manipulation did indeed show a greater frequency of explanations than the other conditions, and these explanations were correlated with learning outcomes, these explanations were also highly correlated with speech acts that were not associated with learning. It may be that these high correlations indicate a certain kind of social discourse may have benefited the explanations that facilitated transfer. Distributed cognition theory posits this social discourse as playing a key role in the cognitive ecology of the group. This theory offers an explanation that supports this line of thinking from the current study.

Practical Implications

The current study finds that the benefits of knowledge diversity (i.e., increased explanations, knowledge coordination, co-construction of knowledge, and transfer learning) can be instilled in a dyad by means of a training task in a virtual collaborative problem-solving learning environment, regardless of whether task roles are assigned. This suggests that cooperative learning activities, particularly those that distribute sub-tasks of a larger complex task among members of a group as a training task (e.g., the jigsaw), can positively affect transfer learning, even in relatively homogeneous groups where the diversity is low. The current study showed these positive effects on learning in a sample population recruited from a women's undergraduate college, but other relatively similar homogeneous communities - such as a selective private school or a military planning group – might experience similar effects. Importantly, these findings were established in collaborative virtual environments that employed a shared interactive drawing space, as well as real-time audio and video to facilitate communication, thus the work to exchange explanations and coordinate shared knowledge was relatively unfettered.

This finding has practical implications for existing teams up against real world constraints on their personnel and meeting space(s). Teams that cannot meet in person (perhaps for health and safety reasons) or that cannot undergo re-formation to increase team knowledge diversity through a team member selection process may find that results from the current study offer valuable insights. These results may be of particular interest to education practitioners, many of whom have had to transition to high frequency virtual meetings and who cannot select their student body. These professionals may be particularly heartened by these findings.

Another practical implication from the current study is that explanations associated with learning gains may be associated with social behaviors that facilitate group discourse, but which may not be directly associated with learning outcomes. Some research in collaborative problem-solving in virtual environments emphasizes that social factors are critical to the achievement of positive cognitive outcomes. This subliterature argues that *cognitive presence* is not possible without *social presence* (Ghosh et al., 2012). Cognitive presence is the "extent to which learners are able to construct and confirm meaning through sustained reflection and discourse" in an online environment (Garrison et al., 2001, p. 11). Social presence is "the ability of participants in a community of inquiry to project themselves socially and emotionally, as real people, through the medium of communication being used" (Garrison & Anderson, 2003, p. 28). This suggests that social-emotional communication plays a critical role in facilitating cognitive presence and cognitive process in online environments.

Education practitioners traditionally tend to prefer "on task" behaviors, which are not characteristically social, and as a result tend to discourage social interactions online (e.g., off topic discourse for the sake of building an amicable environment); however, findings from this study support prior research in virtual learning environments suggesting that some social interaction may be critical to facilitating the cognitive activities that facilitate learning gains. The current study examined *proposals*, *questions* (i.e., questions for information, and questions for consideration), *responses* (i.e., responses to agree, responses to modify a partner's statement or idea), and *social* facilitation and found that each of these speech acts correlates with utterances associated with learning outcomes (i.e., explanations and efforts to coordinate joint attention). Practitioners may do well to carefully discern which social behaviors are facilitate discussion and learning, and endeavor to promote these behaviors as part of the learning experience.

5.6 Limitations

All findings reported from the current study should be considered carefully and generalizations to a larger population are not recommended without further research as there are several limitations to the study design and implementation. First, because participants were recruited from a competitive women's college, results are based on a homogeneous population. Second, the process of random assignment to condition was not ideal, as it (a) created an over-abundance of participants in the individual conditions, and thus (b) created an uneven distribution of participants across conditions. This does not distort reported findings, but it does suggest a need for replication of the current study. Third, the analysis of explanations was based on a frequency of their count within each parsed utterance in a conversation. Unfortunately, utterances were parsed automatically by Zoom's free automatic transcription service. Each of these automatically generated transcripts was carefully reviewed and corrected by a human researcher, but this process left the majority of the initial automated parsing decisions relatively untouched and un-corrected. Fourth, the speech acts used to analyze the quality of the dyadic discourse and individual self-explanations showed weak reliability. Further research is needed to validate the operationalization of these speech acts or create composite speech acts for the sake of ensuring greater clarity for and consistency among a new (better trained) set of raters.

5.7 Future Directions

The current study draws connections between theories of cognition (i.e., cognitive elaboration, distributed cognition), wisdom of crowds (i.e., knowledge diversity), and cooperative learning methods. Each enhances understanding of the other, but these findings would be benefited by further investigation, particularly regarding utterances used to develop theories of the cognitive and social factors that mediated effects of knowledge diversity on learning outcomes.

For example, further analysis is needed to examine the individual utterances of each participant within each study condition to better understand the speech patterns that were identified as each speech act. This analysis might be accomplished by an exploration of these data using unsupervised natural language processing methods to identify new patterns in participant utterances that may not have been adequately captured by the speech acts used in the current study. Finally, additional multivariate analysis of utterances and speech acts to identify sequences of latent variables might offer insights into the larger patterns of discourse that define the collaborative process.

Key Conclusions

Effective cooperative learning methods tend to apply two strategies in tandem to encourage explanations and cognitive elaboration; these are group knowledge diversity and assigned task roles. The current study finds that group knowledge diversity, and not assigned task roles, is key to fostering more explanations during collaborative dyadic problem-solving work in virtual settings. The knowledge diversity examined in this study was induced using a training task that predisposed members of a dyad to different perspectives and solutions to the same problem, thus distributing the necessary problem-solving strategies among both members of the dyad. This distributed knowledge fostered a quality of explanations associated with learning outcomes. Additionally, the findings show that the frequency of explanations mediates an indirect relationship between group knowledge diversity and individual learning outcomes. These results suggest that knowledge diversity can be manipulated with a training task to positively affect learning outcomes, if explanations and social discourse can freely occur to coordinate knowledge; however, generalizations from these findings are limited due to the relatively homogeneous sample population. Future research should seek to replicate these findings in authentic classroom settings (both virtual and physical) and use multivariate analysis coupled with natural language processing techniques to more thoroughly examine the speech patterns that comprise explanations used during collaborative group work and self-explanations.

References

*References with * were included in the systematic literature review and Table 1.*

*Acar, B., & Tarhan, L. (2006). Effect of cooperative learning strategies on students' understanding of concepts in electrochemistry. *International Journal of Science and Mathematics Education, 5*(2), 349-373. https://doi.org/10.1007/s10763-006-9046-7

*Acar, B., & Tarhan, L. (2007). Effects of cooperative learning on students' understanding of metallic bonding. *Research in Science Education, 38*(4), 401-420. https://doi.org/10.1007/s11165-007-9054-9

*Adesoji, F. A., & Ibraheem, T. L. (2009). Effects of student teams-achievement divisions strategy and mathematics knowledge on learning outcomes in chemical kinetics. *Journal of International Social Research,1*(6). https://pdfs.semanticscholar.org/7607/29d0b05b6dde789d1e6cda8f79deb756d3ab.pdf

Aleven, V. A., & Koedinger, K. R. (2002). An effective metacognitive strategy: Learning by doing and explaining with a computer-based cognitive tutor. *Cognitive science*, *26*(2), 147-179.

Amigues, R. (1988). Peer interaction in solving physics problems: Sociocognitive confrontation and metacognitive aspects. Journal of Experimental Child Psychology, 45(1), 141-158.

Amsterlaw, J., & Wellman, H. M. (2006). Theories of mind in transition: A microgenetic study of the development of false belief understanding. *Journal of cognition and development*, *7*(2), 139-172.

Anderson, J. R. (2013). *The architecture of cognition*. Psychology Press.

Anderson, R. J., Heath, C. C., Luff, P., & Moran, T. P. (1993). The social and the cognitive in human-computer interaction. *International Journal of Man-Machine Studies*, *38*(6), 999-1016.

*Anderson, W. L., Mitchell, S. M., & Osgood, M. P. (2005). Comparison of student performance in cooperative learning and traditional lecture-based biochemistry classes. Biochemistry and Molecular Biology Education, 33(6), 387-393.

Armstrong, D. S. (1997). The effect of Student Team Achievement Divisions cooperative learning technique on upper secondary social studies students' academic achievement and attitude towards social studies class. (Doctoral dissertation, University of Southern Mississippi).

Aronson, E., Blaney, N., Stephan, C., Sikes, J., & Snapp, M. (1978). *The Jigsaw Classroom*. Sage Publishing Company.

Ateş, C., Kaymaz, Ö., Kale, H. E., & Tekindal, M. A. (2019). Comparison of Test Statistics of Nonnormal and Unbalanced Samples for Multivariate Analysis of Variance in terms of Type-I Error Rates. *Computational and mathematical methods in medicine*, *2019*, 2173638. https://doi.org/10.1155/2019/2173638

*Aydin, S. (2011). Effect of cooperative learning and traditional methods on students' achievements and identifications of laboratory equipments in science-technology laboratory course. *Educational Research and Reviews, 6*(9), 636-644.

Azmitia, M. (1988). Peer interaction and problem-solving: When are two heads better than one?. Child development, 87-96.

Baddeley, A. D., & Woodhead, M. (1982). Depth of processing, context, and face recognition. Canadian Journal of Psychology/Revue canadienne de psychologie, 36(2), 148.

*Baker, L. J. (1995). *The effect of cooperative study groups on achievement of college-level computer science programming students* (Publication No. 9534716). [Doctoral dissertation, University of Texas] Available from ProQuest Dissertations & Theses Global.

*Banerjee, A. C., & Vidyapati, T. J. (1997). Effect of lecture and cooperative learning strategies on achievement in chemistry in undergraduate classes. International Journal of Science Education, 19(8), 903-910.

Barab, S. A., Scott, B., Siyahhan, S., Goldstone, R., Ingram-Goble, A., Zuiker, S. J., & Warren, S. (2009). Transformational play as a curricular scaffold: Using videogames to support science education. Journal of Science Education and Technology, 18(4), 305.

Barron, B. (2003). When smart groups fail. *The Journal of the Learning Sciences, 12*(3), 307-359. https://doi.org/10.1207/s15327809jls1203_1

*Bayraktar, G. (2011). The effect of cooperative learning on students' approach to general gymnastics course and academic achievements. *Educational Research and Reviews, 6*(1), 62. https://doi.org/10.5897/ERR.9000341

Bos, M. C. (1937). Experimental study of productive collaboration. Acta Psychologica (The Hague).

*Bradley, A. Z., Ulrich, S. M., Jones Jr, M., & Jones, S. M. (2002). Teaching the sophomore organic course without a lecture. Are you crazy? *Journal of Chemical Education*, *79*(4), 514. https://doi.org/10.1021/ed079p514

Brandon, D. P., & Hollingshead, A. B. (1999). Collaborative learning and computer-supported groups. Communication education, 48(2), 109-126.

Brennan, S. E., & Clark, H. H. (1996). Conceptual pacts and lexical choice in conversation. Journal of Experimental Psychology: Learning, Memory, and Cognition, 22(6), 1482.

Bruffee, K. A. (1995). Sharing our toys: Cooperative learning versus collaborative learning. Change: The Magazine of Higher Learning, 27(1), 12-18.

*Bunrasi, J. B. T. (2012). *Algebra I Achievement of Eighth Grade Mexican American Students Using Cooperative Learning Versus Traditional Instruction* (Publication No. 3522382) [Doctoral dissertation, Walden University]. Available from ProQuest Dissertations & Theses Global.

Cheng, W., & Warren, M. (2000). Making a difference: Using peers to assess individual students' contributions to a group project. Teaching in Higher Education, 5(2), 243-255.

Chi, M. T., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. Cognitive science, 13(2), 145-182.

Chi, M. T. H., deLeeuw, N., Chiu, M. H., & Lavancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science, 18*(3), 439–477. https://doi.org/10.1207/s15516709cog1803_3

*Chu, S. Y. (2014). Application of the jigsaw cooperative learning method in economics course. *International Journal of Managerial Studies and Research (IJMSR), 2*(10), 166-172.

Cohen, E. G. (1994). Restructuring the classroom: Conditions for productive small groups. *Review of Educational Research*, *64*(1), 1–35. https://doi.org/10.3102/00346543064001001

Cohen, J. (1960). A coefficient of agreement for nominal scales. *Educational and psychological measurement*, *20*(1), 37-46.

Crowley, K., & Siegler, R. S. (1999). Explanation and generalization in young children's strategy learning. *Child development*, *70*(2), 304-316.

Dansereau, D. F. (1988). Cooperative learning strategies. In C. E. Weinstein, E. T. Goetz, & P. A. Alexander, (Eds.), Learning and study strategies: Issues in assessment, instruction, and evalu-ation (pp. 103–120). Orlando, FL: Academic Press.

Devin-Sheehan, L., Feldman, R. S., & Allen, V. L. (1976). Research on children tutoring children: A critical review. *Review of educational research*, *46*(3), 355-385.

Diehl, M., & Stroebe, W. (1987). Productivity loss in brainstorming groups: Toward the solution of a riddle. Journal of personality and social psychology, 53(3), 497.

Dillenbourg, P., & Betrancourt, M. (2006). Collaboration load. Handling complexity in learning environments: theory and research, 141-165.

*Doymus, K. (2007). Effects of a cooperative learning strategy on teaching and learning phases of matter and one-component phase diagrams. *Journal of Chemical Education, 84*(11), 1857. https://doi.org/10.1021/ed084p1857

*Durukan, E. (2011). Effects of cooperative integrated reading and composition (CIRC) technique on reading-writing skills. Educational Research and Reviews, 6(1), 102-109.

Ellis, H. C. (1965). *The Transfer of Learning*. New York: The Macmillan Company.

Earley, C. E. (1999). *Expertise acquisition in auditing: Training novice auditors to recognize cue relationships in real estate valuation.* Dissertation Abstracts International Section A: Humanities and Social Sciences, 59(9-A), 3529

Fantuzzo, J. W., King, J. A., & Heller, L. R. (1992). Effects of reciprocal peer tutoring on mathematics and school adjustment: A component analysis. Journal of Educational Psychology, 84, 33–339.

Fawcett, L. M., & Garton, A. F. (2005). The effect of peer collaboration on children's problem-solving ability. British Journal of Educational Psychology, 75(2), 157-169.

Fisher, R. P., & Craik, F. I. (1980). The effects of elaboration on recognition memory. Memory & Cognition, 8(5), 400-404.

Freyd, J. J. (1983). Shareability: The social psychology of epistemology. Cognitive science, 7(3), 191-210.

*Fuchs, L. S., Fuchs, D., & Kazdan, S. (1999). Effects of peer-assisted learning strategies on high school students with serious reading problems. *Remedial and Special Education: RASE, 20*(5), 309–318. https://doi.org/10.1177/074193259902000507

*Fuchs, L. S., Fuchs, D., Kazdan, S., Karns, K., Calhoon, M. B., Hamlett, C. L., & Hewlett, S. (2000). Effects of workgroup structure and size on student productivity during collaborative work on complex tasks. *The Elementary School Journal*, *100*(3), 183–212. https://doi.org/10.1086/499639

Gabbert, B., Johnson, D. W., & Johnson, R. T. (1986). Cooperative learning, group-to-individual transfer, process gain, and the acquisition of cognitive reasoning strategies. The Journal of Psychology, 120(3), 265-278.

Garrison, D. R., & Anderson, T. (2003). *E-learning in the 21st century: A framework for research and practice*. London: Routledge Falmer.

Garrison, D. R., Anderson, T., & Archer, W. (2001). Critical thinking, cognitive presence, and computer conferencing in distance education. American Journal of Distance Education, 15(1), 7–23.

Garton, A. F., & Pratt, C. (2001). Peer assistance in children's problem-solving. British Journal of Developmental Psychology, 19(2), 307-318.

Ghosh, R., Rude-Parkins, C., & Kerrick, S. A. (2012). Collaborative problem-solving in virtual environments: Effect of social interaction, social presence, and sociability on critical thinking. In *The next generation of distance education* (pp. 191-205). Springer, Boston, MA.

Gillies, R. M. (2008). The effects of cooperative learning on junior high school students' behaviours, discourse and learning during a science-based learning activity. *School Psychology International*, *29*(3), 328-347.

*Giraud, G. (1997). Cooperative learning and statistics instruction. *Journal of Statistics Education: An International Journal on the Teaching and Learning of Statistics*, *5*(3). https://doi.org/10.1080/10691898.1997.11910598

*Golbeck, S. L., & Sinagra, K. (2000). Effects of gender and collaboration on college students' performance on a Piagetian spatial task. The Journal of experimental education, 69(1), 22-35.

Goldberg, J. A. (1990). Interrupting the discourse on interruptions: An analysis in terms of relationally neutral, power-and rapport-oriented acts. Journal of pragmatics, 14(6), 883-903.

*Gonzalez, G. (2006, March). A systematic approach to active and cooperative learning in CS1 and its effects on CS2. In Proceedings of the 37th SIGCSE technical symposium on Computer science education (pp. 133-137).

Griffin, M. M. (1994). *Learning through testing: An investigation of cooperative assessment* [Paper presentation]. Annual meeting of the American Educational Research Association. New Orleans, LA, United States

Greenwald, N. L. (2000). Learning from problems. The Science Teacher, 67(4), 28-32.

Haller, C. R., Gallagher, V. J., Weldon, T. L., & Felder, R. M. (2000). Dynamics of peer education in cooperative learning workgroups. *Journal of Engineering Education*, *89*(3), 285-293.

*Hänze, M., & Berger, R. (2007). Cooperative learning, motivational effects, and student characteristics: An experimental study comparing cooperative learning and direct instruction in 12th grade physics classes. *Learning and Instruction, 17*(1), 29-41. https://doi.org/10.1016/j.learninstruc.2006.11.004

Harrison, D. A., Price, K. H., Gavin, J. H., & Florey, A. T. (2002). Time, teams, and task performance: Changing effects of surface-and deep-level diversity on group functioning. *Academy of management journal*, *45*(5), 1029-1045.

*Ho, F. F., & Boo, H. K. (2007). Cooperative learning: Exploring its effectiveness in the physics classroom. Asia-Pacific Forum on Science Learning and Teaching, 8(2), 7.

*Holliday, D. C. (1995). *The effects of the cooperative learning strategy Jigsaw II on academic achievement and cross-race relationships in a secondary social studies classroom* (Publication No. 9615265) [Doctoral dissertation, University of Southern Mississippi]. Available from ProQuest Dissertations & Theses Global.

Hogan, K., Nastasi, B. K., & Pressley, M. (2000). Discourse patterns and collaborative scientific reasoning in peer and teacher-guided discussions. Cognition and Instruction, 17, 37

Homan, A. C., Van Knippenberg, D., Van Kleef, G. A., & De Dreu, C. K. (2007). Bridging faultlines by valuing diversity: diversity beliefs, information elaboration, and performance in diverse work groups. *Journal of applied psychology*, *92*(5), 1189.

Hong, L., & Page, S. E. (2004). Groups of diverse problem solvers can outperform groups of high-ability problem solvers. *Proceedings of the National Academy of Sciences*, *101*(46), 16385-16389.

Huber, G., Bogatzki, W., & Winter, M. (1982). Cooperation: Condition and goal of teaching and learning in classrooms. Unpublished manuscript, University of Tübingen, West Germany.

Huber, G. L., & Huber, A. A. (2008). Structuring group interaction to promote thinking and learning during small group learning in high school settings. In R.M. Gillies, A.F. Ashman, & J. Terwel (Eds.), *The teacher's role in implementing cooperative learning in the classroom* (Vol. 8, pp. 110-131). Springer.

Huberty, C. J. (1975). Discriminant Analysis. *Review of Educational Research*, *45*(4), 543–598. https://doi.org/10.3102/00346543045004543

*Hurley, E. A., Allen, B. A., & Boykin, A. W. (2009). Culture and the interaction of student ethnicity with reward structure in group learning. Cognition and Instruction, 27(2), 121-146.

Hutchins, E. (1995). *Cognition in the Wild* (No. 1995). MIT press.

*Işık, D., & Tarım, K. (2009). The effects of the cooperative learning method supported by multiple intelligence theory on Turkish elementary students' mathematics achievement. Asia Pacific Education Review, 10(4), 465.

Jacobs, G. M. (2015). Collaborative Learning or Cooperative Learning? The Name Is Not Important; Flexibility Is. Online Submission, 3(1), 32-52.

*Jalilifar, A. (2010). The effect of cooperative learning techniques on college students' reading comprehension. *System*, *38*(1), 96-108. https://doi.org/10.1016/j.system.2009.12.009

Jeppesen, L. B., & Lakhani, K. R. (2010). Marginality and problem-solving effectiveness in broadcast search. *Organization science*, *21*(5), 1016-1033.

Johnson, D.W. & Johnson, R.T. (1989) Cooperation and competition: Theory and research, Edina, MN: Interaction Book Company.

Johnson, D. W., & Johnson, R. T. (1999). Making cooperative learning work. Theory into practice, 38(2), 67-73.

Johnson, D. W., & Johnson, R. T. (2009). An educational psychology success story: Social interdependence theory and cooperative learning. *Educational Researcher*, *38(5)*, 365–379. https://doi.org/10.3102/0013189x09339057

Johnson, D. W., Johnson, R. T., & Stanne, M. B. (2000). Cooperative learning methods: A meta-analysis. University of Minnesota. https://www.scirp.org/(S(vtj3fa45qm1ean45vvffcz55))/reference/ReferencesPapers.aspx?ReferenceID=756990

*Johnson, D.W., Johnson, R.T., & Taylor, B. (1993). Impact of cooperative and individualistic learning on high-ability students' achievement, self esteem, and social acceptance. Journal of Social Psychology, 133(6), 839-844.

*Johnston, C. G., James, R. H., Lye, J. N., & McDonald, I. M. (2000). An evaluation of collaborative problem-solving for learning economics. The Journal of Economic Education, 31(1), 13-29.

Joyce, B., & Weil, M. (1972). Models of teaching, Englewood Cliffs, NJ.

Karau, S. J., & Williams, K. D. (1993). Social loafing: A meta-analytic review and theoretical integration. *Journal of Personality and Social Psychology*, *65*(4), 681–706. https://doi.org/10.1037/0022-3514.65.4.681 King, A. (1989). Effects of self-questioning training on college students' comprehension of lectures. Contemporary Educational Psychology, 14(4), 366-381.

King, A. (1990). Enhancing peer interaction and learning in the classroom through reciprocal questioning. American Educational Research Journal, 27(4), 664-687.

King, A. (2008). Structuring peer interaction to promote higher-order thinking and complex learning in cooperating groups. In The teacher's role in implementing cooperative learning in the classroom (pp. 73-91). Springer, Boston, MA.

*King, A. (1991). Effects of training in strategic questioning on children's problem-solving performance. *Journal of Educational Psychology, 83*(3), 307-317. https://doi.org/10.1037/0022-0663.83.3.307

King, A. (1994). Guiding knowledge construction in the classroom: Effects of teaching children how to question and how to explain. *American Educational Research Journal*, *31*(2), 338–368. https://doi.org/10.3102/00028312031002338

*King, A., Staffieri, A., & Adelgais, A. (1998). Mutual peer tutoring: Effects of structuring tutorial interaction to scaffold peer learning. *Journal of Educational Psychology, 90*(1), 134–152. https://doi.org/10.1037/0022-0663.90.1.134

*Kırık, Ö. T., & Boz, Y. (2012). Cooperative learning instruction for conceptual change in the concepts of chemical kinetics. *Chemistry Education Research and Practice, 13*(3), 221-236. https://doi.org/10.1039/c1rp90072b

Klayman, J., & Ha, Y. W. (1987). Confirmation, disconfirmation, and information in hypothesis testing. *Psychological review*, *94*(2), 211.

Kuhn, D. (1991). *The Skills of Argument.* Cambridge University Press. https://doi.org/10.1017/cbo9780511571350

Kuhn, D. (2015). Thinking together and alone. Educational Researcher, 44, 46-53

Kuhn, D., & Crowell, A. (2011). Dialogic argumentation as a vehicle for developing young adolescents' thinking. Psychological Science, 22, 545-552.

Kuhn, D., & Katz, J. (2009). Are self-explanations always beneficial?. *Journal of Experimental Child Psychology*, *103*(3), 386-394.

Kuhn, D., Hemberger, L., & Khait, V. (2016). Argue with me: Argument as a path to developing students' thinking and writing. New York: Routledge. (2nd ed.)

*Kumar, S., & Harizuka, S. (1998). Cooperative learning-based approach and development of learning awareness and achievement in mathematics in elementary school. *Psychological Reports, 82(2)*, 587-591. https://doi.org/10.2466/pr0.1998.82.2.587

Laughlin, P. R. (1999). Collective induction: Twelve postulates. *Organizational behavior and human decision processes*, *80*(1), 50-69.

Laughlin, P. R., & Shippy, T. A. (1983). Collective induction. *Journal of Personality and Social Psychology*, *45*(1), 94.

Laughlin, P. R., VanderStoep, S. W., & Hollingshead, A. B. (1991). Collective versus individual induction: Recognition of truth, rejection of error, and collective information processing. *Journal of Personality and Social Psychology*, *61*(1), 50.

Larson Jr, J. R. (2013). *In search of synergy in small group performance*. Psychology Press.

Latané, B., Williams, K., & Harkins, S. (1979). Many hands make light the work: The causes and consequences of social loafing. *Journal of Personality and Social Psychology, 37*(6), 822-832. https://doi.org/10.1037/0022-3514.37.6.822

*Lampe, J. R., Rooze, G. E., & Tallent-Runnels, M. (1996). Effects of cooperative learning among Hispanic students in elementary social studies. *The Journal of Educational Research, 89*(3), 187-191. https://doi.org/10.1080/00220671.1996.9941324

*Lee, C., Ng, M., & Phang, R. (2002). Effects of cooperative learning on elementary school children in Singapore. *Asia Pacific Journal of Education*, *22*(1), 3–15. https://doi.org/10.1080/0218879020220102

Lee, B. C., & Duffy, V. G. (2015). The effects of task interruption on human performance: A study of the systematic classification of human behavior and interruption frequency. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *25*(2), 137-152.

*Leman, P. J., Skipper, Y., Watling, D., & Rutland, A. (2016). Conceptual change in science is facilitated through peer collaboration for boys but not for girls. Child development, 87(1), 176-183.

*Leung, C. M. D., & Chung, C. M. (1997). Student achievement in an educational technology course as enhanced by cooperative learning. Journal of Science Education and Technology, 6(4), 337-343.

Lombrozo, T. (2006). The structure and function of explanations. *Trends in cognitive sciences*, *10*(10), 464-470.

Maynard, S. K. (1990). Conversation management in contrast: Listener response in Japanese and American English. Journal of Pragmatics, 14(3), 397-412.

Mevarech, Z. R., & Kramarski, B. (1997). IMPROVE: A multidimensional method for teaching mathematics in heterogeneous classrooms. American educational research journal, 34(2), 365-394.

*McCall, M. O. (2017). *The Effects of Individual Versus Cooperative Testing in a Flipped Classroom on the Academic Achievement, Motivation Toward Science, and Study Time for 9th Grade Biology Students* (Publication No. 10266260) [Unpublished doctoral dissertation, University of South Alabama]. Available from ProQuest Dissertations & Theses Global.

McHugh, M. L. (2012). Interrater reliability: the kappa statistic. *Biochemia medica*, *22*(3), 276-282.

McWhaw, K., & Schnackenberg, H. (2003). From co-operation to collaboration: Helping students become collaborative learners. In Cooperative Learning (pp. 79-96). Routledge.

Miel, A. (1952). Cooperative procedures in learning. Bureau of Publications, Teachers College, Columbia University.

Moore, K. S., & Corter, J. E. (2020). Can group knowledge diversity be created on-the-fly?: Effects of collaboration task design on performance and transfer. In S. Denison., M. Mack, Y. Xu, & B.C. Armstrong (Eds.), Proceedings of the *42nd Annual Conference of the Cognitive Science Society* (pp. 1539-1545). Cognitive Science Society.

Moore, K., & Corter, J. E. (in press) The Effectiveness of Collaborative Activities in Promoting Individual Learning. In J. S. Vogler & M. M. Buehl (Eds.), Teaching Learning for Effective Instruction. New York: Columbia University.

Newbern, D., Dansereau, D. F., Pattersion, M. E., & Wallace, D. S. (1994, April). Toward a science of cooperation. Paper presented at the annual meeting of the American Educational Research Association, New Orleans.

Newell, A. (1994). *Unified theories of cognition*. Harvard University Press.

*Nichols, J. D. (1996). The effects of cooperative learning on student achievement and motivation in a high school geometry class. *Contemporary Educational Psychology, 21*(4), 467-476. https://doi.org/10.1006/ceps.1996.0031

O'Donnell, A. M. (1996). Effects of explicit incentives on scripted and unscripted cooperation. Journal of Educational Psychology, 88(1), 74.

O’Donnell, A. M., & Dansereau, D. F. (1992). Scripted cooperation in student dyads: A method for analyzing and enhancing academic learning and performance. In R. Hertz-Lazarowitz & N. Miller (Eds.), Interaction in cooperative groups: The theoretical anatomy of group learning (pp.120–144). New York: Cambridge Univ. Press.

O'Donnell, A. M., & Dansereau, D. F. (2000). Interactive effects of prior knowledge and material format on cooperative teaching. *The Journal of Experimental Education*, *68*(2), 101-118.

*Oakes, D. J., Hegedus, E. M., Ollerenshaw, S. L., Drury, H., & Ritchie, H. E. (2019). Using the jigsaw method to teach abdominal anatomy. *Anatomical Sciences Education, 12*(3), 272-283. https://doi.org/10.1002/ase.1802

*Ortiz, A., Johnson, D.W., & Johnson, R.T. (1996). The effect of positive goal and resource interdependence on individual performance. *Journal of Social Psychology, 136*(2), 243-249. https://doi.org/10.1080/00224545.1996.9713998

*Overlock, T.H. (1994). *Comparison of the effectiveness of collaborative learning methods and traditional methods in physics classes at Northern Maine Technical College* (ED 367394). ERIC.

Page, S. E. (2007). Making the difference: Applying a logic of diversity. Academy of Management Perspectives, 21(4), 6-20.

Page, S. E. (2010). Diversity and complexity. Princeton University Press.

Perry, M. (2003). Distributed cognition. *HCI models, theories, and frameworks: Toward a multidisciplinary science*, 193-223.

Qin, Z., Johnson, D. W., & Johnson, R. T. (1995). Cooperative versus competitive efforts and problem-solving. Review of educational Research, 65(2), 129-143.

*Randolph, W.M. (1992). *The effect of cooperative learning on academic achievement in introductory college biology.* [Doctoral dissertation, Washington State University], Dissertation Abstracts International.

Reski, R., & Aswad, M. (2018). The Effect of Interruptions on Rapport Orientation in Formal Meetings. *EDUVELOP*, *2*(1), 37-47.

Rios, J. A., Ling, G., Pugh, R., Becker, D., & Bacall, A. (2020). Identifying Critical 21st-Century Skills for Workplace Success: A Content Analysis of Job Advertisements. Educational Researcher, 49(2), 80-89.

Rittle-Johnson, B. (2006), Promoting Transfer: Effects of Self-Explanation and Direct Instruction. *Child Development*, 77, 1-15. https://doi.org/10.1111/j.1467-8624.2006.00852.x

Rittle-Johnson, B., & Russo, S. R. (1999*). Learning from explaining: Does it matter if someone is listening?* Paper presented at the biennial meeting of the Society for Research in Child Development, Albuquerque, NM.

Robertson, S. I. (2001). *Problem-solving: Perspectives from Cognition and Neuroscience* (1st ed.). Psychology Press. https://doi.org/10.4324/9780203457955

Roschelle, J. & Teasley, S. (1995). The construction of shared knowledge in collaborative problem-solving. In C. E., O'Malley (Ed.), Computer supported collaborative learning (pp. 69–97). Heidelberg: Springer.

Roy, M., & Chi, M. (2005). The self-explanation principle in multimedia learning. In R. Mayer (Ed.), *Cambridge handbook of 287 multimedia learning* (pp. 271–286). Cambridge, UK: Cambridge University Press.

*Shaaban, K. (2006). An initial study of the effects of cooperative learning on reading comprehension, vocabulary acquisition, and motivation to read. *Reading Psychology, 27*(5), 377-403. https://doi.org/10.1080/02702710600846613

*Şahin, A. (2010). Effects of jigsaw II technique on academic achievement and attitudes to written expression course. Educational Research and Reviews, 5(12), 777.

*Şahin, A. (2011). Effects of Jigsaw III technique on achievement in written expression. Asia Pacific Education Review, 12(3), 427-435. doi:10.1007/s12564-010-9135-8

*Şahin, E. Y. (2013). The effect of Jigsaw and cluster techniques on achievement and attitude in turkish written expression. Hacettepe Üniversitesi Eğitim Fakültesi Dergisi, 28(28-2), 521-534.

*Santander, A. F. (2008). Cooperative Learning Combined with Short Periods of Lecturing. Biochemistry and Molecular Biology Education, 36(1).

Sauer, J., Felsing, T., Franke, H., & Rüttinger, B. (2006). Cognitive diversity and team performance in a complex multiple task environment. *Ergonomics*, *49*(10), 934-954.

Schegloff, E. A. (2000). Overlapping talk and the organization of turn-taking for conversation. Language in society, 29(1), 1-63.

Schober, M., & Clark, H. H. (1989). Understanding by addressees and overhearers. *Cognitive Psychology, 21*(21), l-232.

Schwartz, D. L. (1995). The emergence of abstract representations in dyadic problem-solving. *The Journal of the Learning Sciences, 4*(3), 321-354. https://doi.org/10.1207/s15327809jls0403_3

Shachar, H. (2003). Who gains what from cooperative learning: An overview of eight studies. In A. Ashman & R. Gillies (Eds.), *Cooperative learning: The social and intellectual outcomes of learning in groups* (pp. 113-128). Routledge.

*Shachar, H., & Fischer, S. (2004). Cooperative learning and the achievement of motivation and perceptions of students in 11th grade chemistry classes. *Learning and Instruction, 14*(1), 69-87. https://doi.org/10.1016/j.learninstruc.2003.10.003

Sharan, S., & Sharan, Y. (1976). Small-group teaching. Englewood Cliffs, N.J.: Educational Technology Publications.

Sharan, S., Sharan, Y., & Tan, I. G.-C. (1990). The group investigation approach to cooperative learning. In C. E. Hmelo-Silver, C. A. Chinn, C. Chan, and A. M. O'Donnell (Eds.), *The International Handbook of Collaborative Learning* (pp. 351-369). Routledge. https://doi.org/10.4324/9780203837290.ch20

Sheehan, J. K. (1994). *MANOVA simultaneous test procedures: A comparative study of power and robustness* (Order No. 9536589). Available from ProQuest Dissertations & Theses Global. (304107243). http://ezproxy.cul.columbia.edu/login?url=https://www-proquest-com.ezproxy.cul.columbia.edu/dissertations-theses/manova-simultaneous-test-procedures-comparative/docview/304107243/se-2?accountid=10226

Siegler, R. S. (2002). Microgenetic studies of self-explanation. In N. Granott & J. Parziale (Eds.), *Microdevelopment: Transition processes in development and learning* (pp. 31–58). Cambridge University Press. https://doi.org/10.1017/CBO9780511489709.002

Sim, J., & Wright, C. C. (2005). The kappa statistic in reliability studies: use, interpretation, and sample size requirements. *Physical therapy*, *85*(3), 257-268.

*Siregar, I. I., & Slamet, I. (2018, November). Team Assisted Individualization (TAI) in Mathematics Learning Viewed from Multiple Intelligences. In Journal of Physics: Conference Series (Vol. 1108, No. 1, p. 012073). IOP Publishing.

Slavin, R. E. (1996). Research on cooperative learning and achievement: What we know, what we need to know. Contemporary educational psychology, 21(1), 43-69.

Slavin, R. E. (1999). Comprehensive approaches to cooperative learning. Theory into practice, 38(2), 74-79.

Slavin, R. E., Madden, N. A., Dolan, L. J., Wasik, B. A., Ross, S., Smith, L., & Dianda, M. (1996). Success for All: A summary of research. Journal of Education for Students placed at Risk, 1(1), 41-76.

Smith, C. M., Tindale, R. S., & Steiner, L. (1998). Investment decisions by individuals and groups in sunk cost situations: The potential impact of shared representations. Group Processes & Intergroup Relations, 1(2), 175-189.

Souvignier, E., & Kronenberger, J. (2007). Cooperative learning in third graders' jigsaw groups for mathematics and science with and without questioning training. *British Journal of Educational Psychology*, *77*(4), 755-771. https://doi.org/10.1348/000709906x173297

*Stevens, R. J. (2003). Student team reading and writing: A cooperative learning approach to middle school literacy instruction. Educational Research and Evaluation, 9(2), 137-160.

*Stevens, R. J., & Slavin, R. E. (1995). Effects of a cooperative learning approach in reading and writing on academically handicapped and nonhandicapped students. The Elementary School Journal, 95(3), 241-262.

*Stevens, R. J., Slavin, R. E., & Farnish, A. M. (1991). The effects of cooperative learning and direct instruction in reading comprehension strategies on main idea identification. Journal of Educational Psychology, 83(1), 8–16.

Surowiecki, J. (2005). *The wisdom of crowds: Why the many are smarter than the few and how collective wisdom shapes business, economies, societies and nations*. New York, NY: Little, Brown.

*Tan, I. G. C., Sharan, S., & Lee, C. K. E. (2007). Group investigation effects on achievement, motivation, and perceptions of students in Singapore. *The Journal of Educational Research*, *100*(3), 142–154. https://doi.org/10.3200/joer.100.3.142-154

*Tarhan, L., & Sesen, B. A. (2012). Jigsaw cooperative learning: Acid–base theories. *Chemistry Education Research and Practice, 1*3(3), 307-313. https://doi.org/10.1039/c2rp90004a.

*Tarim, K., & Akdeniz, F. (2007). The effects of cooperative learning on Turkish elementary students' mathematics achievement and attitude towards mathematics using TAI and STAD methods. *Educational Studies in Mathematics, 67*(1), 77-91. https://doi.org/10.1007/s10649-007-9088-y

Roschelle, J., & Teasley, S. D. (1995). The construction of shared knowledge in collaborative problem-solving. In *Computer supported collaborative learning* (pp. 69-97). Springer, Berlin, Heidelberg.

Thompson, M., & Pledger, L. (1998). Cooperative learning versus traditional lecture format: A preliminary study. Paper presented at the Annual meeting of the National Communication Association (84th, New York, NY, November 19–24, 1998).

Tindale, R. S. (1993). Decision errors made by individuals and groups. Individual and group decision making: Current issues, 109-124.

*Tudge, J. R. (1992). Processes and consequences of peer collaboration: A Vygotskian analysis. Child development, 63(6), 1364-1379.

*Tudge, J., & Winterhoff, P. (1993). Can young children benefit from collaborative problem-solving? Tracing the effects of partner competence and feedback. Social Development, 2(3), 242-259.

Van Der Veer, G. C., Lenting, B. F., & Bergevoet, B. A. (1996). GTA: Groupware task analysis—Modeling complexity. *Acta psychologica*, *91*(3), 297-322.

Vasquez, B., Johnson, D. W., & Johnson, R. (1993). The impact of cooperative learning on the performance and retention of U.S. Navy air traffic controller trainees. *The Journal of Social Psychology*, *133*(6), 769–783. https://doi.org/10.1080/00224545.1993.9713938

Voiklis, J. & Corter, J. E. (2012). Conventional wisdom: Negotiating conventions of reference enhances category learning. *Cognitive Science*, *36*(4), 607–634. https://doi.org/10.1111/j.1551-6709.2011.01230.x

Vogler, J. S., & Robinson, D. H. (2016). Team-based testing improves individual learning. *The Journal of Experimental Education, 84*(4), 787-803. https://doi.org/10.1080/00220973.2015.1134420

Webb, N. (1985). Student interaction and learning in small groups: A research summary. Learning to cooperate, cooperating to learn, 147-172.

Webb, N. M. (1989). Peer interaction and learning in small groups. International Journal of Educational Research, 13, 21–39.

*Webb, N. M. (1992). Testing a theoretical model of student interaction and learning in small groups. In R. Hertz-Lazarowitz & N. Miller (Eds.), *Interaction in cooperative groups: The theoretical anatomy of group learning* (pp. 102–119). Cambridge Univ. Press.

Webb, N. M. (2008). Teacher practices and small-group dynamics in cooperative learning classrooms. In R. M. Gillies, A. Ashman, & Jan Terwel (Eds.), *The Teacher's Role in Implementing Cooperative Learning in the Classroom* (pp. 201–221). Springer. http://dx.doi.org/10.1007/978-0-387-70892-8_10

Webb, N. M. (2009). The teacher's role in promoting collaborative dialogue in the classroom. *British Journal of Educational Psychology*, *79*(1), 1-28.

Webb, N., Nemer, K., Chizhik, A. & Sugrue, B. (1998). Equity issues in collaborative group assessment: group composition and performance, *American Educational Research Journal, 35*, 607–51. https://doi.org/10.3102/00028312035004607

*Whicker, K. M., Bol, L., & Nunnery, J. A. (1997). Cooperative learning in the secondary mathematics classroom. *The Journal of Educational Research*, *91*(1), 42–48. https://doi.org/10.1080/00220679709597519

Wilkes-Gibbs, D., & Clark, H. H. (1992). Coordinating beliefs in conversation. *Journal of memory and language*, *31*(2), 183-194.

*Williams, J. M., & Tolmie, A. (2000). Conceptual change in biology: Group interaction and the understanding of inheritance. British Journal of Developmental Psychology, 18(4), 625-649.

Wittrock, M. C. (1986). Handbook of research on teaching (3rd ed..). NY: Macmillan Pub. Co.

Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., and Malone, T. W. (2010). Evidence for a collective intelligence factor in the performance of human groups. *Science* 330, 686–688. doi: 10.1126/science.1193147

Wong, R. M., Lawson, M. J., & Keeves, J. (2002). The effects of self-explanation training on students' problem solving in high-school mathematics. *Learning and Instruction*, *12*(2), 233-262.

Woodworth, R. S., & Thorndike, E. L. (1901). The influence of improvement in one mental function upon the efficiency of other functions, (I). *Psychological Review, 8*(3), 247.

*Yetter, G., Gutkin, T. B., Saunders, A., Galloway, A. M., Sobansky, R. R., & Song, S. Y. (2006). Unstructured collaboration versus individual practice for complex problem-solving: A cautionary tale. *The Journal of Experimental Education, 74*(2), 137-160. https://doi.org/10.3200/jexe.74.2.137-160

Zickerick, B., Thönes, S., Kobald, S. O., Wascher, E., Schneider, D., & Küper, K. (2020). Differential effects of interruptions and distractions on working memory processes in an ERP study. *Frontiers in human neuroscience*, *14*, 84.

Appendix A: Supplementary Tables & Figures

A.1 Participant Demographics

This section of Appendix A serves as a repository for supplementary analysis, tables, and figures relating to Section 4.1 Participant Demographics. Analysis in this section focuses on evaluating distribution of participants across conditions using random assignment by determining whether participant demographics differed between study conditions. Significant findings are reported in the Section 4.1. Non-significant findings and findings from tests that suffer from violations of their assumptions are reported here. The section first examines participants Majors, then it continues with an examination of participant gender, age, level of education, and native language.

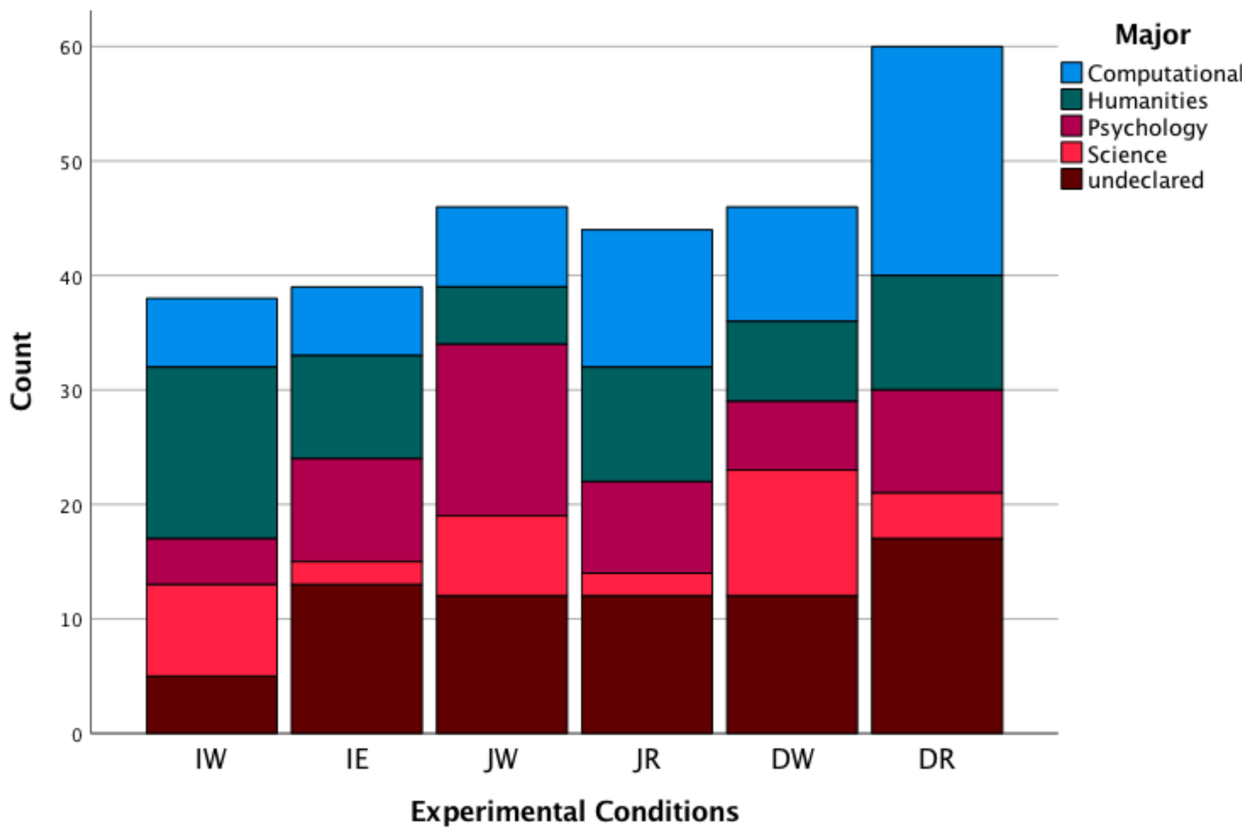


Figure A. Bar graph representing the distribution of participant majors (both declared and soon to be declared) across the six study conditions.

Table A. Proportion of design features applied in Maps 1 and 2 across participant declared majors

Task	Design Feature	Computational		Humanities		Psychology		Science		Undeclared		$X^2(1,273)$	*p*	*φ*
		n	%	*n*	%	*n*	%	*n*	%	*n*	%			
Map 1	Steiner point	20	22	22	24	16	17	7	7	28	30	4.062	.398	.122
	Loop	47	25	37	20	34	18	23	12	49	26	2.218	.696	.090
Map 2	Steiner point	29	25	22	19	25	22	13	11	26	22	3.083	.544	.106
	Loop	47	23	38	19	35	17	28	14	55	27	4.412	.353	.127

Table B. One-way ANOVAs of transfer learning outcome variables across participant declared majors

Transfer Learning Outcome Variables		*df*	*SS*	*MS*	*F*	*p*
Total Transfer Success	Between Groups	4	1.313	.328	.193	.942
	Within Groups	268	456.673	1.704		
	Total	272	457.985			
Steiner point Transfer Success	Between Groups	4	1.392	.348	.610	.656
	Within Groups	268	152.857	.570		
	Total	272	154.249			
Loop Transfer Success	Between Groups	4	.824	.206	.211	.932
	Within Groups	268	262.085	.978		
	Total	272	262.908			

There was a significant difference in the distribution of declared majors across conditions, χ^2 (20, N = 273) = 40.405, p = .004, with an overrepresentation of computational majors in the DR condition (as seen in Figure A). The category of "computational" majors included Computer Science, Computer Engineering, Economics, Mathematics, Statistics, Architecture, or some combination of these topics. It is speculated that expertise in these areas may have given participants knowledge relevant to efficient network design (i.e., Mathematics, Architecture, etc.), which would have given them an advantage over other participants in the collaborative problem-solving task, and possibly distorted results regarding effects of the DR condition on performance and transfer learning.

However, subsequent analysis found no evidence that Computational majors had advantages that positively impacted their network design (on either Map 1 or Map 2) or their learning outcomes. There was no difference in application of design features (i.e., the loop or Steiner point) on Map 1 or Map 2 across majors. Additionally, there was no difference in successful transfer of insights on the post-task network design activities across majors (as seen in Table A and Table B).

These findings suggest that participants with Computational majors did not have an advantage on any of the tasks (i.e., the training task, main collaborative task, or post-task) over participants with majors in Humanities, Sciences, Psychology (or participants who had not yet declared their major).

Table C. Means and standard deviations for all mediating and outcome variables across participant gender

	Prefer Not To Answer (N=2)		Male (N=21)		Female (N=244)		Non-Binary (N=6)		
Variables	M	SD	M	SD	M	SD	M	SD	$F(3,273)$
Task Performance	131.77	10.22	132.18	8.59	133.85	10.17	138.49	8.26	.650
Explanations	25.00	1.41	30.33	18.64	17.82	12.50	20.17	9.58	5.306**
Transfer Learning	3.50	3.54	4.00	1.14	3.04	1.27	3.83	1.17	4.322**

**$p < .001$

Gender did not differ across conditions, $\chi^2(15, N=273) = 10.358$, $p = .797$; however, because of an overrepresentation of females in the sample population 18 cells in the chi-square (75%) have expected count less than 5. The minimum expected count is .28. Thus, findings from this test are inconclusive. ANOVAs of the mediating and outcome variables across gender types also suffer from non-normal distributions and unequal sample sizes. There are several significant findings regarding gender, explanations, and learning outcomes (as seen in Table C), but they are not robust to the violations of the assumptions and few conclusions can be drawn from these tests. Results pertaining to gender are inconclusive.

Table D. Correlation matrix of mediating and outcome variables for all participants (N=273).

	1.	2.	3.	4.
1. Age (years)	--			
2. Task Performance (cm)	.025	--		
3. Explanations [a]	.125	-.052	--	
4. Transfer Learning [b]	.136*	.006	.230**	--

[a] Frequency of speech act

[b] 0 = no transfer, 1 = transfer

**p* > .05, ***p* > .01 (two-tailed).

Participant age has a positive association with transfer learning, $r = .135$, $p = .024$ (as seen in Table D). This suggests that older participants may have had an advantage on transfer learning tasks. Dyads with older participants may also have benefitted from this advantage. However, because of random assignment, there is not difference in participant ages across conditions, $F(5, 272) = 1.187$, $p = .316$. This suggests that any advantages afforded by the participant's age were distributed across study conditions.

Table E. Means, standard deviations, and *t*-tests for all mediating and outcome variables between participant level of education

	Undergraduate Student		Graduate Student				
Variables	M	SD	M	SD	*t* (273)	*p*	*d*

Task Performance	133.80	10.01	135.05	11.64	-.214	.803	-.124
Explanations	18.83	13.38	24.67	7.77	-.753	.452	-.438
Transfer Learning	3.14	1.30	3.00	1.00	.182	.856	.105

Participant level of education does not differ across conditions, $\chi^2(5, N=273) = 5.460$, $p = .362$ (see Table E). Nor does participant level of education afford advantages on any of the mediating or outcome variables.

Table F. Means, standard deviations, and one-way ANOVA for all mediating and outcome variables between participant native language

	Chinese (N=22)		English (N=190)		Korean (N=3)		Spanish (N=17)		Other (N=41)		
Variable	M	SD	M	SD	M	SD	M	SD	M	SD	*F*(4,273)
Performance	132	7.73	134	9.74	127	1.80	133	13.21	134	8.86	.780
Explanation	15	7.14	20	16.29	13	1.92	18	8.85	22	13.12	1.05
Learning	3	1.16	3	1.20	1	1.50	3	1.37	3	1.55	4.69**

**$p < .001$

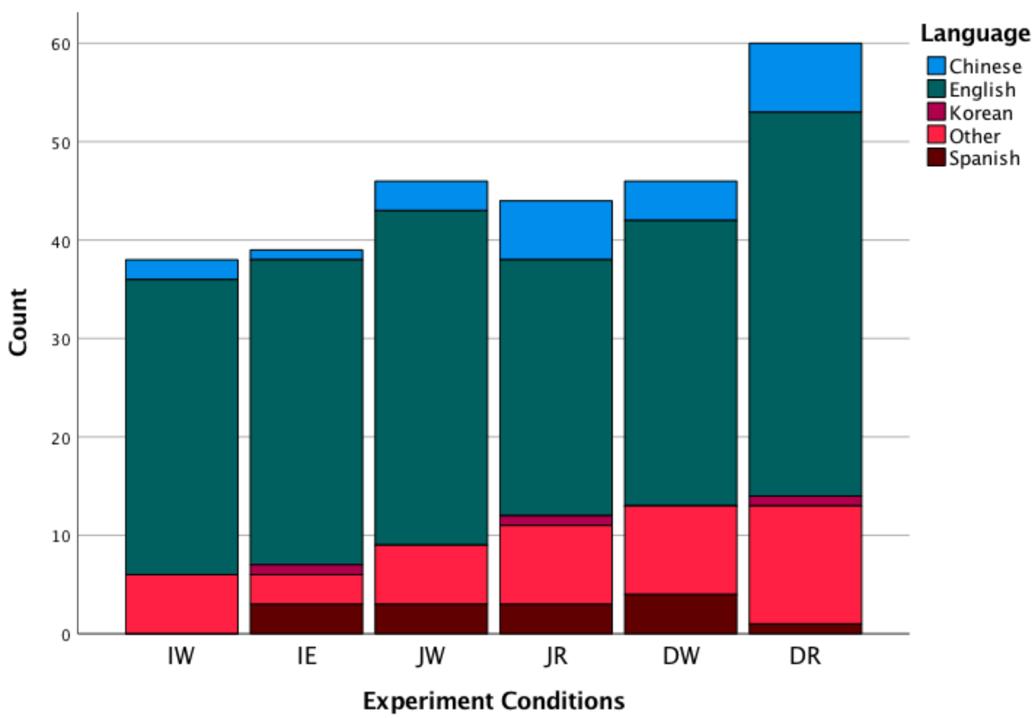


Figure B. Bar graph representing the distribution of participant native language across the experiment six study conditions.

One-way ANOVAs find that native language has a differential effect on transfer learning, $F(4, 273) = 4.687$, $p < .001$ (as seen in Table F). Means and standard deviations suggest that Korean as a native language is more likely to negatively affect learning outcomes than other native languages; however, the data suffers from unequal sample sizes with an underrepresentation of native Korean speakers. Thus, it cannot be determined from this test whether Korean or any native language influences learning outcomes.

Figure F shows the distribution of native languages reported by student participants. Although there is a larger proportion of English speakers in the DR condition than in other conditions, differences are not significant, $\chi^2(20, N = 273) = 18.065$, $p = .583$, $\varphi = .257$.

A.2 Descriptive Statistics

This section of Appendix A serves as a repository for supplementary analysis, tables, and figures relating to Section 4.2 Descriptive Statistics. Analysis in this section focuses on evaluating distribution of discourse characteristics that are not included in the main analysis, i.e., time spent collaborating, number of turns taken, and number of words spoken. The findings reported here reinforced findings are reported in the Section 4.2, but because they do not directly address the research questions they are reported here. The section first offers a comprehension check for task, followed by a manipulation check of the intervention. It then examines the distributions of the discourse characteristics.

Comprehension Check

On average, participants demonstrated understanding of the design task. 73% of participants correctly answered the network design task comprehension check on the post-task questionnaire. A greater proportion of participants tended to show understanding of roads (80% correct responses) more than routes (66%). This pattern of responses did not differ across conditions, $F(5, 272) = .748$, $p = .588$. Results suggest that participants generally understood the task (although imperfectly).

Manipulation Check

Table E shows results from the manipulation check. To determine whether knowledge diversity was instilled in the dyads, application of the design features is compared between participants. Participant B was given task directions designed to predispose them the utility of the design features: the loop and the Steiner point. Participant A was given task directions that would not predispose them to these design features. A pair of *t*-tests comparing application of the design features in Map 1 (the training task) between Participant A and B, show that application of the loop differed between participants A and B, but not the Steiner point (see Table F). This suggests that the manipulation worked for the loop, but not the Steiner point.

Figure C displays results from the second manipulation check. To determine whether task roles were instilled in the dyads (i.e., whether participants were aware of their assigned task roles), the post-task questionnaire included an item the prompted participants to identify whether their believed their training experience differed from their partner's. The language of the item was, "How would you compare your first task to your partner's first task?" Participants could choose one of three options, (1) "We had the same task", (2) "Our first tasks were different", and (3) "I don't know what my partner's first task was, so I can't compare mine to theirs."

Figure C displays participant responses to this item by dyadic condition. While participants tended to report that they did not know what their partner's first task was, participants in the DR condition overwhelmingly reported that they believed their first task was different from their partner's. Interestingly (and appropriately), participants in the JR condition – who were told they had different roles – did not report that they thought they had different first tasks than their partners. These results suggest that the manipulation of participant roles was effective.

Table F. *t*-Tests comparing design features (Loop and Steiner point) by dyad members, Participant A or B

Design Feature Application on Map 1	Participant A		Participant B		*t*(195)	*p*	*d*
	M	*SD*	*M*	*SD*			
Loop	.46	.50	.89	.32	-7.155*	.000	.419
Steiner point	.32	.47	.36	.48	-.602	.548	.475

*Equal variance not assumed

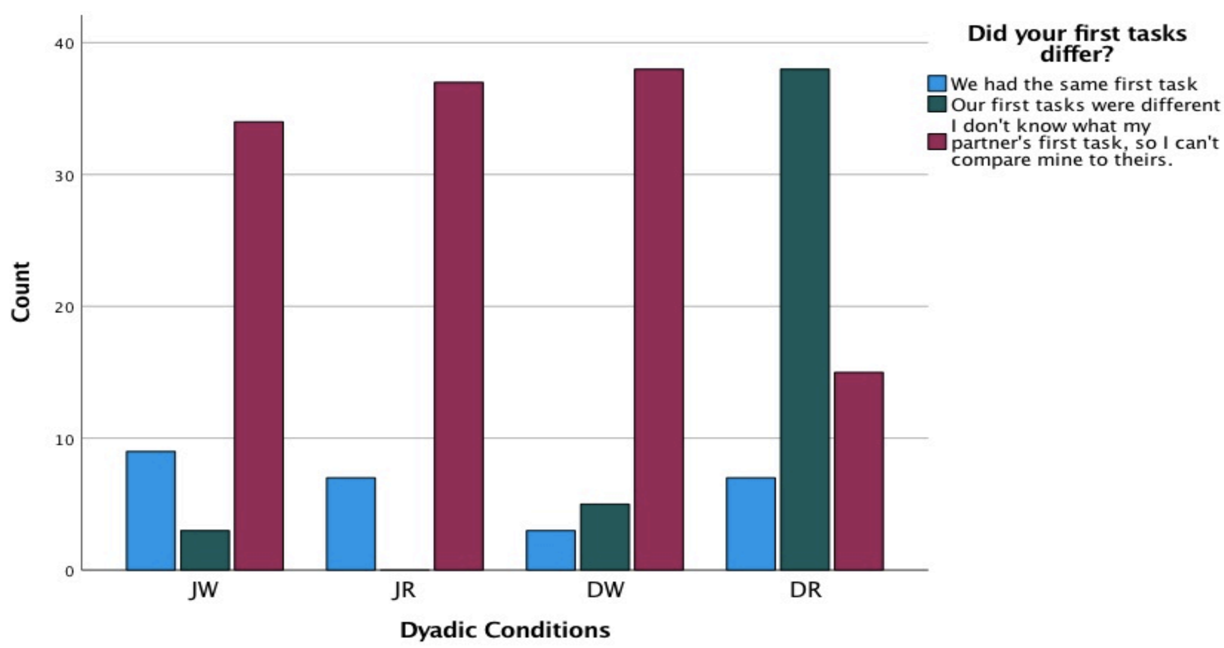


Figure C. Bar graph of participant responses to the post-task questionnaire item, "How would you compare your first task to your partner's first task?" by dyadic condition.

Discourse Characteristics

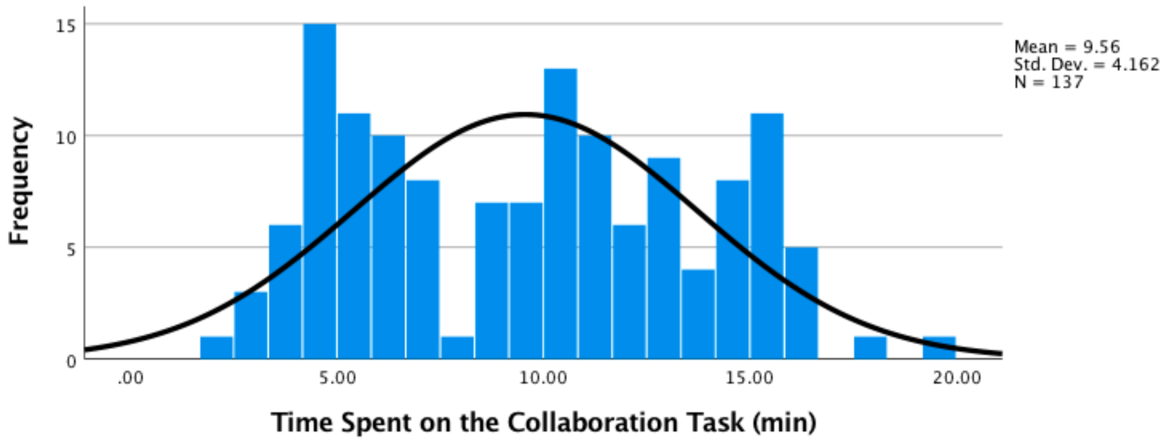


Figure D. Distribution of time spent on the collaboration task (min) for both dyads and individuals who used self-explanation

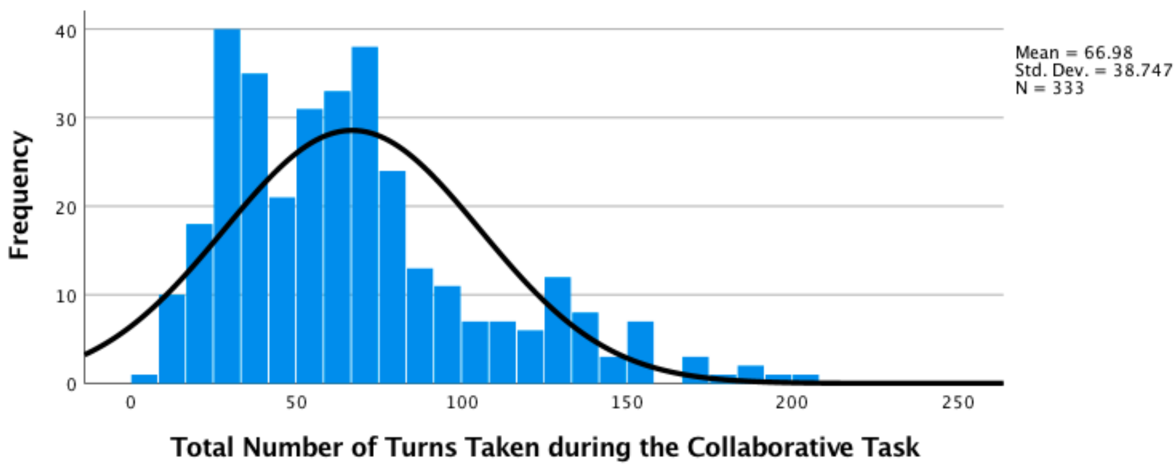


Figure E. Distribution of the number of turns taken during the collaboration task (dyads only)

Figure F. Distribution of the total number of words spoken during the collaboration task by both participant A and B combined.

Table G. Discourse characteristics averaged by condition with one-way ANOVA tests

Discourse	Study Conditions with Verbalization											
	IE		JW		JR		DW		DR			
Characteristics	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*(4,136)	η^2
Time Spent	7	3	9	4	9	3	11	3	10	3.65	6.007**	.156
Turns Taken	40	27	94	39	95	39	120	37	111	40.77	24.775**	.429
Words Spoken	372	233	861	475	843	384	1061	339	1006	448	17.927**	.352

**$p < .001$

Communication Criterion

To further understand the overlap among speech acts (described in Section 4.2), cosine similarity was used to measure the Euclidean distance between vectorized versions of the speech acts. This measure is robust to non-normal data and may be preferable to an analysis of speech act correlations. Table H shows that most cosine similarity scores for the speech acts were over .60, which suggests convergence in speech act application and re-affirms findings from the correlation matrix; there is a great deal of overlap between speech acts, which makes it difficult to analyze each as a distinct variable. Factor analysis may be a preferable method of analyzing relationships among speech acts and relationships with speech acts to any other variable.

Figure G displays an answer to the question, *did any conditions differ in frequency or pattern of speech acts used?* Participants in the Individual with Self-Explanation (IE) condition used a significantly different pattern of speech acts than dyads. Raters interpreted nearly everything individuals said in the self-explanation condition as an explanation.

Figure H displays the scree plot generated for principal component analysis (PCA) (see Section 4.2) in response to the overlap of speech acts. The plot shows an "elbow" at the second eigen value, which suggests the first two components may explain significant latent variables and should be retained for further analysis.

The high degree of overlap in the current study's speech acts suggests the presence of a latent variable. Principal component analysis (PCA) identified two latent variables, which cumulatively explain 48% of the variance in the speech acts: PC1 = 33% variance explained, PC2 = 15% variance explained. Table I displays the principal component matrix.

Table H. Cosine similarity matrix of all speech acts

Speech Acts	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. Explain	--								
2. Propose	0.80	--							
3. Question Consideration	0.68	0.87	--						
4. Question Information	0.59	0.81	0.88	--					
5. Response Agree	0.78	0.86	0.86	0.71	--				
6. Response Modify	0.48	0.76	0.84	0.92	0.63	--			
7. Social Facilitation	0.77	0.78	0.80	0.69	0.86	0.62	--		
8. Joint Attention	0.74	0.69	0.57	0.40	0.75	0.28	0.64	--	
9. Interrupt	0.48	0.42	0.28	0.22	0.50	0.11	0.45	0.61	--

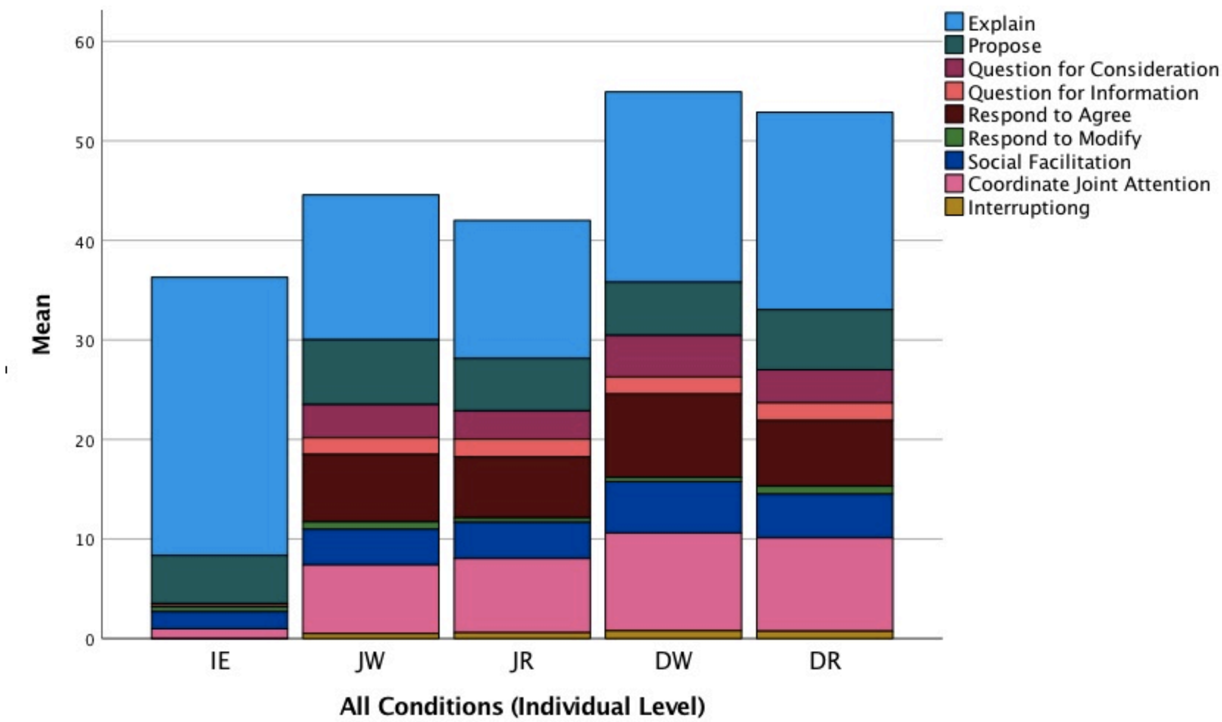


Figure G. Proportion of speech acts used across conditions that involved communication (IW condition not included).

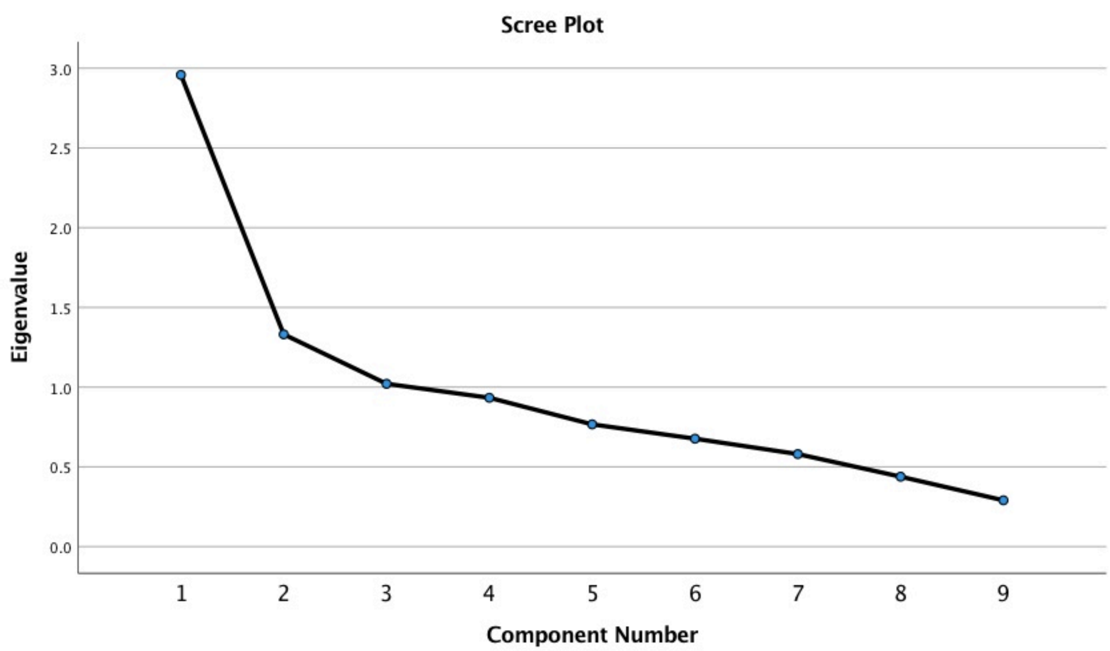


Figure H. Scree plot illustrating the cumulative proportion (%) of variance explained by each principal component in a PCA analysis of speech acts.

Table I. Principal component matrix for all speech acts, with Varimax and Kaiser normalization

	Component	
Speech Acts	1.	2.
1.Explain	.786	.132
2.Propose	.542	.475
3.Question Consideration	.263	.539
4.Question Information	.536	-.047
5.Response Agree	.022	.636
6.Response Modify	-.098	.754
7.Social Facilitation	.192	.656
8.Joint Attention	.791	.306
9.Interruptions	.562	.035

Learning Criterion Item Analysis

Figure I shows the average frequency with which design features were transferred on each post-task activity item (Q1-Q5). Green bars signify “successful transfer” of the design feature; red bars signify “transfer error” of that design feature. Figure I suggests four trends in post-task activity responses. First, Q1 may have been confusing or difficult; while the correct design feature for this item was a Steiner point, there was no difference in participant application of this correct design feature and the incorrect design feature, the loop. Second, participants tended to correctly transfer loops to items Q2 and Q3. Third, when participants did apply a design feature on Q4, they tended to correctly apply the Steiner point. Finally, participant response to Q5 generally agree that both (or neither) design features should be used. If participants applied a design feature on this item, then they applied both features. However, this combination of design features did not tend to appear on Q5.

These results suggest that Q1 and Q5 were either (a) poorly aligned with the network design and learning experiences participants experienced from Map 1 and Map 2, (b) presented more of a challenge than intended, or (c) both. Conversely, Q2, Q3, and Q4 appear to be understandable for the average participant. Despite these discrepancies, these post-task items are combined in the learning criterion, “transfer learning”, in the subsequent analysis.

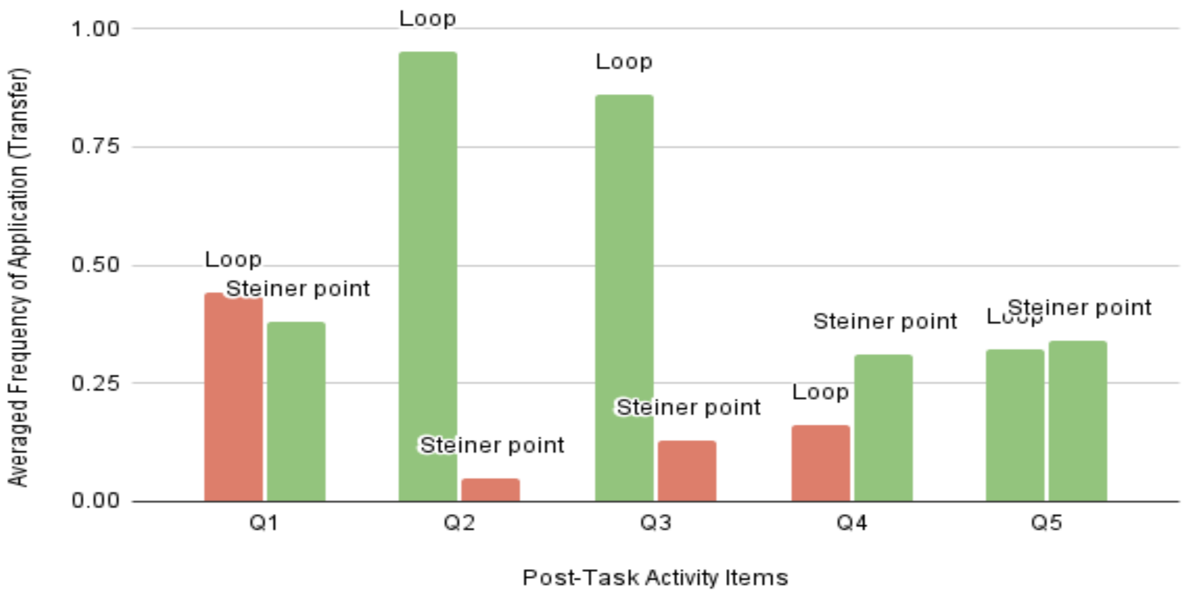


Figure I. Average frequency of application (Transfer) of design features (Loop and the Steiner point) on all post-task activity items Q1 – Q5. Green = successful transfer, Red = transfer error

A.3 Main Analysis

This section of Appendix A serves as a repository for supplementary analysis, tables, and figures relating to Section 4.3 Main Analysis. Tables and figures are organized by the research question they address. Analysis in this section is supplementary to the findings reported in Section 4.3; including reports on tests of statistical assumptions as well as tables and figures detailing the findings reported in the main analysis. Here, tables and figures without accompanying descriptive paragraphs are described in the main body of the Chapter and are displayed here for reference.

Explanations

Table J displays the correlation matrix for all mediating and outcome variables (including all speech acts). Correlations were calculated for all individual participants; thus, members of a dyad were included in the analysis as two individual participants (N=273) as opposed to a single dyad (which would be an N of 137). Table J exhibits several significant moderate correlations that are summarized in Section 4.3, e.g., the correlation between explanations as measured by frequency of explanations and transfer learning (Total Transfer Success), $r = .230$, $p < .001$.

Table J. Correlation matrix of all criterion variables at the level of the individual regardless of condition (N=273).

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. Network Length	--									
2. Transfer Learning [a]	.006	--								
3. Explain [b]	-.052	.230**								
4. Propose [b]	.062	.060	.620**	--						
5. Question Consideration [b]	.026	.055	.508**	.754**	--					
6. Question for Information [b]	.018	.022	.513**	.730**	.817**	--				
7. Response Agree [b]	-.059	.052	.461**	.687**	.724**	.608**	--			
8. Response Modify [b]	-.037	-.072	.448**	.735**	.814**	.858**	.600**	--		
9. Social Facilitation [b]	-.017	-.016	.494**	.544**	.635**	.568**	.667**	.572**	--	
10. Coordinate Attention [b]	-.034	.106	.524**	.508**	.362**	.241**	.461**	.180**	.342**	--
11. Interruptions [b]	-.097	.009	.290**	.224**	.088	.097	.294**	.022	.265**	.452**

[a] 0 = no transfer, 1 = transfer

[b] Frequency of each speech act uttered by each participant during a conversation limited to 15 minutes.

**p* > .05, ***p* > .01 (two-tailed).

RQ4, RQ6, RQ8

Table K. Descriptive statistics (M, *SD*) for discourse variables across all study conditions with verbalization (N=137)

	Study Conditions with Verbalization											
	IE		JW		JR		DW		DR		Full Sample	
Discourse Variables	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Collaboration Time	7.19	3.70	9.19	4.16	9.84	3.87	11.42	3.45	10.78	3.65	9.43	4.03
Turns Taken	40	27	94	39	95	39	120	37	111	40	87	47
Words Spoken	372	234	861	475	843	384	1061	339	1007	448	784	458

Table L. Factorial (2x2) ANOVA results for collaboration time (min) across four dyadic conditions (JW, JR, DW, DR) (N=98)

Total Time Spent Collaborating	*df*	*SS*	*MS*	*F*	*p*
Main Effects					
Knowledge Diversity	1	59.807	59.807	4.169	.044
Task Roles	1	.001	.001	.000	.993
Interaction					
Knowledge Diversity * Task Roles	1	10.032	10.032	.699	.405
Total	95	1387.518			

Table M. Factorial (2x2) ANOVA results for turns taken across four dyadic conditions (JW, JR, DW, DR) (N=98)

Total Number of Turns Taken	*df*	*SS*	*MS*	*F*	*p*
Main Effects					
Knowledge Diversity	1	10356.390	10356.390	6.653	.011
Task Roles	1	478.881	478.881	.308	.580
Interaction					
Knowledge Diversity * Task Roles	1	557.503	557.503	.358	.551
Total	97	157280.500			

Table N. Factorial (2x2) ANOVA results for words spoken across four dyadic conditions (JW, JR, DW, DR) (N=98)

Total Number of Words Spoken	*df*	*SS*	*MS*	*F*	*p*
Main Effects					
Knowledge Diversity	1	794597.244	794597.244	4.544	.036
Task Roles	1	30803.496	30803.496	.176	.676
Interaction					
Knowledge Diversity * Task Roles	1	8263.295	8263.295	.047	.828
Total	97	17245970.0			

RQ11a

Table O. Correlation matrix of all criterion variables at the level of the dyad regardless of condition.

	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. Network Length	--								
2. Explain [b]	-.157	--							
3. Propose [b]	-.123	.647**	--						
4. Question Consideration [b]	-.060	.551**	.820**	--					
5. Question for Information [b]	-.070	.575**	.810**	.878**	--				
6. Response Agree [b]	-.138	.507**	.761**	.813**	.688**	--			
7. Response Modify [b]	-.083	.530**	.811**	.872**	.915**	.658**	--		
8. Social Facilitation [b]	-.054	.524**	.614**	.710**	.641**	.749**	.628**	--	
9. Coordinate Attention [b]	-.126	.462**	.466**	.362**	.235**	.537**	.167	.358**	--
10. Interruptions [b]	-.101	.288**	.231**	.098	.083	.335**	.021	.271**	.504**

[b] Frequency of speech act uttered by each participant during a conversation limited to 15 minutes.

*p > .05, **p > .01 (two-tailed).

RQ11b

Table P. Test of between subject effects of all speech acts across individuals and dyads (N=137)

Frequency of Speech Act	*df*	*MS*	*F*	*p*	η^2
Explain	1	1575.718	3.312	.071	.024
Propose	1	1667.194	11.180	.001	.076
Question for Consideration	1	1715.502	22.255	.000	.142
Question for Information	1	483.243	7.424	.007	.052
Response Agree	1	6268.251	79.073	.000	.369
Response Modify	1	44.130	1.378	.242	.010
Social Facilitation	1	1442.294	28.333	.000	.173
Coordinate Joint Attention	1	7019.506	50.664	.000	.273
Interruption	1	48.339	11.267	.001	.077

RQ12b

Table Q. Correlation matrix of mediating and outcome variables for individuals who used self-explanation (IE) during the problem-solving task (N=39).

	1.	2.	3.
1. Network Length (cm)	--		
2. Transfer Learning [a]	.189	--	
3. Explain [b]	-.006	.310	--

[a] 0 = no transfer, 1 = transfer

[b] Frequency of speech act

*p > .05, **p > .01 (two-tailed).

RQ13

The analysis for RQ13 begins with a multivariate test of the frequency of all speech acts between individuals and dyads to determine whether there is a difference in explanations uttered by individuals as compared to dyads. This is followed by a factor analysis of the speech acts uttered by individuals and dyads to determine *how* explanations differ. Finally, discriminant analysis of the speech acts determines which acts make the greatest contribution to the difference between speech acts used by individuals and dyads.

For the first analysis, Hoteling's Trace test (also known as Hoteling's T-test) is used to determine whether the frequency of speech acts differed between individuals and dyads. The speech act data violates the assumptions of independence and sphericity; speech acts are not independent (utterances in a collaborative conversation rarely are), and Bartlett's Test of Sphericity is significant, $p < .001$. The analysis is conducted despite these violations as there is some research suggesting the Hoteling's T-test is relatively superior to alternative multivariate tests given these violations of independence and sphericity (Ateş et al., 2019; Sheehan, 1994).

Hoteling T-test finds that the frequency of speech acts differs between individuals and dyads, $T^2(9, 127) = 1.541$, $p < .001$ (see Table P for one-way ANOVA tests of between subject effects for each speech act). Figure 12 illustrates differences in the distribution of each speech act for individuals and dyads (Recall that dyadic discourse combines speech acts from two participants).

The second analysis for this research question applies two separate principal components factor analyses (PCAs) of all speech acts uttered by individuals and uttered during dyadic discourse because the speech acts in each group (individuals and dyads) are highly correlated (see Tables R and S for correlation matrixes for both groups). Factor loadings from the analysis of individuals using self-explanation (55% variance explained) suggests explanations and proposals indicate a latent variable related to explanations. Factor loadings from the analysis of dyadic discourse (78% variance explained) suggest that explanations, proposals, questions, responses, and social facilitation indicate a latent factor related to explanations. See Section 4.3, Table 20 for component matrices from both analyses (see Figures I and J for scree plots).

Table R. Correlations of speech acts used by individuals in self-explanation condition.

Speech Acts	1.	2.	3.	4.	5.	6.	7.	8.
1. Explain (E)	--							
2. Propose (P)	.601**	--						
3. Question Consideration (Qc)	-0.016	-0.149	--					
4. Question Information (Qi)	0.204	0.078	-0.056	--				
5. Respond to Agree (Ra)	.393*	0.316	-0.026	.382*	--			
6. Respond to Modify (Rm)	0.282	.321*	-0.066	-0.141	-0.066	--		
7. Social Facilitation (S)	.605**	.461**	0.017	0.05	-0.105	0.18	--	
8. Joint Attention (J)	-0.086	-0.131	.689**	-0.13	-0.061	0.186	0.014	--
9. Interrupt (N)	.c	.c	.c	.c	.c	.c	.c	.c

Table S. Correlations of speech acts used by individuals in dyadic conditions.

Speech Acts	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. Explain (E)	--								
2. Propose (P)	.389**	--							
3. Question Consideration (Qc)	.242**	.346**	--						
4. Question Information (Qi)	.221**	.168*	.154*	--					
5. Respond to Agree (Ra)	0.08	.275**	.188**	0.005	--				
6. Respond to Modify (Rm)	0.061	.269**	.226**	-0.032	.216**	--			
7. Social Facilitation (S)	.256**	.208**	.291**	.198**	.324**	.359**	--		
8. Joint Attention (J)	.623**	.577**	.324**	.253**	.170*	.228**	.219**	--	
9. Interrupt (N)	.289**	.177*	0.02	.157*	.180*	-0.008	.227**	.345**	--

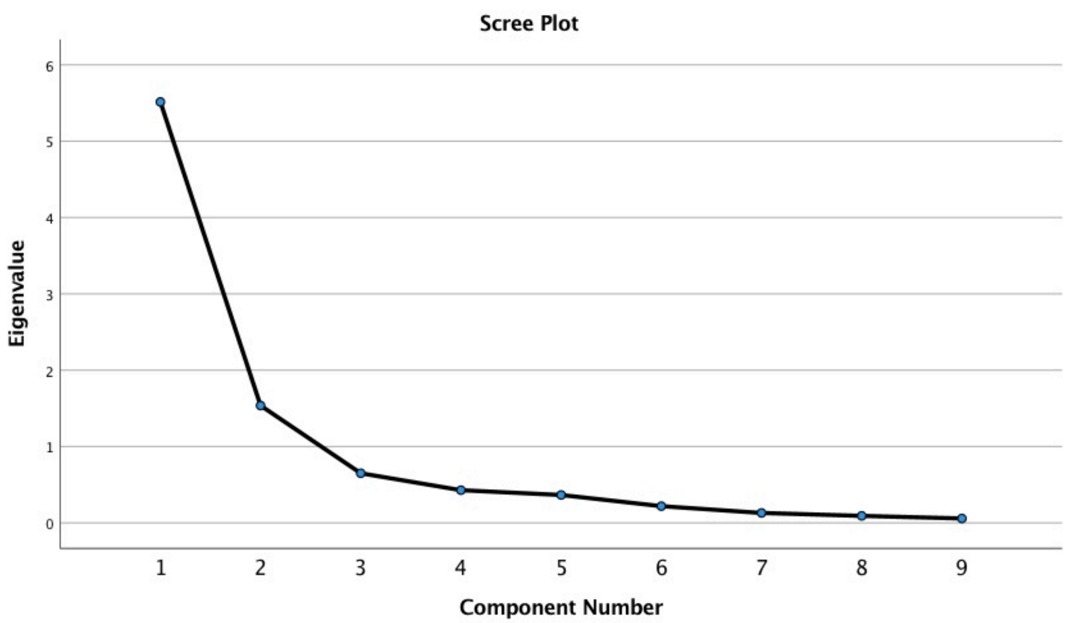


Figure J. Scree plot illustrating the cumulative proportion (%) of variance explained by each principal component in a PCA analysis of speech acts uttered by dyads.

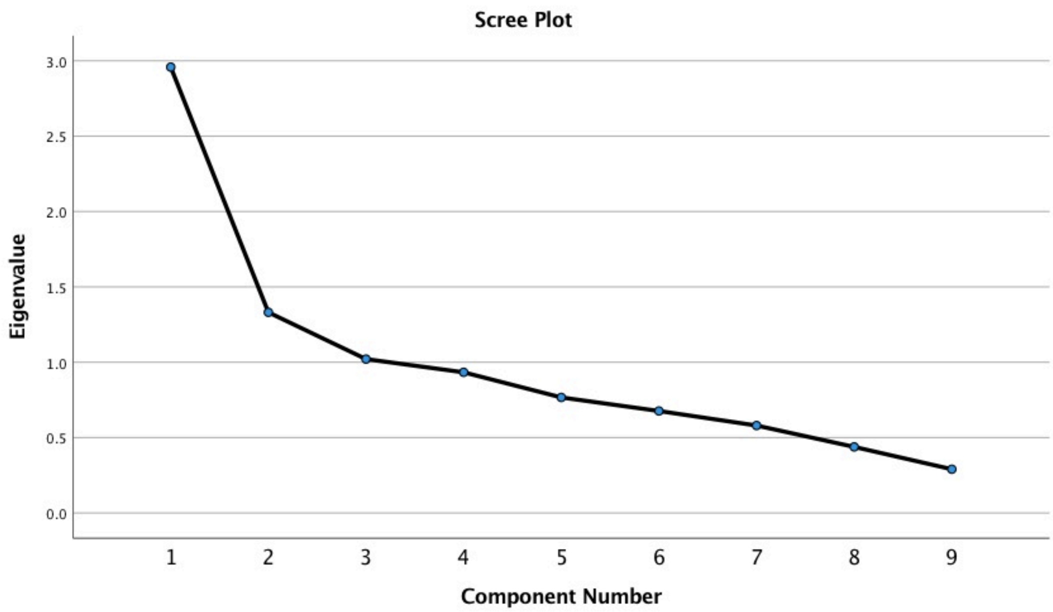
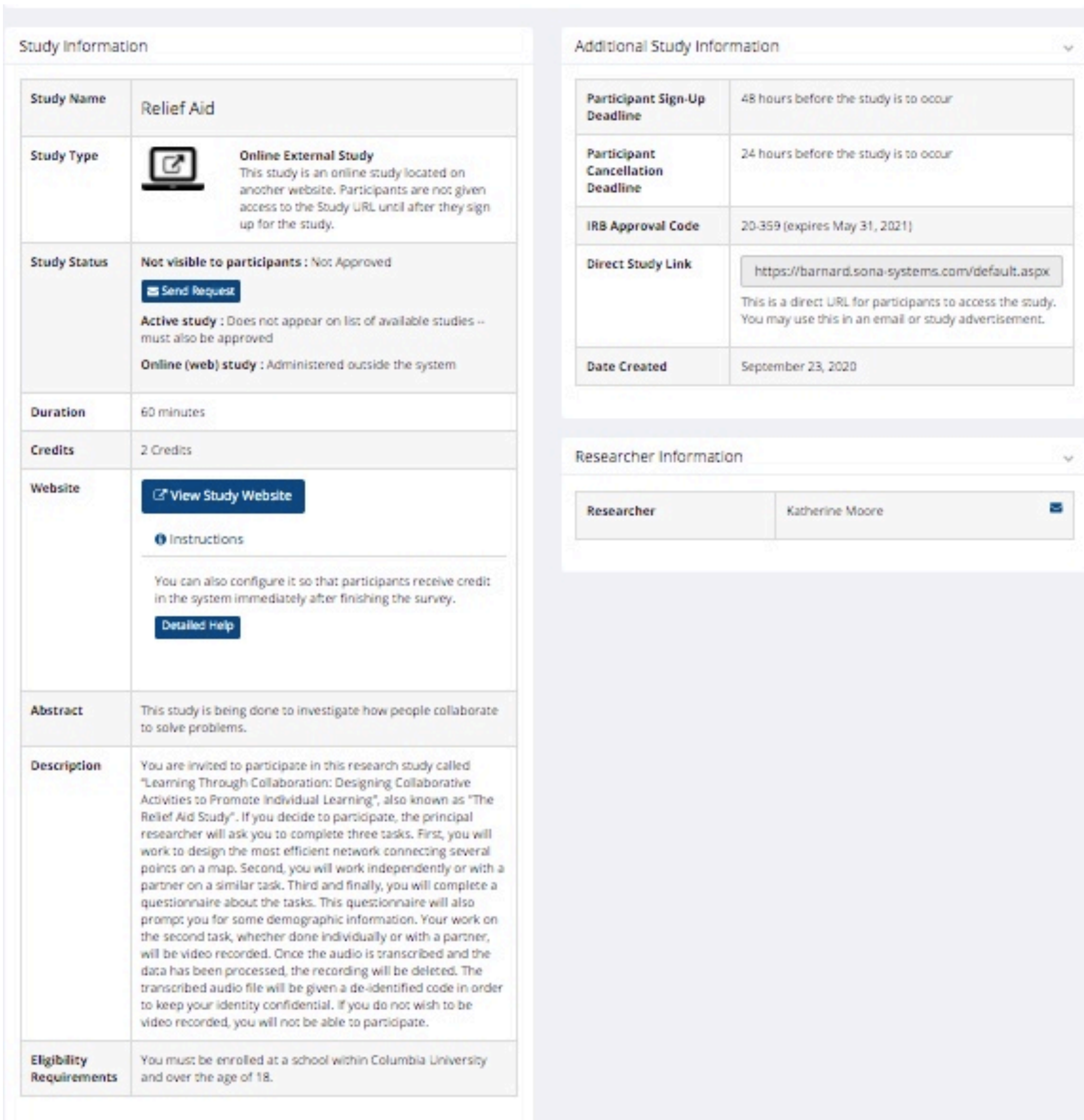


Figure K. Scree plot illustrating the cumulative proportion (%) of variance explained by each principal component in a PCA analysis of speech acts uttered by individuals using self-explanation.

Appendix B: Study Materials

Appendix B includes captioned images of recruitment materials, Consent Forms approved by the Teachers College Institutional Review Board, study session materials, study session scripts, and all communications with participants (i.e, emails).



Study Information

Study Name	Relief Aid
Study Type	**Online External Study** This study is an online study located on another website. Participants are not given access to the Study URL until after they sign up for the study.
Study Status	**Not visible to participants :** Not Approved Send Request **Active study :** Does not appear on list of available studies -- must also be approved **Online (web) study :** Administered outside the system
Duration	60 minutes
Credits	2 Credits
Website	View Study Website Instructions You can also configure it so that participants receive credit in the system immediately after finishing the survey. Detailed Help
Abstract	This study is being done to investigate how people collaborate to solve problems.
Description	You are invited to participate in this research study called "Learning Through Collaboration: Designing Collaborative Activities to Promote Individual Learning", also known as "The Relief Aid Study". If you decide to participate, the principal researcher will ask you to complete three tasks. First, you will work to design the most efficient network connecting several points on a map. Second, you will work independently or with a partner on a similar task. Third and finally, you will complete a questionnaire about the tasks. This questionnaire will also prompt you for some demographic information. Your work on the second task, whether done individually or with a partner, will be video recorded. Once the audio is transcribed and the data has been processed, the recording will be deleted. The transcribed audio file will be given a de-identified code in order to keep your identity confidential. If you do not wish to be video recorded, you will not be able to participate.
Eligibility Requirements	You must be enrolled at a school within Columbia University and over the age of 18.

Additional Study Information

Participant Sign-Up Deadline	48 hours before the study is to occur
Participant Cancellation Deadline	24 hours before the study is to occur
IRB Approval Code	20-359 (expires May 31, 2021)
Direct Study Link	https://barnard.sona-systems.com/default.aspx This is a direct URL for participants to access the study. You may use this in an email or study advertisement.
Date Created	September 23, 2020

Researcher Information

Researcher	Katherine Moore

Figure L. Website used to recruit participants and schedule study sessions, posted using the Barnard Psychology Research Participation System

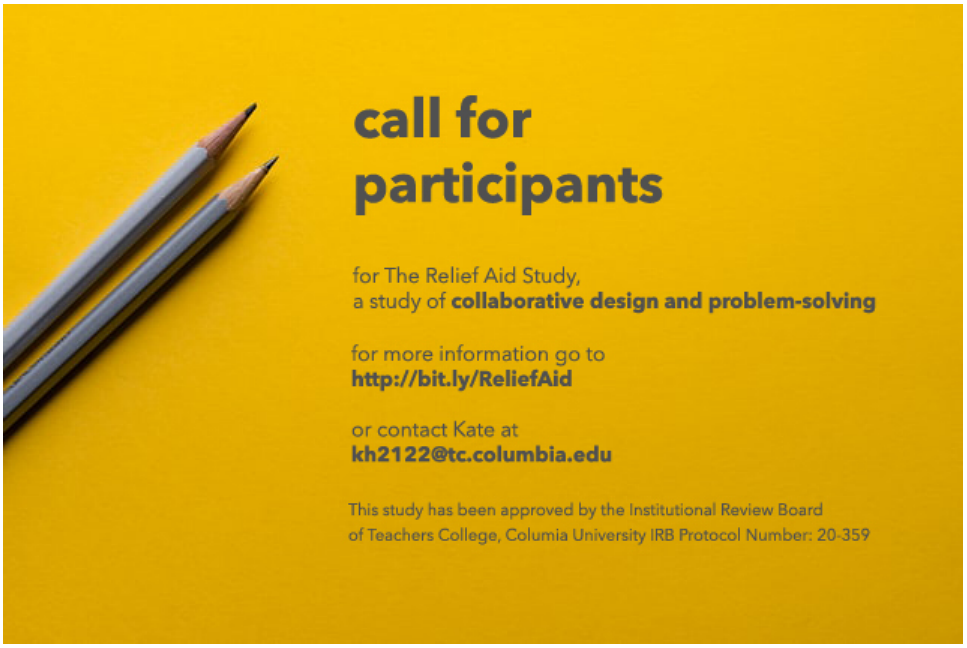
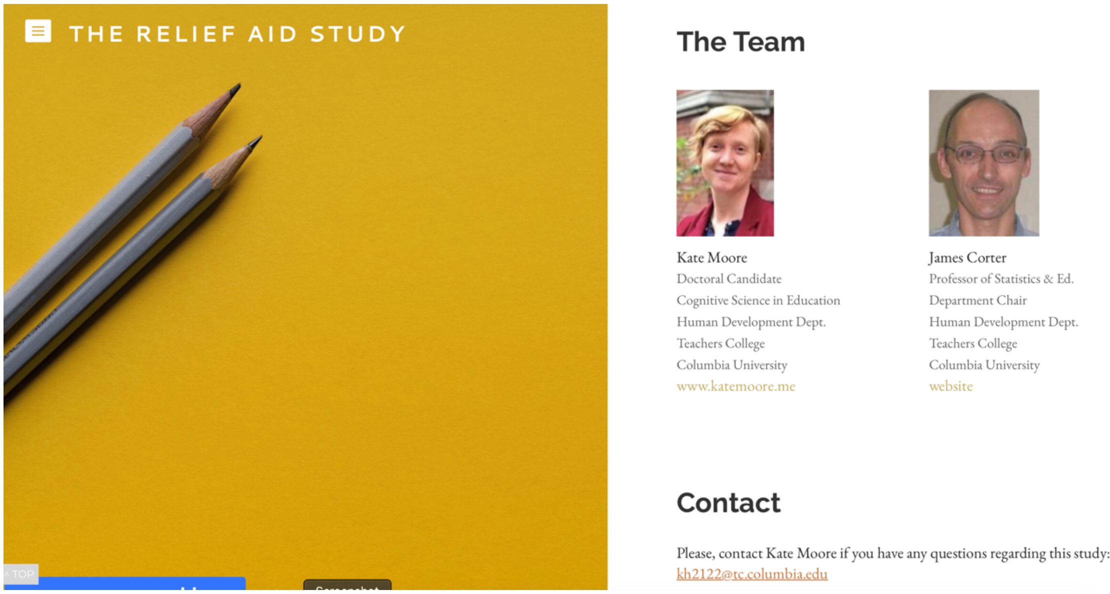


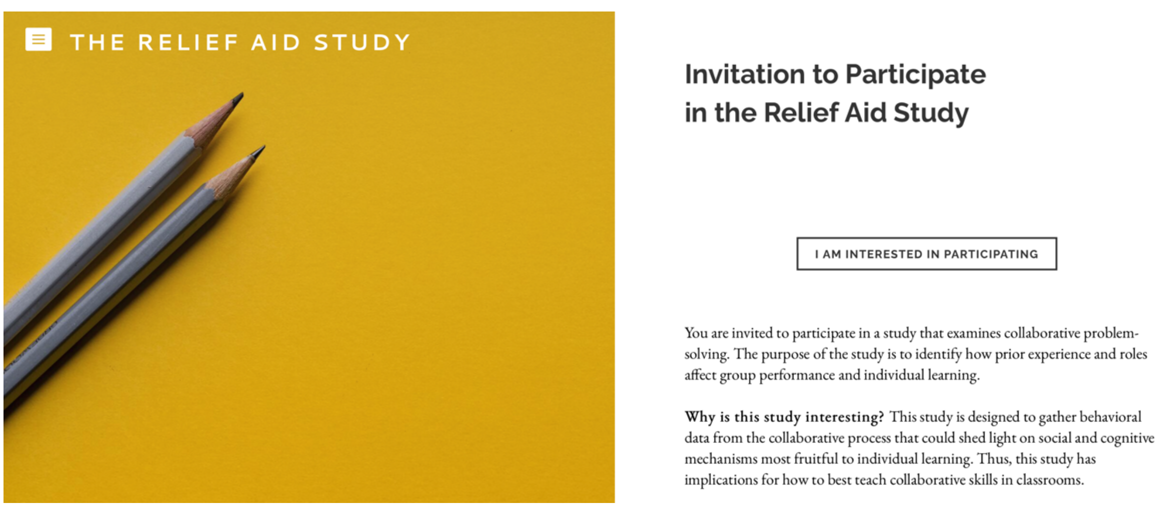
Figure M. Digital flyer used during recruitment.

A

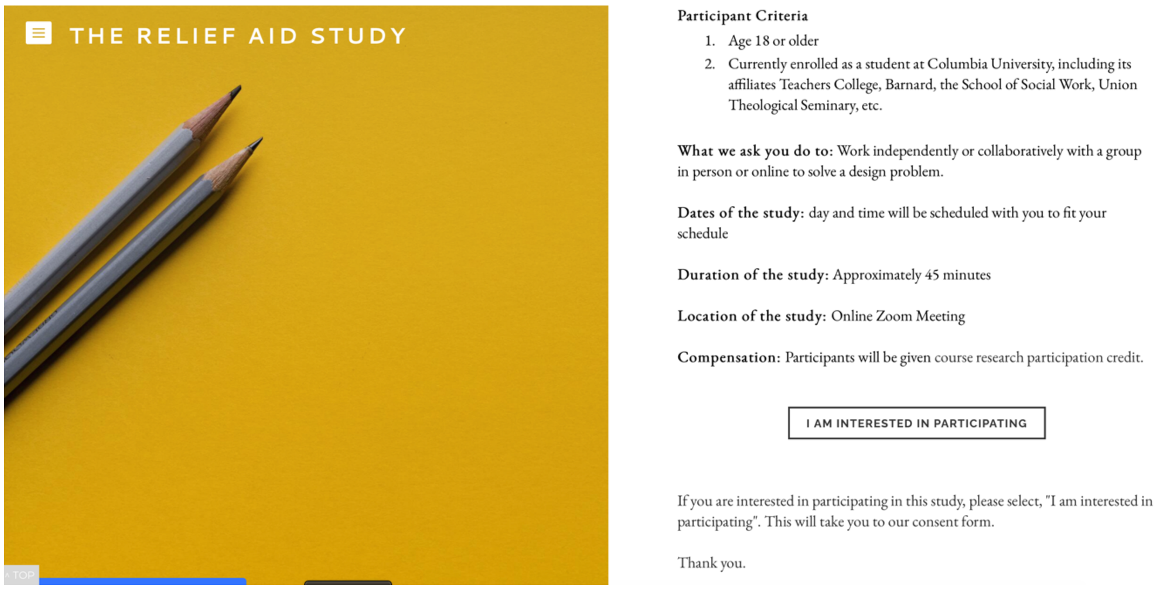


B

Figure N. Landing Page of website created to provide additional information about the research study for participants. Participants viewed A upon arriving at the site. When they scrolled down, B became visible. The link to this website was made available through the Barnard Psychology Research Participation System.

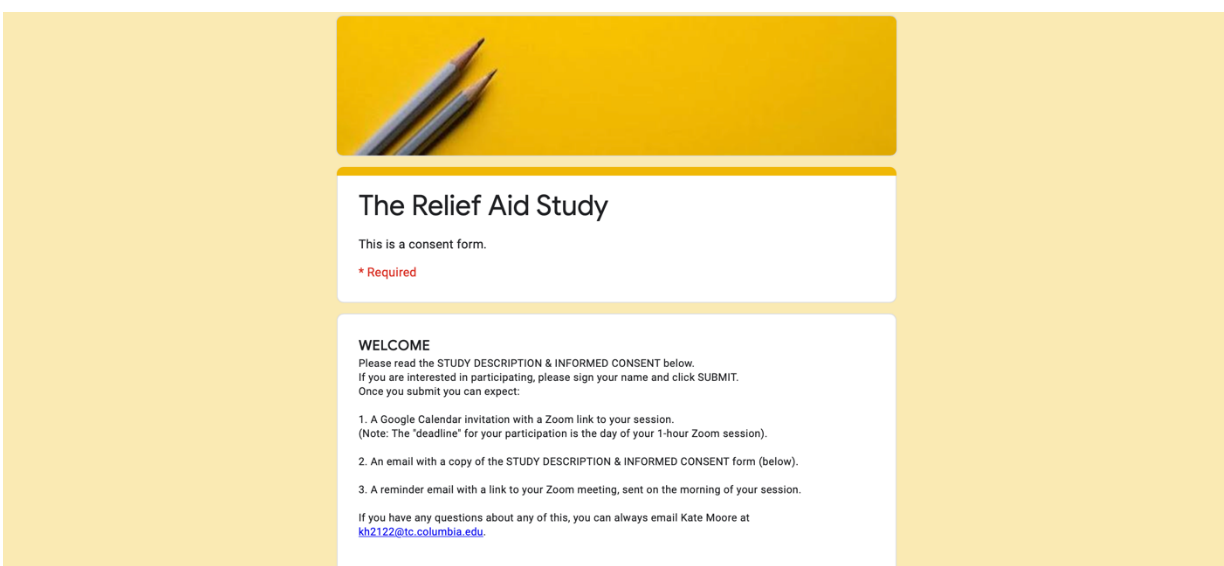


A

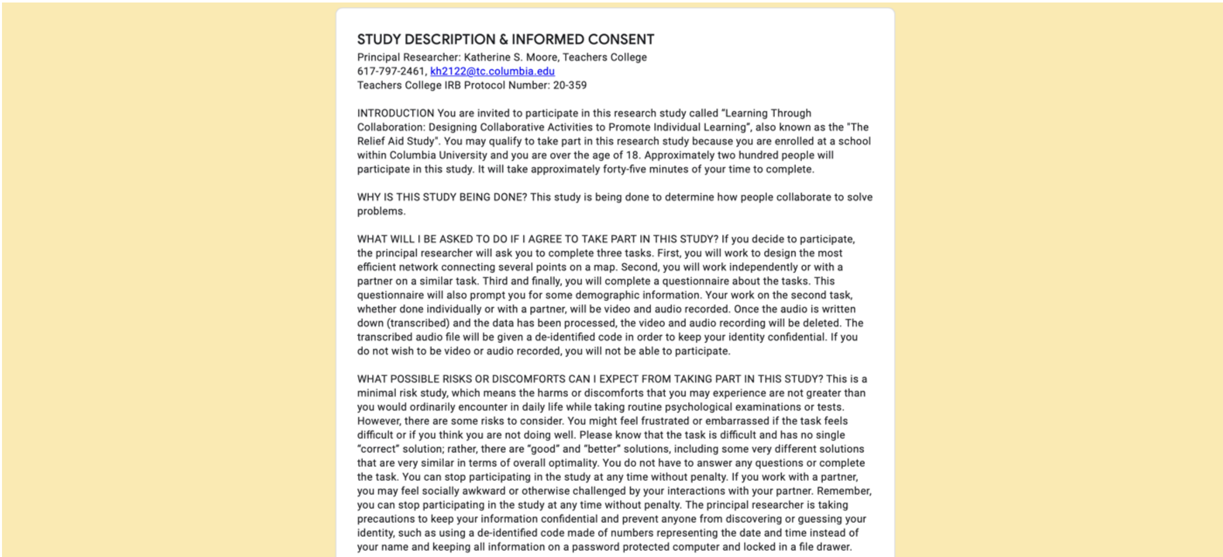


B

Figure O. Tertiary Page of website created to provide additional information about the research study for participants. Participants viewed A after clicking a button labeled "Participation" on the Landing Page. When they scrolled down, B became visible. The link to this website was made available through the Barnard Psychology Research Participation System.



A



STUDY DESCRIPTION & INFORMED CONSENT
Principal Researcher: Katherine S. Moore, Teachers College
617-797-2461, kh2122@tc.columbia.edu
Teachers College IRB Protocol Number: 20-359

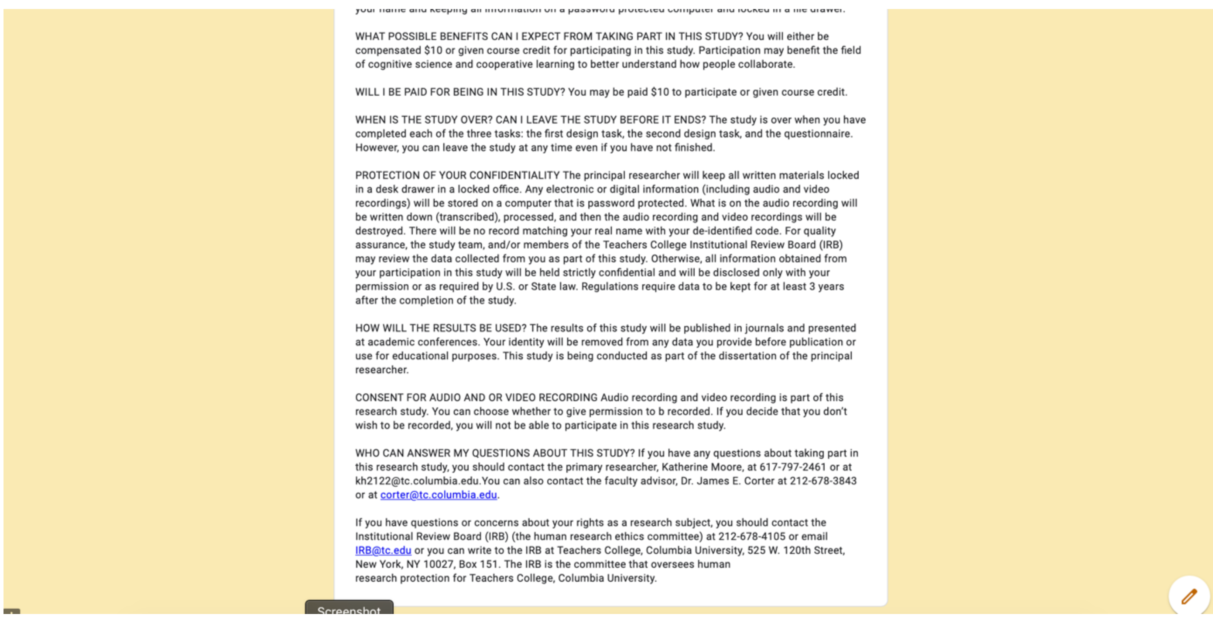
INTRODUCTION You are invited to participate in this research study called "Learning Through Collaboration: Designing Collaborative Activities to Promote Individual Learning", also known as the "The Relief Aid Study". You may qualify to take part in this research study because you are enrolled at a school within Columbia University and you are over the age of 18. Approximately two hundred people will participate in this study. It will take approximately forty-five minutes of your time to complete.

WHY IS THIS STUDY BEING DONE? This study is being done to determine how people collaborate to solve problems.

WHAT WILL I BE ASKED TO DO IF I AGREE TO TAKE PART IN THIS STUDY? If you decide to participate, the principal researcher will ask you to complete three tasks. First, you will work to design the most efficient network connecting several points on a map. Second, you will work independently or with a partner on a similar task. Third and finally, you will complete a questionnaire about the tasks. This questionnaire will also prompt you for some demographic information. Your work on the second task, whether done individually or with a partner, will be video and audio recorded. Once the audio is written down (transcribed) and the data has been processed, the video and audio recording will be deleted. The transcribed audio file will be given a de-identified code in order to keep your identity confidential. If you do not wish to be video or audio recorded, you will not be able to participate.

WHAT POSSIBLE RISKS OR DISCOMFORTS CAN I EXPECT FROM TAKING PART IN THIS STUDY? This is a minimal risk study, which means the harms or discomforts that you may experience are not greater than you would ordinarily encounter in daily life while taking routine psychological examinations or tests. However, there are some risks to consider. You might feel frustrated or embarrassed if the task feels difficult or if you think you are not doing well. Please know that the task is difficult and has no single "correct" solution; rather, there are "good" and "better" solutions, including some very different solutions that are very similar in terms of overall optimality. You do not have to answer any questions or complete the task. You can stop participating in the study at any time without penalty. If you work with a partner, you may feel socially awkward or otherwise challenged by your interactions with your partner. Remember, you can stop participating in the study at any time without penalty. The principal researcher is taking precautions to keep your information confidential and prevent anyone from discovering or guessing your identity, such as using a de-identified code made of numbers representing the date and time instead of your name and keeping all information on a password protected computer and locked in a file drawer.

B



your name and keeping all information on a password protected computer and locked in a file drawer.

WHAT POSSIBLE BENEFITS CAN I EXPECT FROM TAKING PART IN THIS STUDY? You will either be compensated $10 or given course credit for participating in this study. Participation may benefit the field of cognitive science and cooperative learning to better understand how people collaborate.

WILL I BE PAID FOR BEING IN THIS STUDY? You may be paid $10 to participate or given course credit.

WHEN IS THE STUDY OVER? CAN I LEAVE THE STUDY BEFORE IT ENDS? The study is over when you have completed each of the three tasks: the first design task, the second design task, and the questionnaire. However, you can leave the study at any time even if you have not finished.

PROTECTION OF YOUR CONFIDENTIALITY The principal researcher will keep all written materials locked in a desk drawer in a locked office. Any electronic or digital information (including audio and video recordings) will be stored on a computer that is password protected. What is on the audio recording will be written down (transcribed), processed, and then the audio recording and video recordings will be destroyed. There will be no record matching your real name with your de-identified code. For quality assurance, the study team, and/or members of the Teachers College Institutional Review Board (IRB) may review the data collected from you as part of this study. Otherwise, all information obtained from your participation in this study will be held strictly confidential and will be disclosed only with your permission or as required by U.S. or State law. Regulations require data to be kept for at least 3 years after the completion of the study.

HOW WILL THE RESULTS BE USED? The results of this study will be published in journals and presented at academic conferences. Your identity will be removed from any data you provide before publication or use for educational purposes. This study is being conducted as part of the dissertation of the principal researcher.

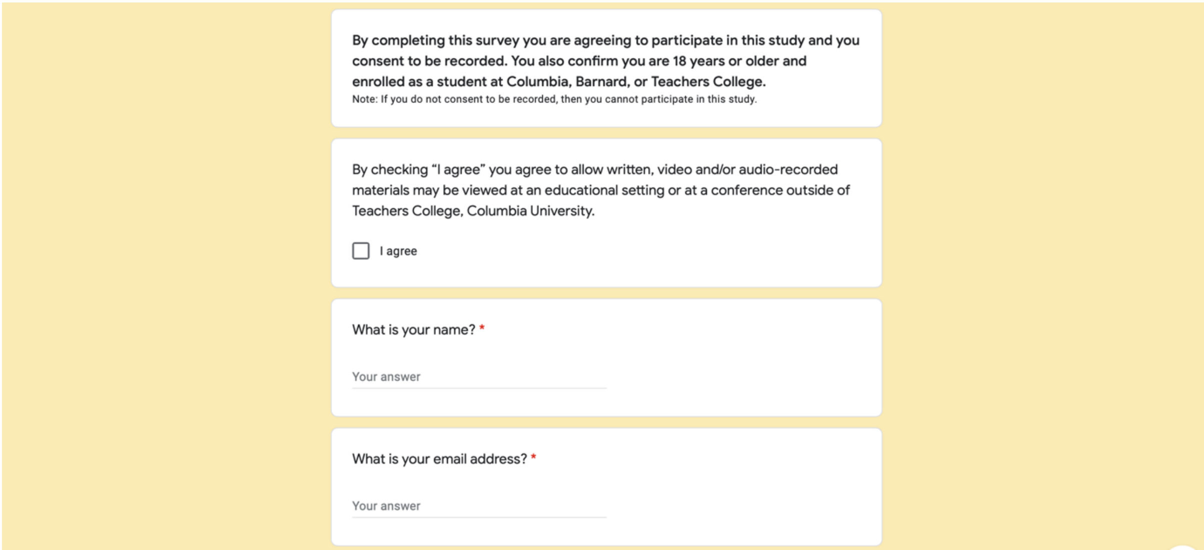
CONSENT FOR AUDIO AND OR VIDEO RECORDING Audio recording and video recording is part of this research study. You can choose whether to give permission to b recorded. If you decide that you don't wish to be recorded, you will not be able to participate in this research study.

WHO CAN ANSWER MY QUESTIONS ABOUT THIS STUDY? If you have any questions about taking part in this research study, you should contact the primary researcher, Katherine Moore, at 617-797-2461 or at kh2122@tc.columbia.edu.You can also contact the faculty advisor, Dr. James E. Corter at 212-678-3843 or at corter@tc.columbia.edu.

If you have questions or concerns about your rights as a research subject, you should contact the Institutional Review Board (IRB) (the human research ethics committee) at 212-678-4105 or email IRB@tc.edu or you can write to the IRB at Teachers College, Columbia University, 525 W. 120th Street, New York, NY 10027, Box 151. The IRB is the committee that oversees human research protection for Teachers College, Columbia University.

Screenshot

C



By completing this survey you are agreeing to participate in this study and you consent to be recorded. You also confirm you are 18 years or older and enrolled as a student at Columbia, Barnard, or Teachers College.
Note: If you do not consent to be recorded, then you cannot participate in this study.

By checking "I agree" you agree to allow written, video and/or audio-recorded materials may be viewed at an educational setting or at a conference outside of Teachers College, Columbia University.

☐ I agree

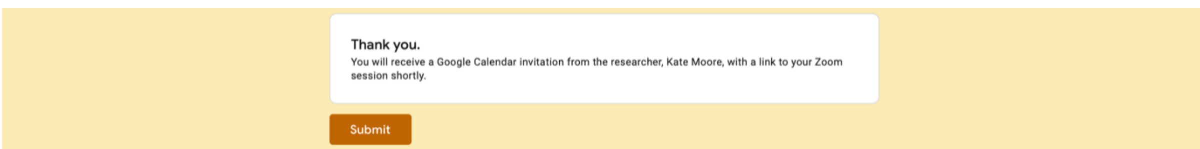
What is your name? *

Your answer

What is your email address? *

Your answer

D



Thank you.
You will receive a Google Calendar invitation from the researcher, Kate Moore, with a link to your Zoom session shortly.

Submit

E

Figure P. Digital Consent Form made available to participants through the Barnard Psychology Research Participation System. The Consent Form was also emailed to participants on an as needed basis.

Confirmation Email

Hello!

Thank you for your interest in participating in the Relief Aid study.

You should have just received a google calendar invitation with a Zoom link to your study session.

Let me know if you have any difficulty finding or accessing it.

Below, I have included a copy of the informed consent document along with your participant rights.

Feel free to review these documents at any time and save them in your records.

If you have not yet signed the consent form,

you can do so here: https://forms.gle/TpYQaUGNvkBR2QTG6

Let me know if you have any questions!

"See" you soon,

Kate Moore

Consent Forms

INFORMED CONSENT

Protocol Title: Learning Through Collaboration: Designing Collaborative Activities to Promote Individual Learning

Principal Researcher: Katherine S. Moore, Teachers College

617-797-2461, kh2122@tc.columbia.edu

INTRODUCTION You are invited to participate in this research study called "Learning Through Collaboration: Designing Collaborative Activities to Promote Individual Learning". You may qualify to take part in this research study because you are enrolled at a school within Columbia University and you are over the age of 18. Approximately two hundred people will participate in this study. It will take approximately forty-five minutes of your time to complete.

WHY IS THIS STUDY BEING DONE? This study is being done to determine how people collaborate to solve problems.

WHAT WILL I BE ASKED TO DO IF I AGREE TO TAKE PART IN THIS STUDY? If you decide to participate, the principal researcher will ask you to complete three tasks. First, you will work to design the most efficient network connecting several points on a map. Second, you will work independently or with a partner on a similar task. Third and finally, you will complete a questionnaire about the tasks. This questionnaire will also prompt you for some demographic information.

Your work on the second task, whether done individually or with a partner, will be video and audio recorded. Once the audio is written down (transcribed) and the data has been processed, the video and audio recording will be deleted. The transcribed audio file will be given a de-identified code in order to keep your identity confidential. If you do not wish to be video or audio recorded, you will not be able to participate.

WHAT POSSIBLE RISKS OR DISCOMFORTS CAN I EXPECT FROM TAKING PART IN THIS STUDY? This is a minimal risk study, which means the harms or discomforts that you may experience are not greater than you would ordinarily encounter in daily life while taking routine psychological examinations or tests. However, there are some risks to consider.

You might feel frustrated or embarrassed if the task feels difficult or if you think you are not doing well. Please know that the task is difficult and has no single "correct" solution; rather, there are "good" and "better" solutions, including some very different solutions that are very similar in terms of overall optimality. You do not have to answer any questions or complete the task. You can stop participating in the study at any time without penalty.

If you work with a partner, you may feel socially awkward or otherwise challenged by your interactions with your partner. Remember, you can stop participating in the study at any time without penalty.

The principal researcher is taking precautions to keep your information confidential and prevent anyone from discovering or guessing your identity, such as using a de-identified code made of numbers representing the date and time instead of your name and keeping all information on a password protected computer and locked in a file drawer.

WHAT POSSIBLE BENEFITS CAN I EXPECT FROM TAKING PART IN THIS STUDY?

You will be compensated $10 for participating in this study. Participation may benefit the field of cognitive science and cooperative learning to better understand how people collaborate.

WILL I BE PAID FOR BEING IN THIS STUDY? You will be paid $10 to participate.

WHEN IS THE STUDY OVER? CAN I LEAVE THE STUDY BEFORE IT ENDS? The study is over when you have completed each of the three tasks: the first design task, the second design task, and the questionnaire. However, you can leave the study at any time even if you have not finished.

PROTECTION OF YOUR CONFIDENTIALITY The principal researcher will keep all written materials locked in a desk drawer in a locked office. Any electronic or digital information (including audio and video recordings) will be stored on a computer that is password protected. What is on the audio recording will be written down (transcribed), processed, and then the audio recording and video recordings will be destroyed. There will be no record matching your real name with your de-identified code.

For quality assurance, the study team, and/or members of the Teachers College Institutional Review Board (IRB) may review the data collected from you as part of this study. Otherwise, all information obtained from your participation in this study will be held strictly confidential and will be disclosed only with your permission or as required by U.S. or State law.

HOW WILL THE RESULTS BE USED? The results of this study will be published in journals and presented at academic conferences. Your identity will be removed from any data you provide before publication or use for educational purposes. This study is being conducted as part of the dissertation of the principal researcher.

CONSENT FOR AUDIO AND OR VIDEO RECORDING Audio recording and video recording is part of this research study. You can choose whether to give permission to be recorded. If you decide that you don't wish to be recorded, you will not be able to participate in this research study.

WHO CAN ANSWER MY QUESTIONS ABOUT THIS STUDY?

If you have any questions about taking part in this research study, you should contact the primary researcher, Katherine Moore, at 617-797-2461 or at kh2122@tc.columbia.edu. You can also contact the faculty advisor, Dr. James E. Corter at 212-678-3843 or at corter@tc.columbia.edu.

If you have questions or concerns about your rights as a research subject, you should contact the Institutional Review Board (IRB) (the human research ethics committee) at 212-678-4105 or email IRB@tc.edu or you can write to the IRB at Teachers College, Columbia University, 525 W. 120th Street, New York, NY 10027, Box 151. The IRB is the committee that oversees human research protection for Teachers College, Columbia University.

PARTICIPANT'S RIGHTS

- I have read the Informed Consent Form and have been offered the opportunity to discuss the form with the researcher.
- I have had ample opportunity to ask questions about the purposes, procedures, risks and benefits regarding this research study.

- I understand that my participation is voluntary. I may refuse to participate or withdraw participation at any time without penalty.
- The researcher may withdraw me from the research at their professional discretion, for example, if the audio failed to capture sound or if the directions were not adhered to.
- If, during the course of the study, significant new information that has been developed becomes available which may relate to my willingness to continue my participation, the researcher will provide this information to me.
- Any information derived from the research study that personally identifies me will not be voluntarily released or disclosed without my separate consent, except as specifically required by law.
- Identifiers may be removed from the data. De-identified data may be used for future research studies, or distributed to another researcher for future research without additional informed consent from you (the research participant or the research participant's representative).
- I should receive a copy of the Informed Consent Form document.

Study Session Scripts

Distributed Experience (subtasks) with Roles Condition

Start.

When both participants have arrived in the Zoom meeting,

1. Follow the script (below) for introducing participants to the study and to Miro

Script for Introducing Participants to the Study & Miro

Welcome!

Let's get started. I am going to give you a brief introduction followed by an overview of the session, so you know what to expect. Then, we'll start. The entire experience should take about one hour. So we should be done by about [state time] EST. Ok? Great. A quick introduction. My name is Kate Moore. I am the principal researcher on this project and I am doing this study as part of my dissertation research. To give you a brief overview, the study is made up of three tasks: Task 1, Task 2, and Task 3. Task 2 will be recorded. I will let you know when the recording starts and stops. Once you've completed all three tasks you will see a link to a Post-Task Questionnaire. This questionnaire has 14 questions. Once you've answered all the questions and submitted the questionnaire, I can award you 2 credits through Barnard's Sona System. Do you have any questions about any of this? ** If they haven't signed the Consent Form yet: Informed Consent & Participant's Rights https://docs.google.com/forms/d/e/1FAIpQLSd0AOeXsWCTUgFY_-fkKryi3TYeTmUsMP0CYeeqYif3TpYxzA/viewform Great. One last thing to discuss before we start is the Informed Consent and Participant's Rights document. In the chat, I am posting a link to this form. Once you have signed this form, we can begin. ** Alright, now I am going to show you a short video that will explain how to use the online platform. The video is about 4 minutes. Afterwards, let me know if you have any questions.

2. Share my screen to show the **Miro training video**.

3. Share my screen to show the **Miro training board*****.***

Then say…

Do you have any questions about how to use the online platform or your Miro board?

Great. Now, let's talk about what you are going to be doing on this board. In the chat, I am about to post a link to a video in which I read the directions for your first task, Task 1. A few seconds later, I will post the link to your Miro board. I am also going to turn off your microphone and video so that you can't talk with each other while you work on your first task.

Task 1

4. In the chat, privately send…

Participant A's link to the *Task 1 Participant A (road) directions video:*	*Participant B's link to the* *Task 1 Participant B (route) directions video:*
Please click on this link to review your directions for Task 1. https://drive.google.com/file/d/1k1sQQEyK8DXJCxC2GU_LkzElrUR9VfPc/view?usp=sharing This is a video in which I read the task directions to you. The video is about 2.5 minutes. If you have any questions, type them into the chat. Once the video is over, check your chat again. I will send you a link to your Miro board, where you can begin Task 1.	Please click on this link to review your directions for Task 1. https://drive.google.com/file/d/1-xjDC95zHYf9PAuR17mdC03REqypyO3T/view?usp=sharing This is a video in which I read the task directions to you. The video is about 2.5 minutes. If you have any questions, type them into the chat. Once the video is

	over, check your chat again. I will send you a link to your Miro board, where you can begin Task 1.

5. After about 1 minute, privately send…

Participant A's link to the Task 1 Participant A board for road builders:	*Participant B's link to the Task 1 Participant B board for route builders:*
Here is the link to your Miro board for Task 1. https://miro.com/app/board/o9J_kn_Ze-Y=/?moveToWidget=3074457349703361644&cot=12 You have 15 minutes to complete this Task. If you finish early, type "I am done" into this chat. If your partner is also finished, I will end this task a little early, otherwise please wait until 15 minutes is up.	Here is the link to your Miro board for Task 1. https://miro.com/app/board/o9J_kn-mthk=/?moveToWidget=3074457349702973989&cot=12 You have 15 minutes to complete this Task. If you finish early, type "I am done" into this chat. If your partner is also finished, I will end this task a little early, otherwise please wait until 15 minutes is up.

When both participants have arrived in their respective Miro boards,

6. Start 15 min timer

7. After 10 min, send both participants a 5 minute warning

8. When their 15 minutes is up, change "Share" setting to "No Access" on their Miro boards

Task 2

Once "Share" settings have been changed to "No Access"…

Say…
Welcome back! You just completed Task 1. Onto Task 2! In this task, you will be working together so I will play the directions video on my screen for all of us to watch together. Afterwards, feel free to ask any questions.

9. Share my screen with the appropriate **Task 2 Map 2 directions video**:

*** Make sure you select to "share computer sound" when sharing your screen.

Then say…
Do you have any questions about Task 2?

Ok. Great. I am posting the link to your second Miro board in the chat. Please click on that link as soon as you see it. It will take you both to the same board.

10. In the chat, send both participants a link to Task 2 board:

Link to Task 2 Miro board

Here is the link to your second Miro board: https://miro.com/app/board/o9J_kn9t0mk=/?moveToWidget=3074457349708093607&cot=12 If you have any questions, say, “Kate, we have a question.”

Once both participants have arrived, say…

Welcome to the second design task. This one is collaborative, which means you can talk to each other to decide on the best solution together. Your work and conversation during this task will be video recorded. Once the task is complete, I will stop recording. Do you have any questions?

Then say…

Ok great. I am starting the recording. You have 15 minutes. You may begin!

11. Start 15 min timer
12. After 10 min, give participants a 5 minute warning
13. When their 15 minutes is up, change “Share” setting to “No Access” on their Miro boards

Post-task Questionnaire

Read this script….

Say…

That is 15 minutes. Your time is up. Onto Task 3! In this last task, you will be working independently again so please mute your microphones and turn off your camera / video. Great. I am posting the link to your third Miro board for Task 3 in the chat. Please click on that link as soon as you see it. There is no directions video.

14. In the chat, privately send each participant a link to their Task 3.

Participant A’s link to Task 3 Participant A Miro board:	*Participant B’s link to Task 3 Participant B Miro board:*
Here is the link to the last design task. https://miro.com/app/board/o9J_km9_Cdg=/?moveToWidget=3074457350635866123&cot=14 There are 5 parts. There is no time limit. Write any questions you have into the chat. You can find the link to the Post-Task Questionnaire on the far right.	Here is the link to the last design task. https://miro.com/app/board/o9J_khRwamI=/?moveToWidget=3074457351019171893&cot=12 There are 5 parts. There is no time limit. Write any questions you have into the chat. You can find the link to the Post-Task Questionnaire on the far right.

In case participants need a direct link, below is the link to the post-task questionnaire on Qualtrics:

https://tccolumbia.qualtrics.com/jfe/form/SV_8AqF9CbJS3xGbL7

Once a participant has arrived on their Task 3 Miro board,Then say…

Welcome to Task 3! This looks different from the first two tasks. The directions for each task are above, and the drawing space is below. These smaller design tasks may call on some of the skills or strategies that you developed during the previous two tasks. However, there is no time limit. You are not being recorded. You are working independently. In fact, once I have finished giving directions, you should feel free to leave the Zoom meeting if you like. The only reason to stay in the meeting now is to stay connected to the chat, so you can ask me questions if you need to. Once you have finished all 5 parts, click on the blue link on the far right of the design tasks. This will open a new tab with your Post-Task Questionnaire. Once you have answered all 14 questions and clicked "Submit" your study session is complete and I can award you 2 credits through the Sona system. Do you have any questions about this? Thank you for your time. It has been a pleasure working with you.

In case participants need a direct link, below is the link to the post-task questionnaire on Qualtrics:

https://tccolumbia.qualtrics.com/jfe/form/SV_8AqF9CbJS3xGbL7

Once participants have started their work…

Type into the chat…

Now that you have started Task 3, you are free to finish the rest of the study at your own pace. I will be here until the end of the hour in case you have any questions, but you are free to leave the meeting at any time. Once you submit the Post-Task Questionnaire, your participation in the study is complete and I will award you 2 credits through Barnard's Sona system. Thank you. Your time and insights are greatly appreciated.

Distributed Experience (subtasks) without Roles Condition

Start.

When both participants have arrived in the Zoom meeting,

15. Follow the script (below) for introducing participants to the study…

Script for Introducing Participants to the Study & Miro

Welcome!

Let's get started. I am going to give you a brief introduction followed by an overview of the session, so you know what to expect. Then, we'll start. The entire experience should take about one hour. So we should be done by about [state time] EST. Ok? Great. A quick introduction. My name is Kate Moore. I am the principal researcher on this project and I am doing this study as part of my dissertation research. To give you a brief overview, the study is made up of three tasks: Task 1, Task 2, and Task 3. Task 2 will be recorded. I will let you know when the recording starts and stops. Once you've completed all three tasks you will see a link to a Post-Task Questionnaire. This questionnaire has 14 questions. Once you've answered all the questions and submitted the questionnaire, I can award you 2 credits through Barnard's Sona System. Do you have any questions about any of this? ** If they haven't signed the Consent Form yet: Informed Consent & Participant's Rights https://docs.google.com/forms/d/e/1FAIpQLSd0AOeXsWCTUgFY_-fkKryi3TYeTmUsMP0CYeeqYif3TpYxzA/viewform Great. One last thing to discuss before we start is the Informed Consent and Participant's Rights document. In the chat, I am posting a link to this form. Once you have signed this form, we can begin. ** Alright, now I am going to show you a short video that will explain how to use the online platform. The video is about 4 minutes. Afterwards, let me know if you have any questions.

16. Share my screen to show the **Miro training video**.
17. Share my screen to show the **Miro training board**.

Then say…

Do you have any questions about how to use the online platform or your Miro board?

Great. Now, let's talk about what you are going to be doing on this board. In the chat, I am about to post a link to a video in which I read the directions for your first task, Task 1. A few seconds later, I will post the link to your Miro board. I am also going to turn off your microphone and video so that you can't talk with each other while you work on your first task.

Task 1

In the chat, privately send…

Participant A's link to the Task 1 Participant A (road) directions video:	*Participant B's link to the Task 1 Participant B (route) directions video:*
Please click on this link to view your directions for Task 1. https://drive.google.com/file/d/1k1sQQEyK8DXJCxC2GU_LkzElrUR9VfPc/view?usp=sharing This is a video in which I read the task directions to you. The video is about 2.5 minutes. If you have any questions, type them into the chat. Once the video is over, check your chat again. I will send you a link to your Miro board, where you can begin Task 1.	Please click on this link to view your directions for Task 1. https://drive.google.com/file/d/1-xjDC95zHYf9PAuR17mdC03REqypyO3T/view?usp=sharing This is a video in which I read the task directions to you. The video is about 2.5 minutes. If you have any questions, type them into the chat. Once the video is

	over, check your chat again. I will send you a link to your Miro board, where you can begin Task 1.

18. After about 1 minute, privately send…

Participant A's link to the Task 1 Participant A board for road builders:	*Participant B's link to the Task 1 Participant B board for route builders:*
Here is the link to your Miro board for Task 1. https://miro.com/app/board/o9J_kn_Ze-Y=/?moveToWidget=3074457349703361644&cot=12 You have 15 minutes to complete this Task. If you finish early, type "I am done" into this chat. If your partner is also finished, I will end this task a little early, otherwise please wait until 15 minutes is up.	Here is the link to your Miro board for Task 1. https://miro.com/app/board/o9J_kn-mthk=/?moveToWidget=3074457349702973989&cot=12 You have 15 minutes to complete this Task. If you finish early, type "I am done" into this chat. If your partner is also finished, I will end this task a little early, otherwise please wait until 15 minutes is up.

When both participants have arrived in their respective Miro boards,

19. Start 15 min timer

20. After 10 min, send both participants a 5 minute warning

21. When their 15 minutes is up, change "Share" setting to "No Access" on their Miro boards

Task 2

Once "Share" settings have been changed to "No Access"…

Say…

Welcome back! You just completed Task 1. Onto Task 2! In this task, you will be working together so I will play the directions video on my screen for all of us to watch together. Afterwards, feel free to ask any questions.

22. Share my screen with the appropriate **Task 2 Map 2 directions video**:

*** Make sure you select to "share computer sound" when sharing your screen.

Then say…

Do you have any questions about Task 2?

Ok. Great. I am posting the link to your second Miro board in the chat. Please click on that link as soon as you see it. It will take you both to the same board.

23. In the chat, send both participants a link to Task 2 board:

Link to Task 2 Miro board

Here is the link to your second Miro board: https://miro.com/app/board/o9J_kn9J4E0=/?moveToWidget=3074457349708055356&cot=12 If you have any questions, say, "Kate, we have a question."

Once both participants have arrived, say…

Welcome to the second design task. This one is collaborative, which means you can talk to each other to decide on the best solution together. Your work and conversation during this task will be video recorded. Once the task is complete, I will stop recording. Do you have any questions?

Then say…

Ok great. I am starting the recording. You have 15 minutes. You may begin!

24. Start 15 min timer

25. After 10 min, give participants a 5 minute warning

26. When their 15 minutes is up, change "Share" setting to "No Access" on their Miro boards

Post-task Questionnaire

Read this script….

Say…

That is 15 minutes. Your time is up. Onto Task 3! In this last task, you will be working independently again so please mute your microphones and turn off your camera / video. Great. I am posting the link to your third Miro board for Task 3 in the chat. Please click on that link as soon as you see it. There is no directions video.

27. In the chat, privately send each participant a link to their Task 3.

Participant A's link to Task 3 Participant A Miro board:	*Participant B's link to Task 3 Participant B Miro board:*
Here is the link to the last design task. https://miro.com/app/board/o9J_km9_Cdg=/?moveToWidget=3074457350635866123&cot=14 There are 5 parts. There is no time limit. Write any questions you have into the chat. You can find the link to the Post-Task Questionnaire on the far right.	Here is the link to the last design task. https://miro.com/app/board/o9J_khRwamI=/?moveToWidget=3074457351019171893&cot=12 There are 5 parts. There is no time limit. Write any questions you have into the chat. You can find the link to the Post-Task Questionnaire on the far right.

Then say…

Welcome to Task 3! This looks different from the first two tasks. The directions for each task are above, and the drawing space is below. These smaller design tasks may call on some of the skills or strategies that you

developed during the previous two tasks. However, there is no time limit. You are not being recorded. You are working independently. In fact, once I have finished giving directions, you should feel free to leave the Zoom meeting if you like. The only reason to stay in the meeting now is to stay connected to the chat, so you can ask me questions if you need to.
Once you have finished all 5 parts, click on the blue link on the far right of the design tasks. This will open a new tab with your Post-Task Questionnaire. Once you have answered all 14 questions and clicked "Submit" your study session is complete and I can award you 2 credits through the Sona system. Do you have any questions about this?
Thank you for your time. It has been a pleasure working with you.

In case participants need a direct link, below is the link to the post-task questionnaire on Qualtrics:

https://tccolumbia.qualtrics.com/jfe/form/SV_8AqF9CbJS3xGbL7

Once participants have started their work…

Type into the chat…

Now that you have started Task 3, you are free to finish the rest of the study at your own pace. I will be here until the end of the hour in case you have any questions, but you are free to leave the meeting at any time.
Once you submit the Post-Task Questionnaire, your participation in the study is complete and I will award you 2 credits through Barnard's Sona system.
Thank you. Your time and insights are greatly appreciated.

Joint Experience (no subtasks) with Roles Conditions

Start.

When both participants have arrived in the Zoom meeting,

28. Follow the script (below) for introducing participants to the study and to Miro

Script for Introducing Participants to the Study & Miro

Welcome!
Let's get started. I am going to give you a brief introduction followed by an overview of the session, so you know what to expect. Then, we'll start. The entire experience should take about one hour. So we should be done by about [state time] EST. Ok?
Great. A quick introduction. My name is Kate Moore. I am the principal researcher on this project and I am doing this study as part of my dissertation research.
To give you a brief overview, the study is made up of three tasks: Task 1, Task 2, and Task 3. Task 2 will be recorded. I will let you know when the recording starts and stops. Once you've completed all three tasks you will see a link to a Post-Task Questionnaire. This questionnaire has 14 questions. Once you've answered all the questions and submitted the questionnaire, I can award you 2 credits through Barnard's Sona System. Do you have any questions about any of this?
**
If they haven't signed the Consent Form yet:
Informed Consent & Participant's Rights

https://docs.google.com/forms/d/e/1FAIpQLSd0AOeXsWCTUgFY_-fkKryi3TYeTmUsMP0CYeeqYif3TpYxzA/viewform Great. One last thing to discuss before we start is the Informed Consent and Participant's Rights document. In the chat, I am posting a link to this form. Once you have signed this form, we can begin. ** Alright, now I am going to show you a short video that will explain how to use the online platform. The video is about 4 minutes. Afterwards, let me know if you have any questions.

29. Share my screen to show the **Miro training video**.

30. Share my screen to show the **Miro training board*****.***

Then say…

Do you have any questions about how to use Miro?

Great. Now, let's talk about what you are going to be doing on this board. In the chat, I am about to post a link to a video in which I read the directions for your first task, Task 1. A few seconds later, I will post the link to your Miro board. I am also going to turn off your microphone and video so that you can't talk with each other while you work on your first task.

Task 1

In the chat, privately send…

Participant A's link to the *Task 1 Participant A directions video:*	*Participant B's link to the* *Task 1 Participant B directions video:*
Please click on this link to review your directions for Task 1. https://drive.google.com/file/d/1_jfrB-PnHsGZ4oKSP31WmZjVPpkM20Zb/view?usp=sharing This is a video in which I read the task directions to you. The video is about 2.5 minutes. If you have any questions, type them into the chat. Once the video is over, check your chat again. I will send you a link to your Miro board, where you can begin Task 1.	Please click on this link to review your directions for Task 1. https://drive.google.com/file/d/1gNBV3rAt-rsr46NZoL3YyakkZa859iqq/view?usp=sharing This is a video in which I read the task directions to you. The video is about 2.5 minutes. If you have any questions, type them into the chat. Once the video is over, check your chat again. I will send you a link to your Miro board, where you can begin Task 1.

31. After about 1 minute, privately send…

Participant A's link to the *Task 1 Participant A board:*	*Participant B's link to the* *Task 1 Participant B board:*
Here is the link to your Miro board for Task 1. https://miro.com/app/board/o9J_knxnHqY=/?moveToWidget=3074457349703260558&cot=12 You have 15 minutes to complete this Task. If you finish early, type "I am done" into this chat. If your	Here is the link to your Miro board for Task 1. https://miro.com/app/board/o9J_kn_etWo=/?moveToWidget=3074457349703292876&cot=12 You have 15 minutes to complete this Task. If you finish early, type "I am done" into this chat. If your

partner is also finished, I will end this task a little early, otherwise please wait until 15 minutes is up.	partner is also finished, I will end this task a little early, otherwise please wait until 15 minutes is up.

When both participants have arrived in their respective Miro boards,

32. Start 15 min timer
33. After 10 min, send both participants a 2 minute warning
34. When their 15 minutes is up, change "Share" setting to "No Access" on their Miro boards

Task 2

When both participants have returned to the main meeting, welcome them back…

Say…

Welcome back! You just completed Task 1. Onto Task 2! In this task, you will be working together so I will play the directions video on my screen for all of us to watch together. Afterwards, feel free to ask any questions.

35. Share my screen with the appropriate **Task 2 Map 2 directions video**:

*** Make sure you select to "share computer sound" when sharing your screen.

Then say…

Do you have any questions about Task 2?

Ok. Great. I am posting the link to your second Miro board in the chat. Please click on that link as soon as you see it. It will take you both to the same board.

36. In the chat, send both participants a link to Task 2 board:

Link to Task 2 Miro board

Here is the link to your second Miro board: https://miro.com/app/board/o9J_kn9J4BY=/?moveToWidget=3074457349708060480&cot=12 If you have any questions, say, "Kate, we have a question."

Once both participants have arrived, say…

Welcome to the second design task. This one is collaborative, which means you can talk to each other to decide on the best solution together. Your work and conversation during this task will be video recorded. Once the task is complete, I will stop recording. Do you have any questions?

Then say…

Ok great. I am starting the recording. You may begin!

37. Start 15 min timer

38. After 10 min, give participants a 5 minute warning

39. When their 15 minutes is up, change "Share" setting to "No Access" on their Miro boards

Post-task Questionnaire

Read this script….

Say…

That is 15 minutes. Your time is up. Onto Task 3! In this last task, you will be working independently again so please mute your microphones and turn off your camera / video. Great. I am posting the link to your third Miro board for Task 3 in the chat. Please click on that link as soon as you see it. There is no directions video.

40. In the chat, privately send each participant a link to their Task 3.

Participant A's link to Task 3 Participant A Miro board:	*Participant B's link to Task 3 Participant B Miro board:*
Here is the link to the last design task. https://miro.com/app/board/o9J_km9_Cdg=/?moveToWidget=3074457350635866123&cot=14 There are 5 parts. There is no time limit. Write any questions you have into the chat. You can find the link to the Post-Task Questionnaire on the far right.	Here is the link to the last design task. https://miro.com/app/board/o9J_khRwamI=/?moveToWidget=3074457351019171893&cot=12 There are 5 parts. There is no time limit. Write any questions you have into the chat. You can find the link to the Post-Task Questionnaire on the far right.

Then say…

Welcome to Task 3! This looks different from the first two tasks. The directions for each task are above, and the drawing space is below. These smaller design tasks may call on some of the skills or strategies that you developed during the previous two tasks. However, there is no time limit. You are not being recorded. You are working independently. In fact, once I have finished giving directions, you should feel free to leave the Zoom meeting if you like. The only reason to stay in the meeting now is to stay connected to the chat, so you can ask me questions if you need to. Once you have finished all 5 parts, click on the blue link on the far right of the design tasks. This will open a new tab with your Post-Task Questionnaire. Once you have answered all 14 questions and clicked "Submit" your study session is complete and I can award you 2 credits through the Sona system. Do you have any questions about this? Thank you for your time. It has been a pleasure working with you.

In case participants need a direct link, below is the link to the post-task questionnaire on Qualtrics:

https://tccolumbia.qualtrics.com/jfe/form/SV_8AqF9CbJS3xGbL7

Once participants have started their work…

Type into the chat…

Now that you have started Task 3, you are free to finish the rest of the study at your own pace. I will be here until the end of the hour in case you have any questions, but you are free to leave the meeting at any time. Once you submit the Post-Task Questionnaire, your participation in the study is complete and I will award you 2 credits through Barnard's Sona system. Thank you. Your time and insights are greatly appreciated.

Joint Experience (no subtasks) without Roles Condition

Start.

When both participants have arrived in the Zoom meeting,

41. Follow the script (below) for introducing participants to the study and to Miro

Script for Introducing Participants to the Study & Miro

Welcome! Let's get started. I am going to give you a brief introduction followed by an overview of the session, so you know what to expect. Then, we'll start. The entire experience should take about one hour. So we should be done by about [state time] EST. Ok? Great. A quick introduction. My name is Kate Moore. I am the principal researcher on this project and I am doing this study as part of my dissertation research. To give you a brief overview, the study is made up of three tasks: Task 1, Task 2, and Task 3. Task 2 will be recorded. I will let you know when the recording starts and stops. Once you've completed all three tasks you will see a link to a Post-Task Questionnaire. This questionnaire has 14 questions. Once you've answered all the questions and submitted the questionnaire, I can award you 2 credits through Barnard's Sona System. Do you have any questions about any of this? ** If they haven't signed the Consent Form yet: Informed Consent & Participant's Rights https://docs.google.com/forms/d/e/1FAIpQLSd0AOeXsWCTUgFY_-fkKryi3TYeTmUsMP0CYeeqYif3TpYxzA/viewform Great. One last thing to discuss before we start is the Informed Consent and Participant's Rights document. In the chat, I am posting a link to this form. Once you have signed this form, we can begin. ** Alright, now I am going to show you a short video that will explain how to use the online platform. The video is about 4 minutes. Afterwards, let me know if you have any questions.

42. Share my screen to show the **Miro training video**.

43. Share my screen to show the **Miro training board*****.***

Then say…

Do you have any questions about how to use the online platform? I am going to be referring to it as your drawing board or just "your board".

Great. Now, let's talk about what you are going to be doing on this board. In the chat, I am about to post a link to a video in which I read the directions for your first task, Task 1. A few seconds later, I will post the link to your Miro board. I am also going to turn off your microphone and video so that you can't talk with each other while you work on your first task.

Task 1

44. In the chat, privately send…

Participant A's link to the Task 1 Participant A directions video:	*Participant B's link to the Task 1 Participant B directions video:*
Please click on this link to review your directions for Task 1. https://drive.google.com/file/d/1_jfrB-PnHsGZ4oKSP31WmZjVPpkM20Zb/view?usp=sharing This is a video in which I read the task directions to you. The video is about 2.5 minutes. If you have any questions, type them into the chat. Once the video is over, check your chat again. I will send you a link to your Miro board, where you can begin Task 1.	Please click on this link to review your directions for Task 1. https://drive.google.com/file/d/1gNBV3rAt-rsr46NZoL3YyakkZa859iqq/view?usp=sharing This is a video in which I read the task directions to you. The video is about 2.5 minutes. If you have any questions, type them into the chat. Once the video is over, check your chat again. I will send you a link to your Miro board, where you can begin Task 1.

45. After about 1 minute, privately send…

Participant A's link to the Task 1 Participant A board:	*Participant B's link to the Task 1 Participant B board:*
Here is the link to your Miro board for Task 1. https://miro.com/app/board/o9J_knxnHqY=/?moveToWidget=3074457349703260558&cot=12 You have 15 minutes to complete this Task. If you finish early, type "I am done" into this chat. If your partner is also finished, I will end this task a little early, otherwise please wait until 15 minutes is up.	Here is the link to your Miro board for Task 1. https://miro.com/app/board/o9J_kn_etWo=/?moveToWidget=3074457349703292876&cot=12 You have 15 minutes to complete this Task. If you finish early, type "I am done" into this chat. If your partner is also finished, I will end this task a little early, otherwise please wait until 15 minutes is up.

When both participants have arrived in their respective Miro boards,

46. Start 15 min timer

47. After 10 min, send both participants a 5 minute warning

48. When their 15 minutes is up, change "Share" setting to "No Access" on their Miro boards

Task 2

Once you have changed the "Settings" to "No Access", start Task 2…

Say…

Welcome back! You just completed Task 1. Onto Task 2! In this task, you will be working together so I will play the directions video on my screen for all of us to watch together. Afterwards, feel free to ask any questions.

49. Share my screen with the appropriate **Task 2 Map 2 directions video**:

*** Make sure you select to "share computer sound" when sharing your screen.

Then say…

Do you have any questions about Task 2?

Ok. Great. I am posting the link to your second Miro board for Task 2 in the chat. Please click on that link as soon as you see it. It will take you both to the same board.

50. In the chat, send both participants a link to Task 2 board:

Link to Task 2 Miro board

Here is the link to your second Miro board: https://miro.com/app/board/o9J_kn9ZM2k=/?moveToWidget=3074457349708088497&cot=12 If you have any questions, say, "Kate, we have a question."

Once both participants have arrived, say…

Welcome to the second design task. This one is collaborative, which means you can talk to each other to decide on the best solution together. Your work and conversation during this task will be video recorded. Once the task is complete, I will stop recording. Do you have any questions?

Then say…

Ok great. I am starting the recording. You have 15 minutes. You may begin!

51. Start 15 min timer

52. After 10 min, give participants a 5 minute warning

53. When their 15 minutes is up, change "Share" setting to "No Access" on their Miro boards

Post-task Questionnaire

Once you have changed the "Settings" to "No Access", start Task 3 / Post-Task Questionnaire…

Say…

That is 15 minutes. Your time is up. Onto Task 3! In this last task, you will be working independently again so please mute your microphones and turn off your camera / video. Great. I am posting the link to your third Miro board for Task 3 in the chat. Please click on that link as soon as you see it. There is no directions video.

54. In the chat, privately send each participant a link to their Task 3.

Participant A's link to Task 3 Participant A Miro board:	*Participant B's link to Task 3 Participant B Miro board:*
Here is the link to the last design task. https://miro.com/app/board/o9J_km9_Cdg=/?moveToWidget=3074457350635866123&cot=14 There are 5 parts. There is no time limit. Write any questions you have into the chat. You can find the link to the Post-Task Questionnaire on the far right.	Here is the link to the last design task. https://miro.com/app/board/o9J_khRwamI=/?moveToWidget=3074457351019171893&cot=12 There are 5 parts. There is no time limit. Write any questions you have into the chat. You can find the link to the Post-Task Questionnaire on the far right.

Then say…

Welcome to Task 3! I'm sure you have noticed that this looks different from the first two tasks. This has 5 smaller design tasks that prompt you to design small networks using some of the skills and strategies you may have developed while working on the passed two tasks. The directions are written above. The drawing space is below. There is no time limit to this part of the study session. You are also not being recorded. You are also working independently. Feel free to type any questions that you have into the Zoom chat. Once you have finished all 5 parts, click on the blue link on the far right. This will open a new tab with your Post-Task Questionnaire. There are 14 questions. Once you have answered all the questions and clicked "Submit" your study session is complete and I can award you 2 credits through the Sona system. Do you have any questions about this? Thank you for your time. It has been a pleasure working with you.

In case participants need a direct link, below is the link to the post-task questionnaire on Qualtrics:

https://tccolumbia.qualtrics.com/jfe/form/SV_8AqF9CbJS3xGbL7

Once participants have started their work…

Type into the chat…

Now that you have started Task 3, you are free to finish the rest of the study at your own pace. I will be here until the end of the hour in case you have any questions, but you are free to leave the meeting at any time.

Once you submit the Post-Task Questionnaire, your participation in the study is complete and I will award you 2 credits through Barnard's Sona system. Thank you. Your time and insights are greatly appreciated.

No Self Explanation

Start.

When both participants have arrived in the Zoom meeting,

55. Follow the script (below) for introducing participants to the study and to Miro

Script for Introducing Participants to the Study & Miro

Welcome! Let's get started. I am going to give you a brief introduction followed by an overview of the session, so you know what to expect. Then, we'll start. The entire experience should take about one hour. So we should be done by about [state time] EST. Ok? Great. A quick introduction. My name is Kate Moore. I am the principal researcher on this project and I am doing this study as part of my dissertation research. To give you a brief overview, the study is made up of three tasks: Task 1, Task 2, and Task 3. Task 2 will be recorded. I will let you know when the recording starts and stops. Once you've completed all three tasks you will see a link to a Post-Task Questionnaire. This questionnaire has 14 questions. Once you've answered all the questions and submitted the questionnaire, I can award you 2 credits through Barnard's Sona System. Do you have any questions about any of this? ** If they haven't signed the Consent Form yet: Informed Consent & Participant's Rights https://docs.google.com/forms/d/e/1FAIpQLSd0AOeXsWCTUgFY_-fkKryi3TYeTmUsMP0CYeeqYif3TpYxzA/viewform Great. One last thing to discuss before we start is the Informed Consent and Participant's Rights document. In the chat, I am posting a link to this form. Once you have signed this form, we can begin. ** Alright, now I am going to show you a short video that will explain how to use the online platform. The video is about 4 minutes. Afterwards, let me know if you have any questions.

56. Share my screen to show the **Miro training video**.

57. Share my screen to show the **Miro training board*.***

Then say…

Do you have any questions about how to use the online platform or your Miro board?

Great. Now, let's talk about what you are going to be doing on this board. In the chat, I am about to post a link to a video in which I read the directions for your first task, Task 1. A few seconds later, I will post the link to your Miro board. I am also going to turn off your microphone and video so that you can't talk with each other while you work on your first task.

Task 1

In the chat, privately send…

Participant A's link to the Task 1 Participant A directions video:	*Participant B's link to the Task 1 Participant B directions video:*
Please click on this link to review your directions for Task 1. https://drive.google.com/file/d/185v3lwGeFM47_7bECYvo1bvilkKQ85mu/view?usp=sharing This is a video in which I read the task directions to you. The video is about 2.5 minutes. If you have any questions, type them into the chat. Once the video is over, check your chat again. I will send you a link to your Miro board, where you can begin Task 1.	Please click on this link to review your directions for Task 1. https://drive.google.com/file/d/1mr4lgwZhh8Fr5-dcnr8Enn63rjxAemhY/view?usp=sharing This is a video in which I read the task directions to you. The video is about 2.5 minutes. If you have any questions, type them into the chat. Once the video is over, check your chat again. I will send you a link to your Miro board, where you can begin Task 1.

58. After about 1 minute, privately send…

Participant A's link to the Task 1 Participant A board:	*Participant B's link to the Task 1 Participant B board:*
Here is the link to your Miro board for Task 1. https://miro.com/app/board/o9J_kn-5EO4=/?moveToWidget=3074457349703331463&cot=12 You have 15 minutes to complete this Task. If you finish early, type "I am done" into this chat.	Here is the link to your Miro board for Task 1. https://miro.com/app/board/o9J_kn9ty-8=/?moveToWidget=3074457349703375366&cot=12 You have 15 minutes to complete this Task. If you finish early, type "I am done" into this chat.
If there are two people completing this condition together, add… If your partner is also finished, I will end this task a little early, otherwise please wait until 15 minutes is up.	

When both participants have arrived in their respective Miro boards,

59. Start 15 min timer
60. After 10 min, send both participants a 5 minute warning
61. When their 15 minutes is up, change "Share" setting to "No Access" on their Miro boards

Task 2

When both participants have returned to the main meeting, welcome them back…

Say…

Welcome back! You just completed Task 1. Onto Task 2! In this task, you will be working on a similar, but different task. This time, I will play the directions video on my screen for all of us to watch together. Afterwards, feel free to ask any questions.

62. Share my screen with the appropriate **Task 2 Map 2 directions video**:

Then say…

Do you have any questions about Task 2?

Ok. Great. In the chat, I am about to post the link to your second Miro board. Please make sure your microphone and video are off so that you can't talk with each other. You have 15 minutes to complete this task. If you finish early, you can let me know by typing "I'm done" into the chat. I will reply with a link to your third Miro board, Task 3, followed by the Post-Task Questionnaire. Do you have any questions about any of this? Thank you for your time. It has been a pleasure working with you.

63. In the chat, privately send both participants a link to their Task 2 boards:

Link to Participant A's Task 2 Miro board	*Link to Participant B's Task 2 Miro board*
Here is the link to your second Miro board: https://miro.com/app/board/o9J_kn8txsE=/?moveToWidget=3074457349708071440&cot=12 If you finish before the 15 minutes are up, type "I'm done" into this chat.	Here is the link to your second Miro board: https://miro.com/app/board/o9J_km2DFGM=/?moveToWidget=3074457349708131932&cot=12 If you finish before the 15 minutes are up, type "I'm done" into this chat.

64. Start 15 min timer

65. After 10 min, give participants a 5 minute warning

66. When their 15 minutes is up, change "Share" setting to "No Access" on their Miro boards

Post-task Questionnaire

Once either participant has finished Task 2 (or their 15 min is up), in the chat, privately send each participant a link to their post task questionnaire.

Participant A's link to Task 3 Participant A Miro board: *Participant B's link to Task 3 Participant B Miro board:*

That is 15 min. Your time to work on Task 2 is over.

Here is the link to the last design task. You can start working on it right away. https://miro.com/app/board/o9J_km9_Cdg=/?moveToWidget=3074457350013172443&cot=12 There are 5 parts. There is no time limit. Write any questions you have into the chat. You can find the link to the Post-Task Questionnaire on the far right.	Here is the link to the last design task. You can start working on it right away. https://miro.com/app/board/o9J_khRwamI=/?moveToWidget=3074457351019171893&cot=12 There are 5 parts. There is no time limit. Write any questions you have into the chat. You can find the link to the Post-Task Questionnaire on the far right.

In case participants need a direct link, below is the link to the post-task questionnaire on Qualtrics:

https://tccolumbia.qualtrics.com/jfe/form/SV_8AqF9CbJS3xGbL7

Once a participant has arrived on their Task 3 Miro board,

Type into the chat…

Now that you have started Task 3, you are free to finish the rest of the study at your own pace. I will be here until the end of the hour in case you have any questions, but you are free to leave the meeting at any time. Once you submit the Post-Task Questionnaire, your participation in the study is complete and I will award you 2 credits through Barnard's Sona system. Thank you. Your time and insights are greatly appreciated.

Self-Explanation

Start.

When the participant has arrived in the Zoom meeting,

67. Follow the script (below) for introducing them to the study and to Miro

Script for Introducing Participants to the Study & Miro

Welcome! I'm glad you could make it. My name is Kate Moore. I am the principal researcher on this project and I am doing this study as part of my dissertation research. I am going to walk you through each part of this study and answer any questions you have along the way. First, I'm going to show you how to use the online platform that you will use during your study session. Then, the study session will begin. The session is composed of 3 tasks followed by a post-task questionnaire. The entire experience should take one hour, so you can expect to be finished by the end of the hour [state time, EST]. Do you have any questions about any of this? Informed Consent & Participant's Rights https://docs.google.com/document/d/101FTIqeh35JSHUu9XnhvGKYHLG01abF4lpkB9OFjf9g/edit?usp=sharing Great. One last item to discuss before we start is the Informed Consent and Participant's Rights document. In the chat, I am posting a link to this document. You have already signed this and I emailed this to you a couple weeks ago, but I would like to give you an opportunity to ask any questions about it or review it one more time if you want to. Do you have any questions about it? Would you like to review before we start?

** If they haven't signed the Consent Form yet:
Informed Consent & Participant's Rights
https://docs.google.com/forms/d/e/1FAIpQLSd0AOeXsWCTUgFY_-fkKryi3TYeTmUsMP0CYeeqYif3TpYxzA/viewform
Great. One last item to discuss before we start is the Informed Consent and Participant's Rights document. In the chat, I am posting a link to this form. Once you have signed this form, we can begin.**
Alright, now I am going to show you a short video that will explain how to use the online platform. The video is about 4 minutes. Afterwards, let me know if you have any questions.

68. Share my screen to show the **Miro training video** on how to use Miro.

69. Share my screen to show the **Miro training board.**

Then say…

Do you have any questions about how to use the online platform or your Miro board?

Great. Now, let's talk about what you are going to be doing on this board. In the chat, I am about to post a link to a video in which I read the directions for your first task, Task 1. A few seconds later, I will post the link to your Miro board. I am also going to turn off your microphone and video so that you can't talk with each other while you work on your first task.

Task 1

70. In the chat, privately send…

Participant A's link to the
Task 1 Participant A directions video:

Please click on this link to review your directions for Task 1.
https://drive.google.com/file/d/185v3lwGeFM47_7bECYvo1bvilkKQ85mu/view?usp=sharing
This is a video in which I read the task directions to you. The video is about 2.5 minutes. If you have any questions, type them into the chat. Once the video is over, check your chat again. I will send you a link to your Miro board, where you can begin Task 1.

71. After about 1 minute, send…

Participant A's link to the
Task 1 Participant A board:

Here is the link to your Miro board for Task 1.
https://miro.com/app/board/o9J_kn-5EO4=/?moveToWidget=3074457349703331463&cot=12
You have 15 minutes to complete this Task. When you are finished, say "I am done" or type it into the chat.

When the participant has arrived in their respective Miro boards,

72. Start 15 min timer

73. After 10 min, give a 5 min warning

74. When their 15 minutes is up, change "Share" setting to "No Access" on their Miro boards

Task 2

Participant A has finished Task 1 (or when 15 min is up), say…

Say…

That is 15 minutes. Your time is up. You just completed Task 1. Onto Task 2! This time, I will play the directions video on my screen for us to watch together. Afterwards, feel free to ask any questions.

75. Share my screen with the appropriate **Task 2 Map 2 directions video**:

Then say…

Do you have any questions about Task 2? Remember, during this task you are "explaining what you are doing and thinking out loud as you work." Do you have any questions about this? Ok. Great. I am going to post a link to your second Miro board in the chat. Please click on that link as soon as you see it. Once you arrive, I will start recording. I will stop recording once you finish this second task. Let me know you are finished by saying, "I am done."

76. In the chat, privately send Participant A a link to their Task 2 boards

Link to Participant A's Task 2 Miro board

Here is the link to your second Miro board: https://miro.com/app/board/o9J_kn82ev8=/?moveToWidget=3074457349708137994&cot=12 If you have any questions, say "Kate, I have a question."

77. Start 15 min timer

78. After 10 min, give Participant A a 5 minute warning

79. When their 15 minutes is up, change "Share" setting to "No Access" on their Miro boards

Post-task Questionnaire

80. Participant A has finished Task 2 (or 15 min has passed), say…

Say…

That is 15 minutes. Your time is up. Onto Task 3! Great. I am posting the link to your third Miro board for Task 3 in the chat. Please click on that link as soon as you see it. There is no directions video.

81. In the chat, privately send each participant a link to their Task 3.

Participant A's link to the Task 3 Participant A Miro board:

Here is the link to the last design task. https://miro.com/app/board/o9J_km9_Cdg=/?moveToWidget=3074457350635866123&cot=12 There are 5 parts. There is no time limit. Feel free to ask any questions that you have out loud. You can find the link to the Post-Task Questionnaire on the far right.

Then say…

Welcome to Task 3! I'm sure you have noticed that this looks different from the first two tasks. This has 5 smaller design tasks that prompt you to design small networks using some of the skills and strategies you may have developed while working on the passed two tasks. The directions are written above. The drawing space is below. There is no time limit to this part of the study session. You are also not being recorded. You are also working independently. Feel free to type any questions that you have into the Zoom chat. Once you have finished all 5 parts, click on the blue link on the far right. This will open a new tab with your Post-Task Questionnaire. There are 8 questions. Once you have answered all the questions and clicked "Submit" your study session is complete and I can award you 2 credits through the Sona system. Do you have any questions about this? Thank you for your time. It has been a pleasure working with you.

In case participants need a direct link, below is the link to the post-task questionnaire on Qualtrics:

https://tccolumbia.qualtrics.com/jfe/form/SV_8AqF9CbJS3xGbL7

Once a participant has arrived on their Task 3 Miro board,

Type into the chat…

Now that you have started Task 3, you are free to finish the rest of the study at your own pace. I will be here until the end of the hour in case you have any questions, but you are free to leave the meeting at any time. Once you submit the Post-Task Questionnaire, your participation in the study is complete and I will award you 2 credits through Barnard's Sona system.

Thank you. Your time and insights are greatly appreciated.

Thank you Email

Thank you for your participation in the Relief Aid Study.

Your time, work, and insights are very much appreciated.

I have just awarded you 2 credits through Barnard's Sona system.

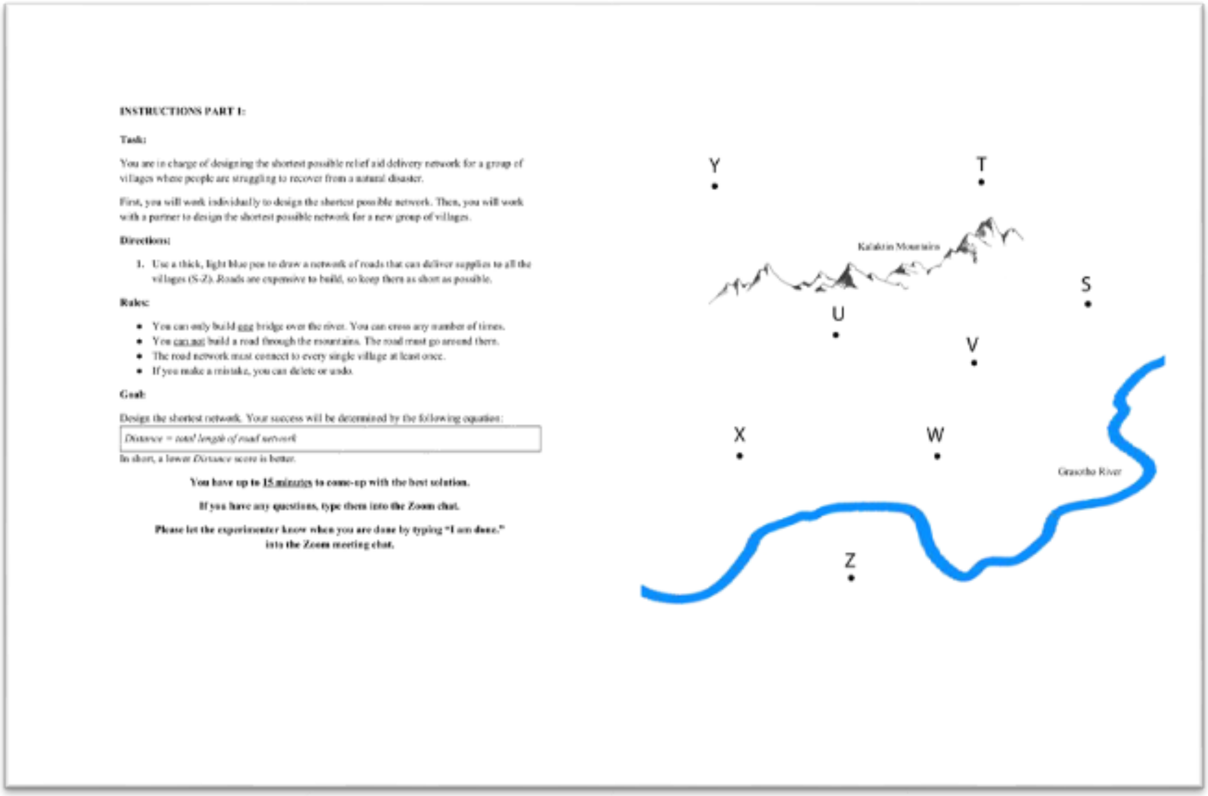
Please let me know if you have any questions about the study or if any issues arise with the award of credits.

Lastly, if you are interested in providing feedback on this study, please use **this link**.

Your feedback is greatly appreciated.

Best regards and be well,

Kate



INSTRUCTIONS PART 1:

Task:

You are in charge of designing the shortest possible relief aid delivery network for a group of villages where people are struggling to recover from a natural disaster.

First, you will work individually to design the shortest possible network. Then, you will work with a partner to design the shortest possible network for a new group of villages.

Directions:

1. Use a thick, light blue pen to draw a network of roads that can deliver supplies to all the villages (S-Z). *Roads are expensive to build, so keep them as short as possible.*

Rules:

- You can only build one bridge over the river. You can cross any number of times.
- You can not build a road through the mountains. The road must go around them.
- The road network must connect to every single village at least once.
- If you make a mistake, you can delete or undo.

Goal:

Design the shortest network. Your success will be determined by the following equation:

Distance = total length of road network

In short, a lower *Distance* score is better.

You have up to 15 minutes to come-up with the best solution.

If you have any questions, type them into the Zoom chat.

Please let the experimenter know when you are done by typing "I am done." into the Zoom meeting chat.

Figure Q. Task directions and map for Participant A's first task (the training task) when assigned to the both the Distributed Experience without Roles condition (DW) and the Distributed Experience with Roles condition (DR).

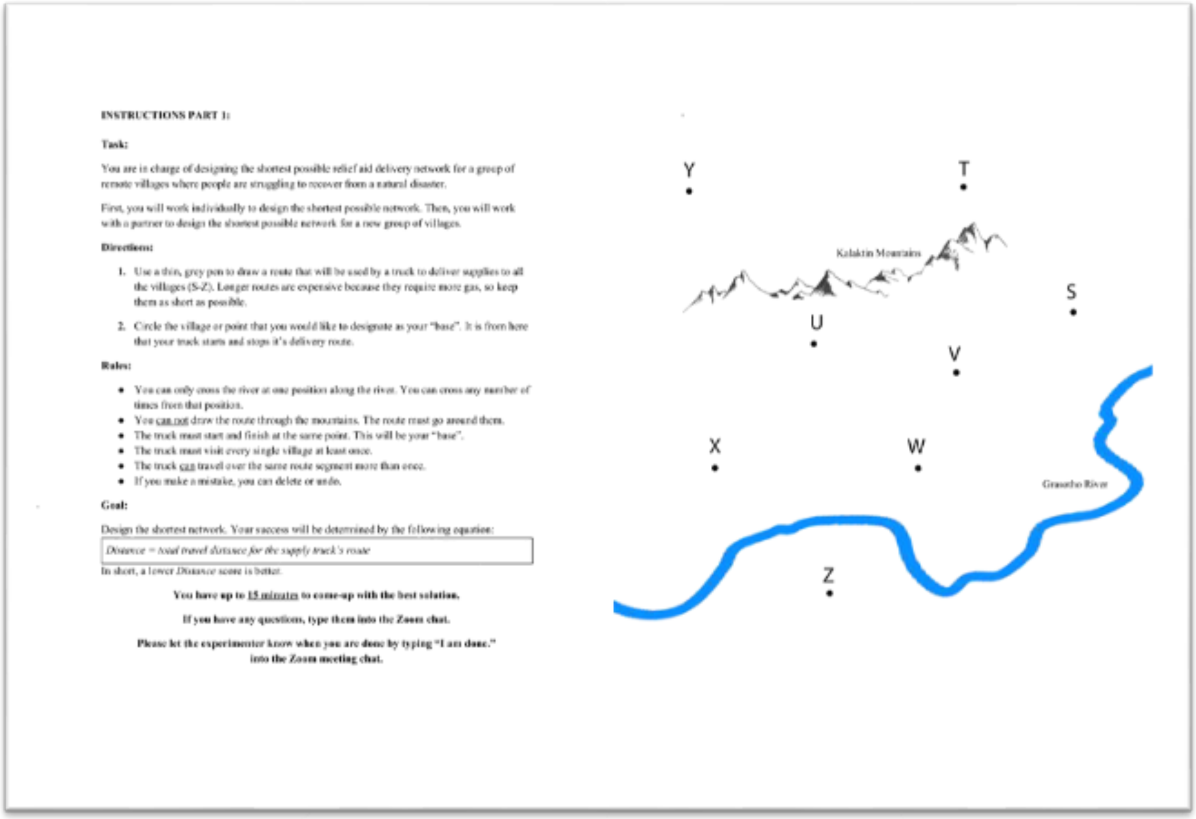


Figure R. Task directions and map for Participant B's first task (the training task) when assigned to the both the Distributed Experience without Roles condition (DW) and the Distributed Experience with Roles condition (DR).

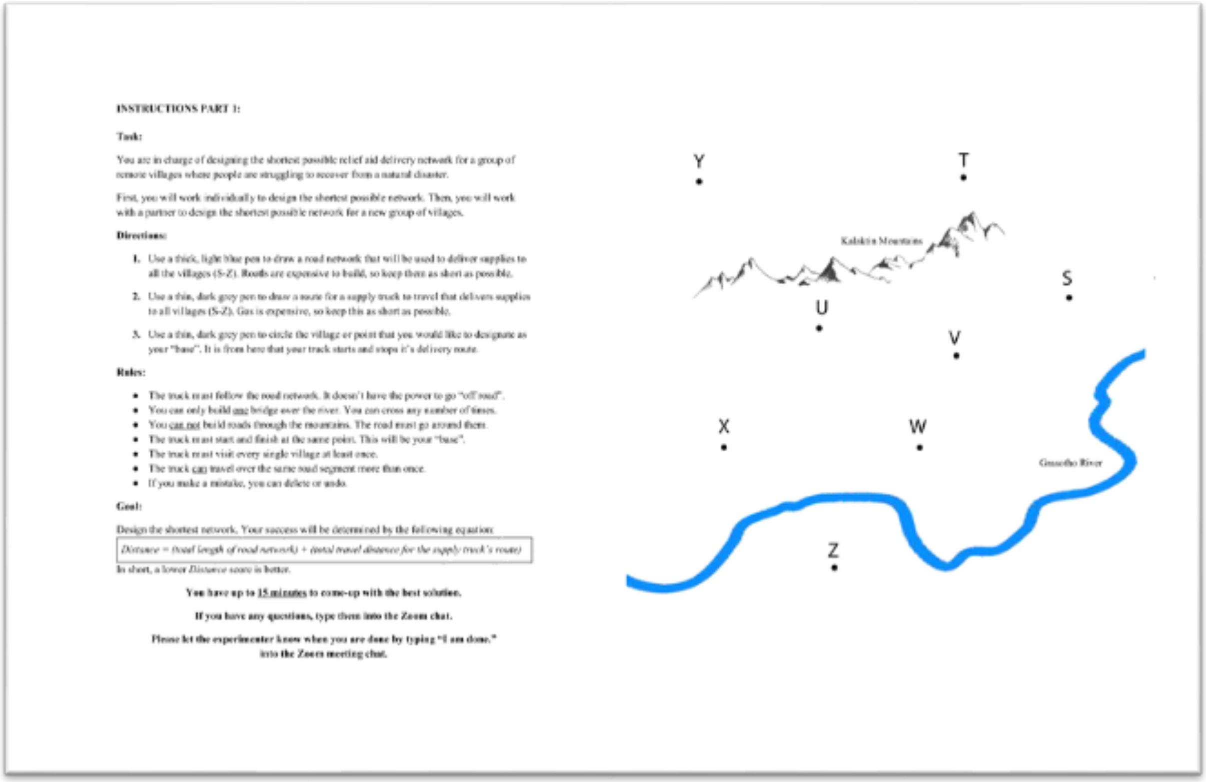
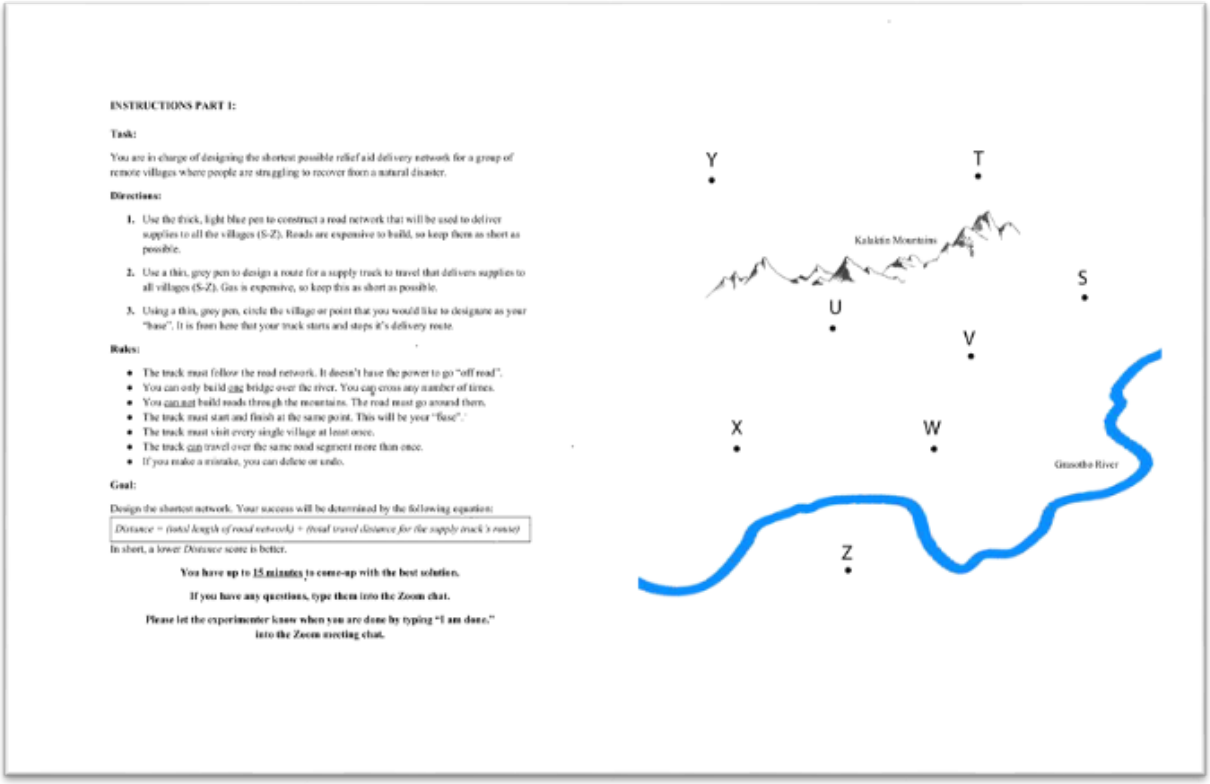


Figure S. Task directions and map for Participant A and B's first task (the training task) when assigned to the both the Joint Experience without Roles condition (JW) and the Joint Experience with Roles condition (JR).



INSTRUCTIONS PART 1:

Task:

You are in charge of designing the shortest possible relief aid delivery network for a group of remote villages where people are struggling to recover from a natural disaster.

Directions:

1. Use the thick, light blue pen to construct a road network that will be used to deliver supplies to all the villages (S-Z). Roads are expensive to build, so keep them as short as possible.
2. Use a thin, grey pen to design a route for a supply truck to travel that delivers supplies to all villages (S-Z). Gas is expensive, so keep this as short as possible.
3. Using a thin, grey pen, circle the village or point that you would like to designate as your "base". It is from here that your truck starts and stops it's delivery route.

Rules:

- The truck must follow the road network. It doesn't have the power to go "off road".
- You can only build one bridge over the river. You can cross any number of times.
- You can not build roads through the mountains. The road must go around them.
- The truck must start and finish at the same point. This will be your "base".
- The truck must visit every single village at least once.
- The truck can travel over the same road segment more than once.
- If you make a mistake, you can delete or undo.

Goal:

Design the shortest network. Your success will be determined by the following equation:

Distance = (total length of road network) + (total travel distance for the supply truck's route)

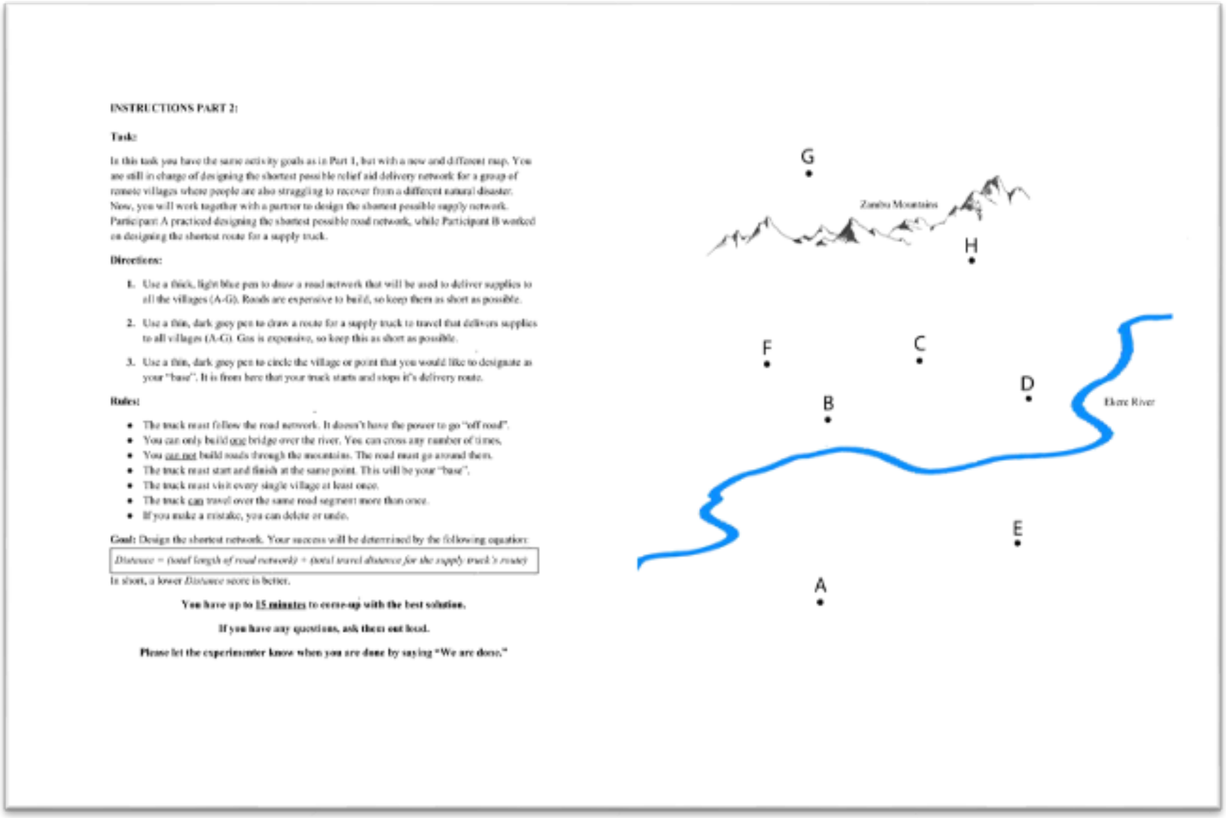
In short, a lower *Distance* score is better.

You have up to 15 minutes to come-up with the best solution.

If you have any questions, type them into the Zoom chat.

Please let the experimenter know when you are done by typing "I am done." into the Zoom meeting chat.

Figure T. Task directions and map for Participant A and B's first task (the training task) when assigned to the Individual without Self-Explanation condition (IW) or the Individual with Self-Explanation condition (IE).



INSTRUCTIONS PART 2:

Task:

In this task you have the same activity goals as in Part 1, but with a new and different map. You are still in charge of designing the shortest possible relief aid delivery network for a group of remote villages where people are also struggling to recover from a different natural disaster. Now, you will work together with a partner to design the shortest possible supply network. Participant A practiced designing the shortest possible road network, while Participant B worked on designing the shortest route for a supply truck.

Directions:

1. Use a thick, light blue pen to draw a road network that will be used to deliver supplies to all the villages (A-G). Roads are expensive to build, so keep them as short as possible.
2. Use a thin, dark grey pen to draw a route for a supply truck to travel that delivers supplies to all villages (A-G). Gas is expensive, so keep this as short as possible.
3. Use a thin, dark grey pen to circle the village or point that you would like to designate as your "base". It is from here that your truck starts and stops it's delivery route.

Rules:

- The truck must follow the road network. It doesn't have the power to go "off road".
- You can only build one bridge over the river. You can cross any number of times.
- You can not build roads through the mountains. The road must go around them.
- The truck must start and finish at the same point. This will be your "base".
- The truck must visit every single village at least once.
- The truck can travel over the same road segment more than once.
- If you make a mistake, you can delete or undo.

Goal: Design the shortest network. Your success will be determined by the following equation:

Distance = (total length of road network) + (total travel distance for the supply truck's route)

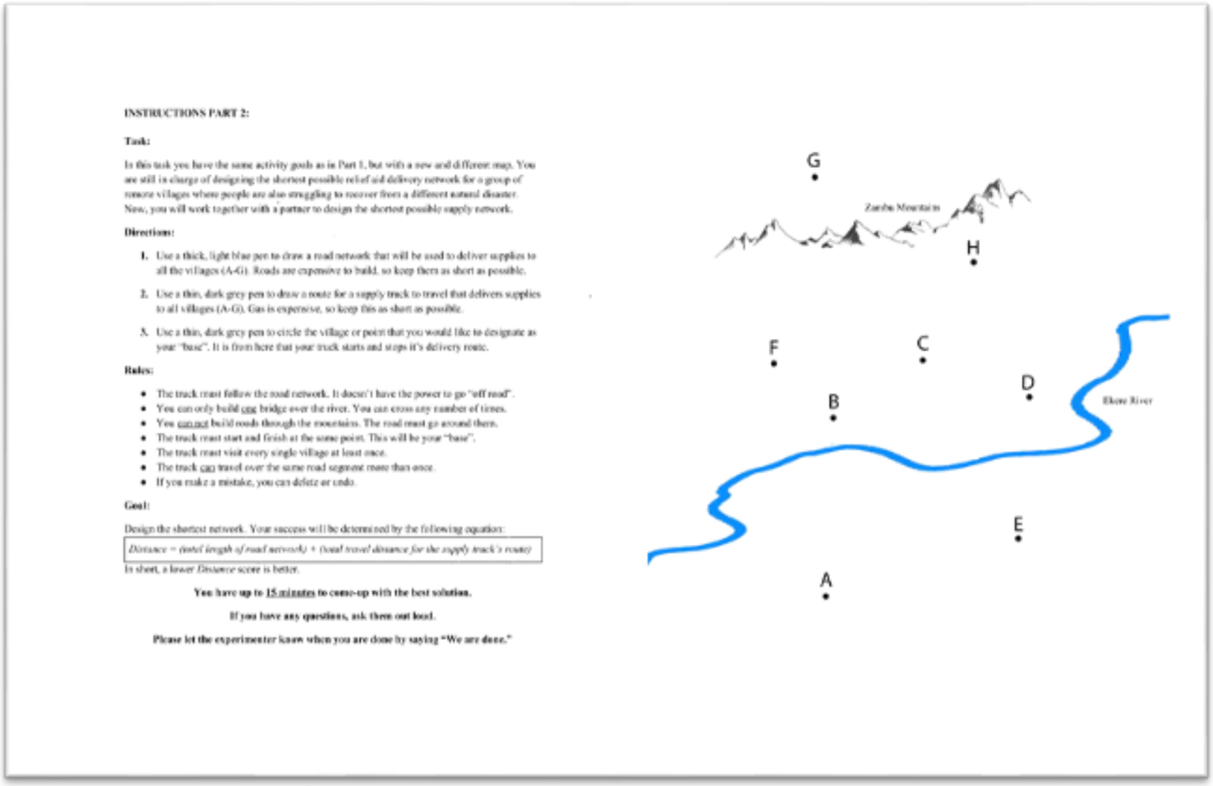
In short, a lower *Distance* score is better.

You have up to 15 minutes to come-up with the best solution.

If you have any questions, ask them out loud.

Please let the experimenter know when you are done by saying "We are done."

Figure U. Task directions and map for Participant A and B's second task (the main task) when assigned to the Distributed Experience with Roles condition (DR).



INSTRUCTIONS PART 2:

Task:

In this task you have the same activity goals as in Part 1, but with a new and different map. You are still in charge of designing the shortest possible relief aid delivery network for a group of remote villages where people are also struggling to recover from a different natural disaster. Now, you will work together with a partner to design the shortest possible supply network.

Directions:

1. Use a thick, light blue pen to draw a road network that will be used to deliver supplies to all the villages (A-G). Roads are expensive to build, so keep them as short as possible.
2. Use a thin, dark grey pen to draw a route for a supply truck to travel that delivers supplies to all villages (A-G). Gas is expensive, so keep this as short as possible.
3. Use a thin, dark grey pen to circle the village or point that you would like to designate as your "base". It is from here that your truck starts and stops it's delivery route.

Rules:

- The truck must follow the road network. It doesn't have the power to go "off road".
- You can only build one bridge over the river. You can cross any number of times.
- You can not build roads through the mountains. The road must go around them.
- The truck must start and finish at the same point. This will be your "base".
- The truck must visit every single village at least once.
- The truck can travel over the same road segment more than once.
- If you make a mistake, you can delete or undo.

Goal:

Design the shortest network. Your success will be determined by the following equation:

Distance = (total length of road network) + (total travel distance for the supply truck's route)

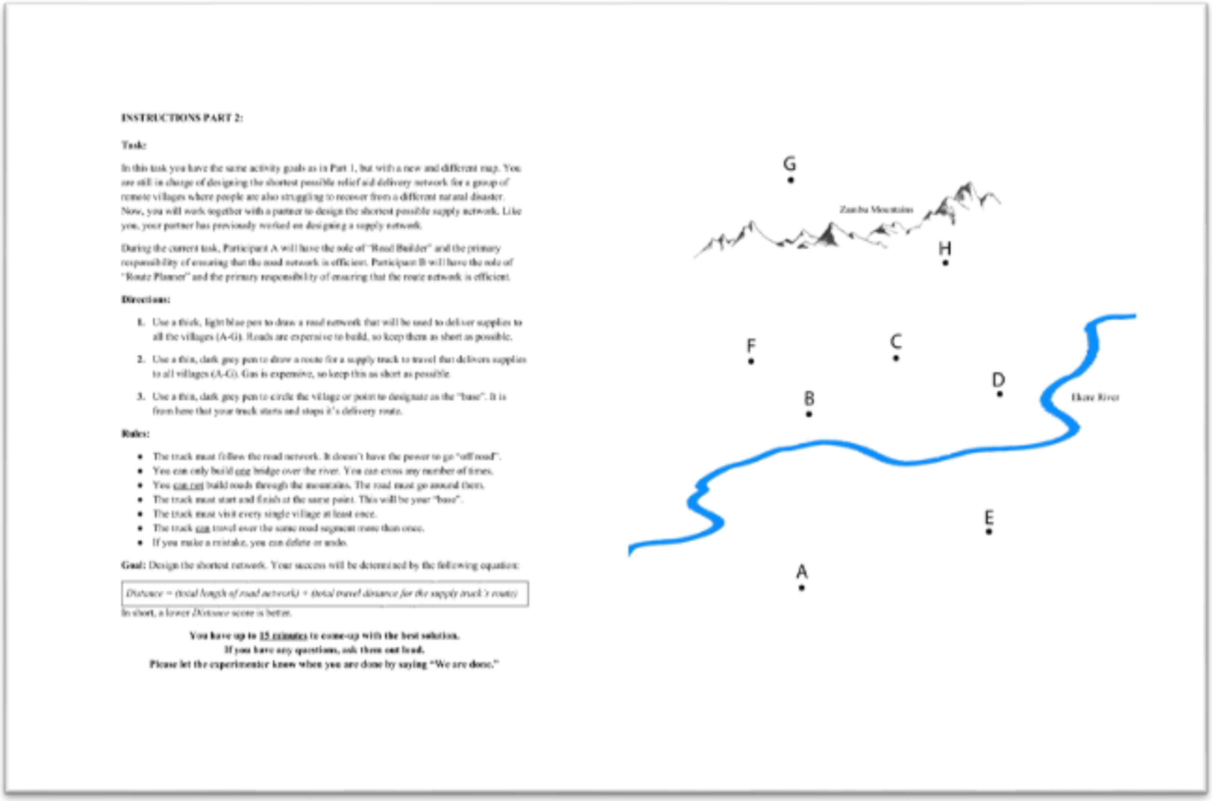
In short, a lower *Distance* score is better.

You have up to 15 minutes to come-up with the best solution.

If you have any questions, ask them out loud.

Please let the experimenter know when you are done by saying "We are done."

Figure V. Task directions and map for Participant A and B's second task (the main task) when assigned to the Distributed Experience without Roles condition (DR).



INSTRUCTIONS PART 2:

Task:

In this task you have the same activity goals as in Part 1, but with a new and different map. You are still in charge of designing the shortest possible relief aid delivery network for a group of remote villages where people are also struggling to recover from a different natural disaster. Now, you will work together with a partner to design the shortest possible supply network. Like you, your partner has previously worked on designing a supply network.

During the current task, Participant A will have the role of "Road Builder" and the primary responsibility of ensuring that the road network is efficient. Participant B will have the role of "Route Planner" and the primary responsibility of ensuring that the route network is efficient.

Directions:

1. Use a thick, light blue pen to draw a road network that will be used to deliver supplies to all the villages (A-G). Roads are expensive to build, so keep them as short as possible.
2. Use a thin, dark grey pen to draw a route for a supply truck to travel that delivers supplies to all villages (A-G). Gas is expensive, so keep this as short as possible.
3. Use a thin, dark grey pen to circle the village or point to designate as the "base". It is from here that your truck starts and stops it's delivery route.

Rules:

- The truck must follow the road network. It doesn't have the power to go "off road".
- You can only build one bridge over the river. You can cross any number of times.
- You can not build roads through the mountains. The road must go around them.
- The truck must start and finish at the same point. This will be your "base".
- The truck must visit every single village at least once.
- The truck can travel over the same road segment more than once.
- If you make a mistake, you can delete or undo.

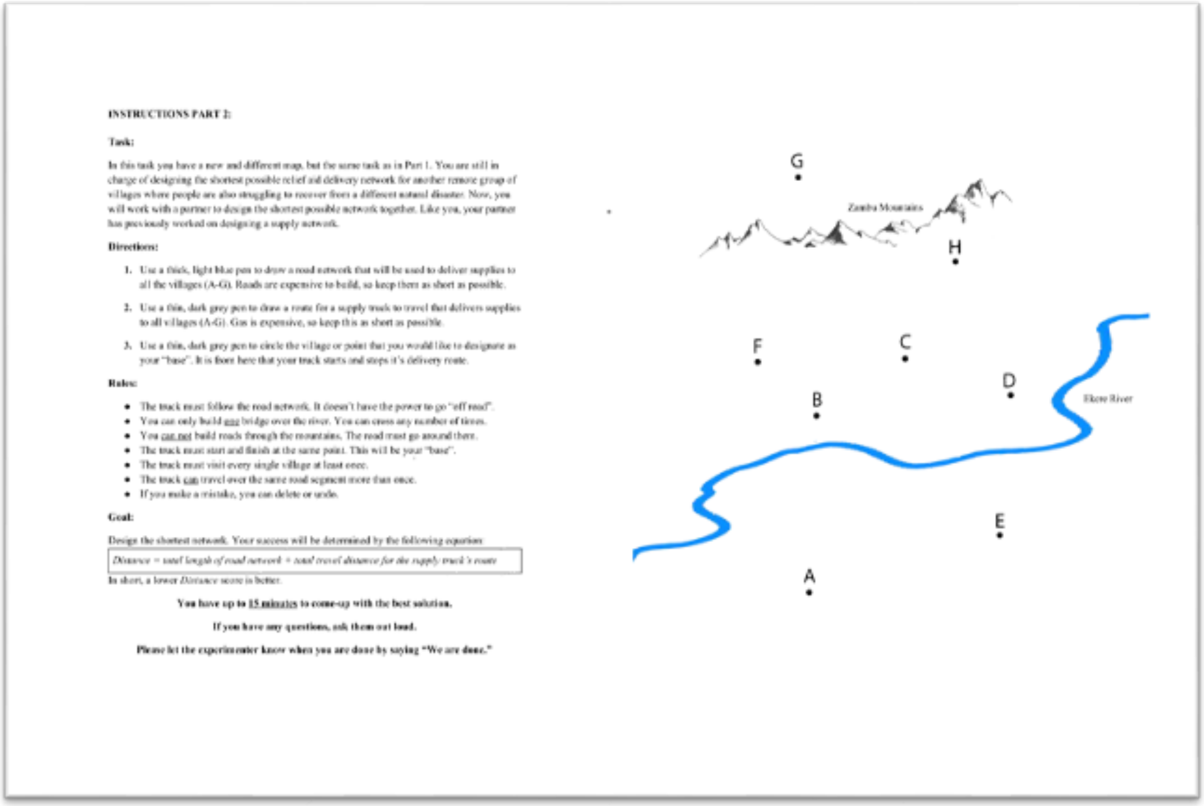
Goal: Design the shortest network. Your success will be determined by the following equation:

Distance = (total length of road network) + (total travel distance for the supply truck's route)

In short, a lower *Distance* score is better.

You have up to 15 minutes to come-up with the best solution.
If you have any questions, ask them out loud.
Please let the experimenter know when you are done by saying "We are done."

Figure W. Task directions and map for Participant A and B's second task (the main task) when assigned to the Joint Experience with Roles condition (JR).



INSTRUCTIONS PART 2:

Task:

In this task you have a new and different map, but the same task as in Part 1. You are still in charge of designing the shortest possible relief aid delivery network for another remote group of villages where people are also struggling to recover from a different natural disaster. Now, you will work with a partner to design the shortest possible network together. Like you, your partner has previously worked on designing a supply network.

Directions:

1. Use a thick, light blue pen to draw a road network that will be used to deliver supplies to all the villages (A-G). Roads are expensive to build, so keep them as short as possible.
2. Use a thin, dark grey pen to draw a route for a supply truck to travel that delivers supplies to all villages (A-G). Gas is expensive, so keep this as short as possible.
3. Use a thin, dark grey pen to circle the village or point that you would like to designate as your "base". It is from here that your truck starts and stops it's delivery route.

Rules:

- The truck must follow the road network. It doesn't have the power to go "off road".
- You can only build one bridge over the river. You can cross any number of times.
- You can not build roads through the mountains. The road must go around them.
- The truck must start and finish at the same point. This will be your "base".
- The truck must visit every single village at least once.
- The truck can travel over the same road segment more than once.
- If you make a mistake, you can delete or undo.

Goal:

Design the shortest network. Your success will be determined by the following equation:

Distance = total length of road network + total travel distance for the supply truck's route

In short, a lower *Distance* score is better.

You have up to 15 minutes to come-up with the best solution.

If you have any questions, ask them out loud.

Please let the experimenter know when you are done by saying "We are done."

Figure X. Task directions and map for Participant A and B's second task (the main task) when assigned to the Joint Experience without Roles condition (JW).

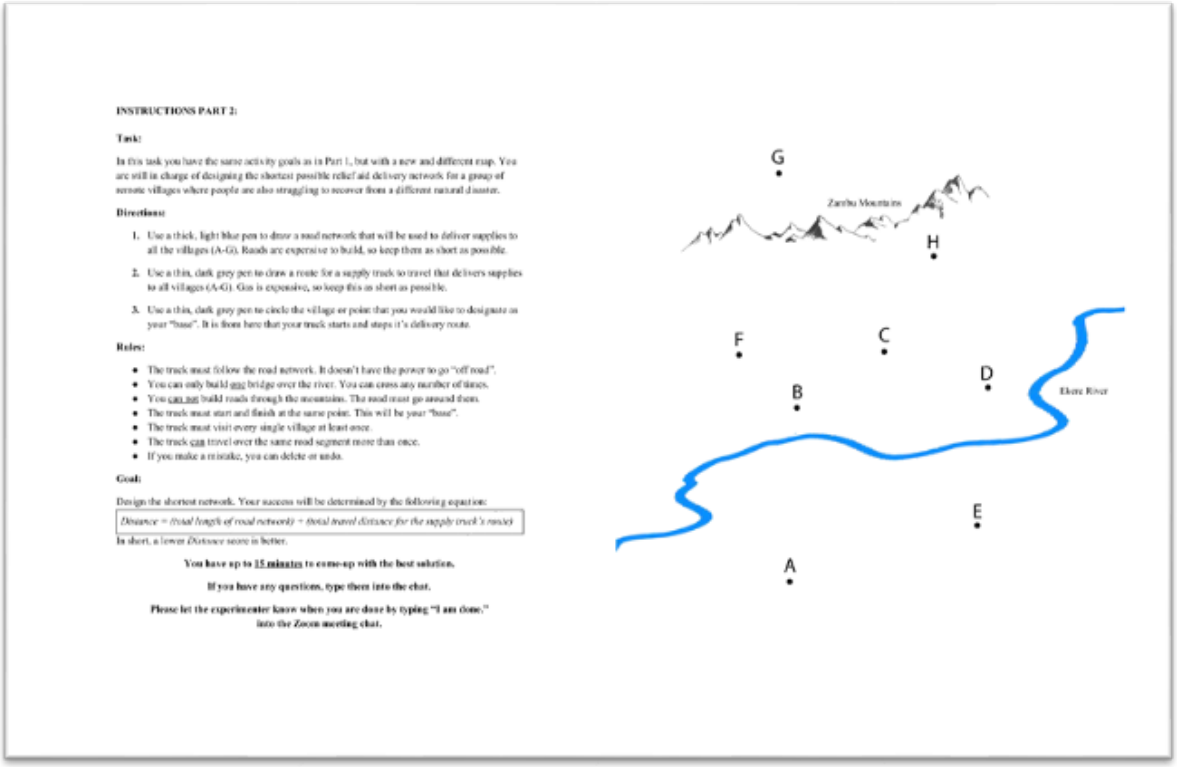
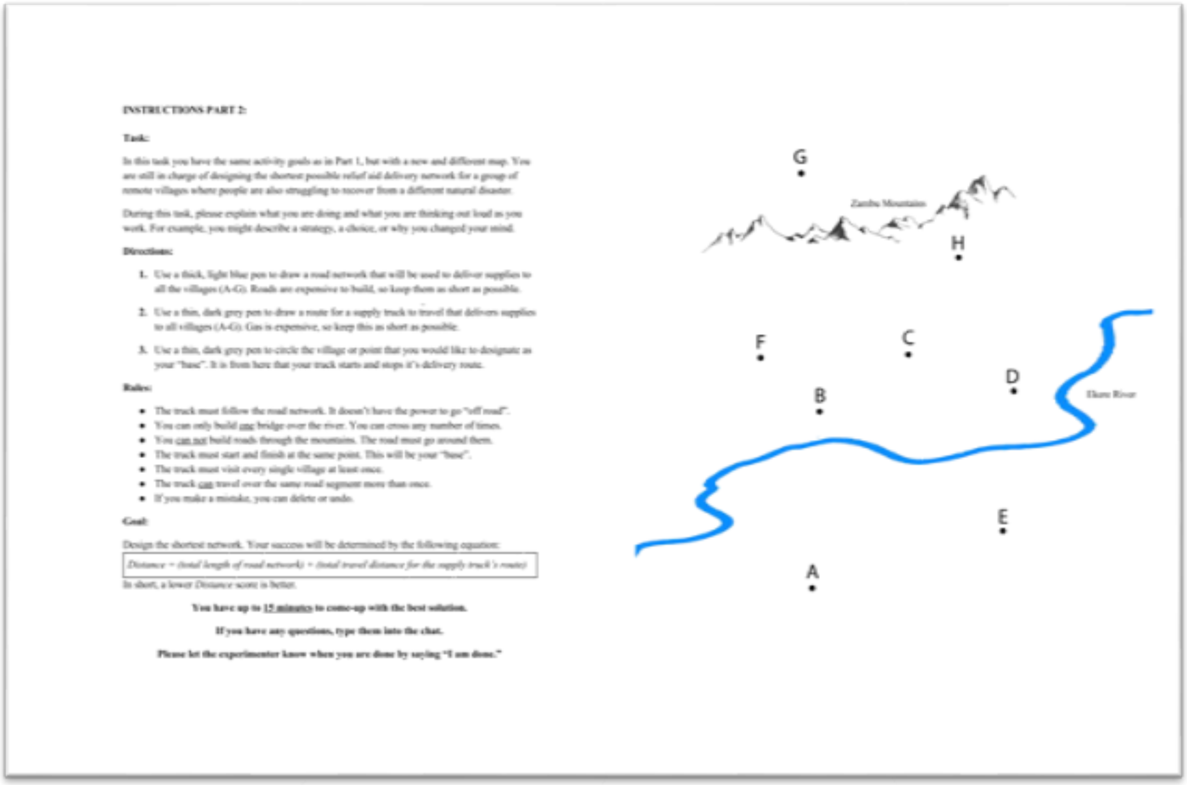


Figure Y. Task directions and map for Participant A and B's second task (the main task) when assigned to the Individual without Self-Explanation condition (IW).



INSTRUCTIONS PART 2:

Task:

In this task you have the same activity goals as in Part 1, but with a new and different map. You are still in charge of designing the shortest possible relief aid delivery network for a group of remote villages where people are also struggling to recover from a different natural disaster.

During this task, please explain what you are doing and what you are thinking out loud as you work. For example, you might describe a strategy, a choice, or why you changed your mind.

Directions:

1. Use a thick, light blue pen to draw a road network that will be used to deliver supplies to all the villages (A-G). Roads are expensive to build, so keep them as short as possible.
2. Use a thin, dark grey pen to draw a route for a supply truck to travel that delivers supplies to all villages (A-G). Gas is expensive, so keep this as short as possible.
3. Use a thin, dark grey pen to circle the village or point that you would like to designate as your "base". It is from here that your truck starts and stops it's delivery route.

Rules:

- The truck must follow the road network. It doesn't have the power to go "off road".
- You can only build one bridge over the river. You can cross any number of times.
- You can not build roads through the mountains. The road must go around them.
- The truck must start and finish at the same point. This will be your "base".
- The truck must visit every single village at least once.
- The truck can travel over the same road segment more than once.
- If you make a mistake, you can delete or undo.

Goal:

Design the shortest network. Your success will be determined by the following equation:

Distance = (total length of road network) + (total travel distance for the supply truck's route)

In short, a lower *Distance* score is better.

You have up to 15 minutes to come-up with the best solution.

If you have any questions, type them into the chat.

Please let the experimenter know when you are done by saying "I am done."

Figure Z. Task directions and map for Participant A and B's second task (the main task) when assigned to the Individual with Self-Explanation condition (IE).

Appendix C: Instruments & Measures

C.1 Instruments

Coding Protocol

Purpose: Our code scheme is the "meat and potatoes" of this study. Our codes will be assigned to each utterance of each transcription in the study to indicate the type of speech act used by each participant. These codes will be used to train our natural language processing algorithm. When the training process is complete, we hope to have a tool that can identify strategies people use when collaborating on a problem solving task.

Task: Code the Relief Aid transcripts while simultaneously watching the corresponding videos. Pause and replay the video as needed to be sure you have a good sense of the social context, participant's affect, and the pragmatic effect of their utterance on the conversation.

Opening Protocol:

1. Turn on the lab desktop computer.
2. Login using Username: *CorterLab*, Password: *powerplant2013*
3. Get the Relief Aid external hard drive from the yellow cabinet.
4. Plug the external hard drive USB into the desktop CPU.
5. Select *Open folder to view files.*
6. Open file *Relief Aid 2017 - Kuang&Hibbard*, then *All Files*
7. Select the file that you've been assigned by Hibbard. This could be any file (*Study 1, Study 2,* or *Study 2B*) to work on with the label *to be coded* in the file name.
8. Once you have located your new file, open it, then open the ExCel spreadsheet inside
9. Review the spreadsheet. Make sure that the transcription is complete.

   Note: Complete transcriptions should have the following:

   - File name in cell A1

- Time stamps starting in cell A3, continuing without a break through the length of the transcript.
- Speaker assignments of A or B marked in cell B3, continuing without a break through the length of the transcript.
- Utterances recorded in cell C3, continuing without a break through the length of the transcript.

If any of the above criteria are not met:

- mark your observations in your Lab Notebook
- Tell Hibbard
- close the file. Hibbard will direct you to another file to work on.

10. When you have decided to code a transcript, open the corresponding video.

    Note: You must watch the video while coding. Do not code only using the transcript.

11. Play the video and begin coding.
12. Save often.

Coding Protocol:

When coding…

- Assign multiple codes to a single utterance as needed.
- Feel free to add notes in the comments column T if you feel rationale or justification is needed.
- Record any anomalies or observations in your Lab Notebook. Include as much data as possible in these entries: *date, file name, line or column*
- If you notice anything unusual, feel free to email or text Kate.
  email: kh2122@tc.columbia.edu
  cell: (617) 797-2461

Do Not…

- Do not look at another coder's work.
- Do not change the transcript. If you see an error in the transcript, let Hibbard know.
  Cell: (617) 797-2461
  email: kh2122@tc.columbia.edu

Closing Protocol:

1. Save changes.

2. Update the *Transcription Status Tracker* to reflect your changes:

   LINK:
   https://docs.google.com/spreadsheets/d/18IKG0tLWQJ6zI_ou7TmRvTwkPGh7oHII301pHF2b1Ds/edit?usp=sharing

   Note:

   2.1 Review the *Code* assigned to each stage of work if needed. You can find this in the *Summary* sheet

   2.2 Find your file name on *File Progress* sheet.

   2.3 Adjust the code for *Human Progress* in column C to reflect your recent work on the document

3. Close out of all windows: video and spreadsheet.

4. Make sure that you have no stray files saved anywhere outside of the external hard drive. If you do, please put them in the *Trash* and *Empty Trash*.

   Note: *All files should be saved on the external hard drive. Not on either lab computer.*

5. Safely remove the external hard drive.

6. Place the external hard drive in the bottom drawer of the avocado drawers.

7. If you are working on the Desktop powered by the DELL CPU, please shut it down. If you are working on the Desktop powered by the Apple CPU, please just log off.

Thank you!

If you have any questions, please email or text Kate Hibbard
email: kh2122@tc.columbia.edu
cell: (617) 797-2461

Relief Aid Code Scheme

developed by Kate Moore and James Corter (V5, 02/22/2018)

E - Explain	(E) explain, reason aloud, cite prior knowledge or task instructions	An utterance that performs any of the following speech acts: Signals consideration of an idea; Puts thinking into words; Facilitates thought; Explains an action or a thought; States the rules, instructions or constraints of the assigned task; Cites prior knowledge. For example, Thinking about a proposal, but not suggesting an action.
P - Propose	(P) propose specific task-related action	Proposes a task-related action, such as adding or removing a link or proposing a route. Note: This can be formed implicitly as a question, "What if…"
Q - Question	(Qc) ask for consideration	An utterance posed as a question to encourage a participant to consider something. An utterance marked with this speech act may include the phrase, "What do you think about..."
	(Qi) ask for information / clarification	An utterance posed explicitly as a question to solicit information or seek clarification on a previously mentioned, written, or drawn piece of information. Phrases: "Do you mean..." "Just to be clear, you're saying..." "What do you mean by..."
R - Response	(Ra) agree	A response to any type of previous statement that expresses agreement. This includes affirmative memes like "yeah" "ok" "uh-huh". [Note: Tone matters. It can indicate whether a sound expresses agreement (this code), or other cases (not this code): e.g., when a sound is ambiguous and used simply to acknowledge the request/question or to hold the floor.]
	(Rm) consider, modify, restate, counter proposal (or an ambiguous statement)	A response to any type of previous statement (or question) that audibly signals active consideration of the statement, suggests modifications to the statement, augments the statement by suggesting an addition, or restates the information in the same or slightly different words. This can include a counter proposal.
S - Social	(S) social facilitation	An attempt to address, manage, or grow a social relationship with a participant. This includes telling a joke, expressing an emotion, sharing a piece of personable information, or performing a social service, such as introducing oneself, inquiring as to a person's health, saying "bless you" after a person sneezes, offering a compliment

J - Coordinate Joint Attention	(J) attempting to manage the interaction or focus joint attention	Any utterance or sound meant to direct partner's attention. This may include directing a partner's attention to an area on the map, an area in the directions, or another item/object.
N - Interruption	(N) interrupt or cut-off another participant's utterance	An utterance that interrupts another participant (not oneself). In each case a second person's utterance interrupts the former speaker. It should have the immediate effect of cutting off the former speaker's utterance, such that they are not able to complete their utterance. Note: This does not include speaking after a pause or speaking after another speaker has trailed off. Note: an interruption does not necessarily change the topic. A participant may, for example, interrupt another person to contribute to their idea/utterance.

C.2 Measures

Directions: Please answer the questions below by drawing your answer.

1. Three farms (A, B, C) are arranged roughly in an equilateral triangle on perfectly flat terrain (see below). Use a thin, dark grey line to draw the shortest possible network of irrigation canals that would connect the three farms, allowing them to share water.

B

A

C

Figure AA. Post-task Activity (Task 3) Item 1 of 5 (Q1)

2. Elliot has to leave work, then run some errands quickly and get back to work. The location of each stop for each errand relative to each other is represented below by letters (W is Elliot's work location). Use a thin, dark grey line to draw the shortest possible way Elliot should travel to get to all the stops and get back to work quickly.

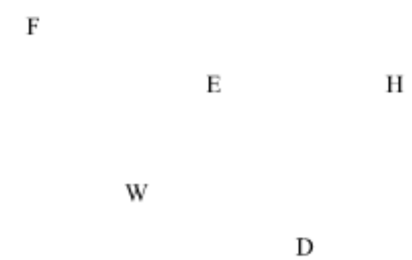


Figure AB. Post-task Activity (Task 3) Item 2 of 5 (Q2)

3. A school bus route must connect all the houses in a small town to the school. The school bus route must visit all the houses (AC, AD, AE, AF, AG) at least once. The route must also start and stop at the school. Use a thin, dark grey line to draw the shortest bus route possible connecting all the houses in the town to the school.

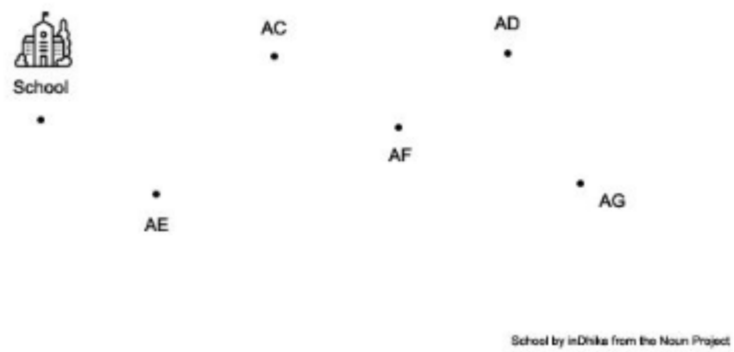


Figure AC. Post-task Activity (Task 3) Item 3 of 5 (Q3)

4. An engineer is designing a network of power lines to bring electricity to homes on an island and on either side of a river. To save on cost, they want to use as few lines as possible, the shorter the better. It costs twice as much to span power lines across the river as it does to erect them on land. So, another important cost saving measure is to keep the lines crossing the rivers as short as possible. Use a thin, dark grey line to draw a cost efficient network connecting the power plant to the homes (labeled W, X, Y, Z, AA, AB).

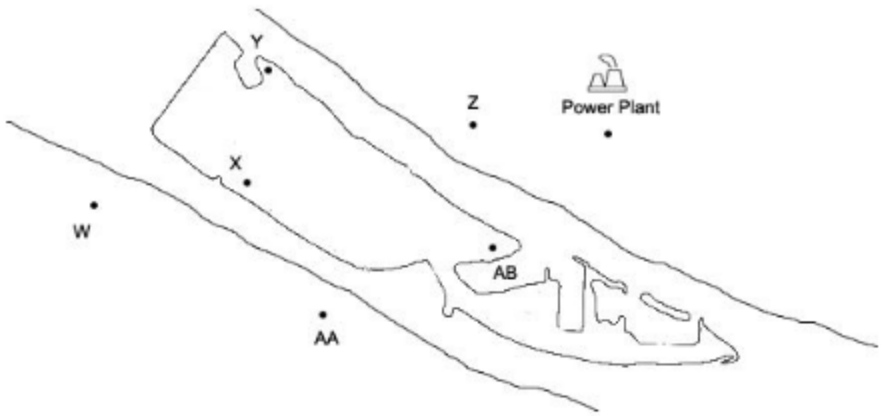


Figure AD. Post-task Activity (Task 3) Item 4 of 5 (Q4)

5. Hannah has hidden 4 cubes of sugar in her ant farm. Of course, her pet ants feel a powerful urge to get to these cubes and bring them back to their ant nest. Starting from the ant nest, draw the shortest network of tunnels Hannah's ants can dig to get to each of the 4 cubes (R, S, U, V) as directly as possible. Then, draw directional arrows indicating the quickest way back to the ant nest along these tunnels.

Note: The best tunnel network will be determined using the length of the tunnel network plus the distance the ants have to travel: network length + distance traveled. This means you should design a tunnel network that avoids extra digging and follows the quickest route to all the sugar cubes and back to the ant nest. In other words, your tunnel network should be both short in length and quick to travel.

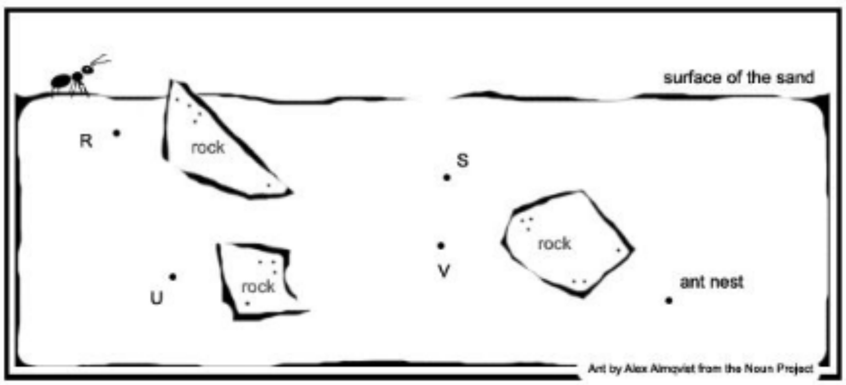


Figure AE. Post-task Activity (Task 3) Item 5 of 5 (Q5)

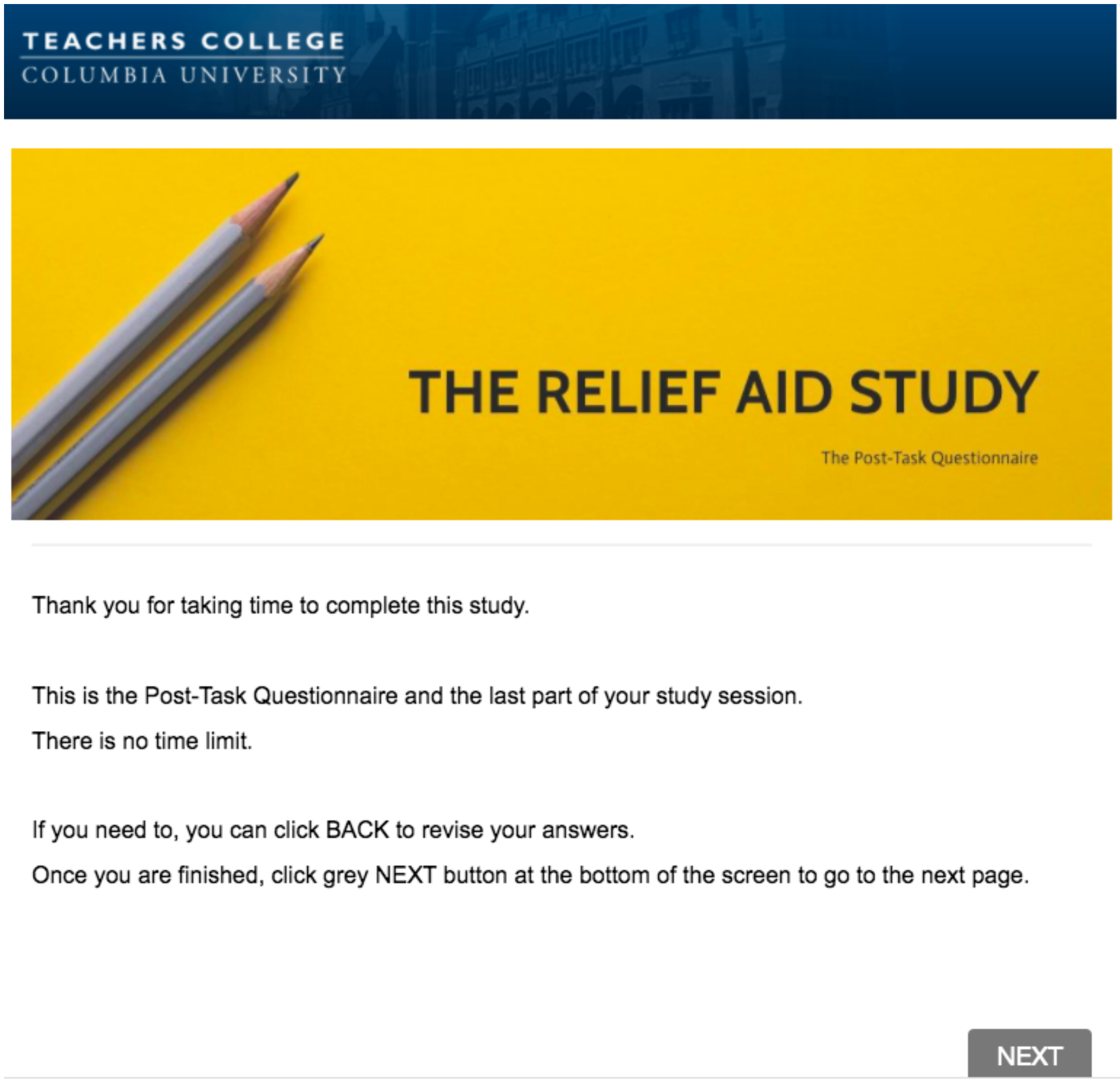


Figure AF. Landing Page of Post-task Questionnaire

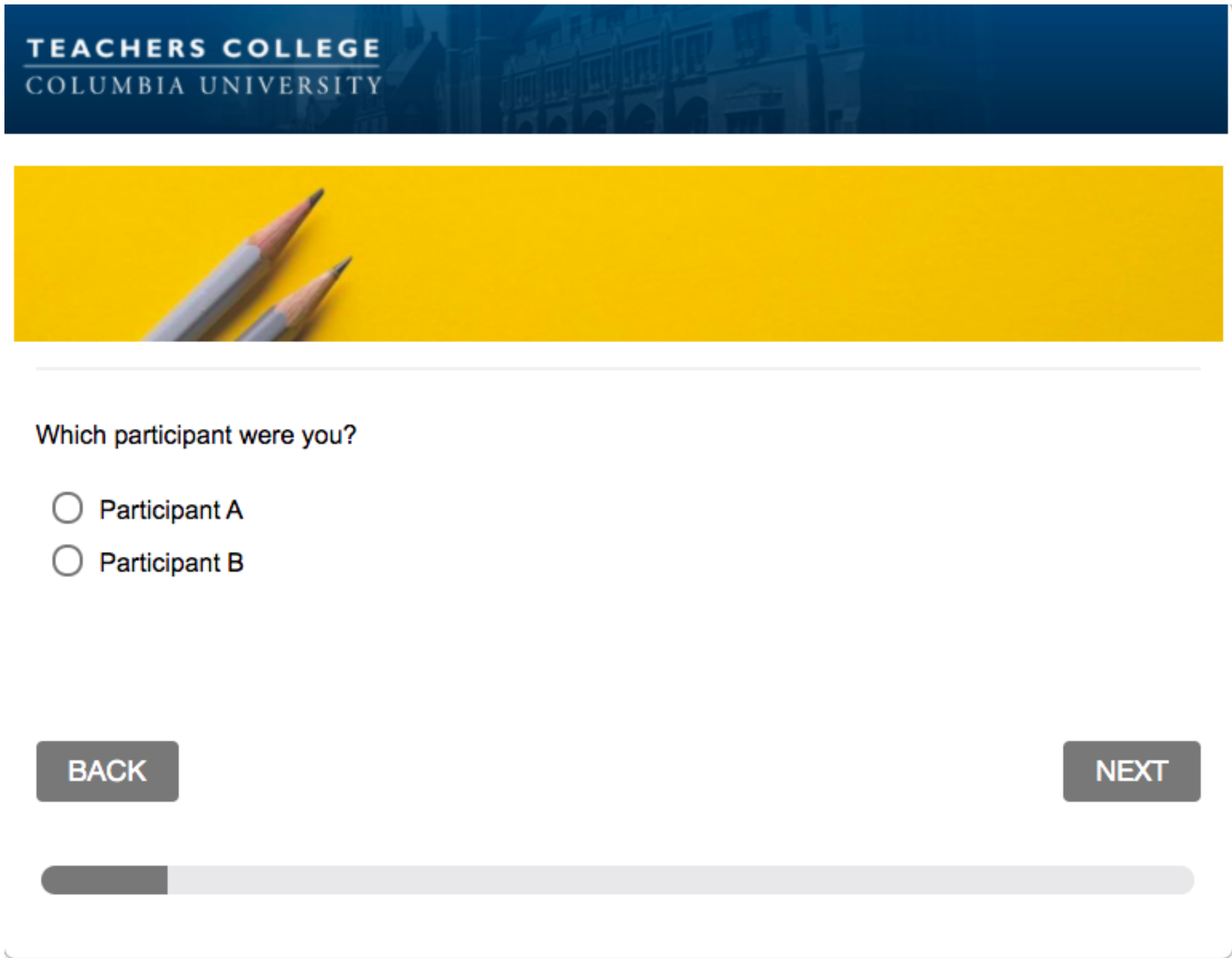


Figure AG. Page 2 of Post-task Questionnaire

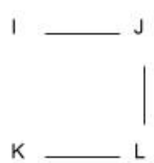
TEACHERS COLLEGE
COLUMBIA UNIVERSITY

Questions about the design tasks

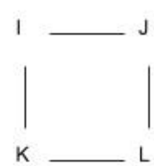
Directions: Please answer the questions below by writing your answer on the space provided.

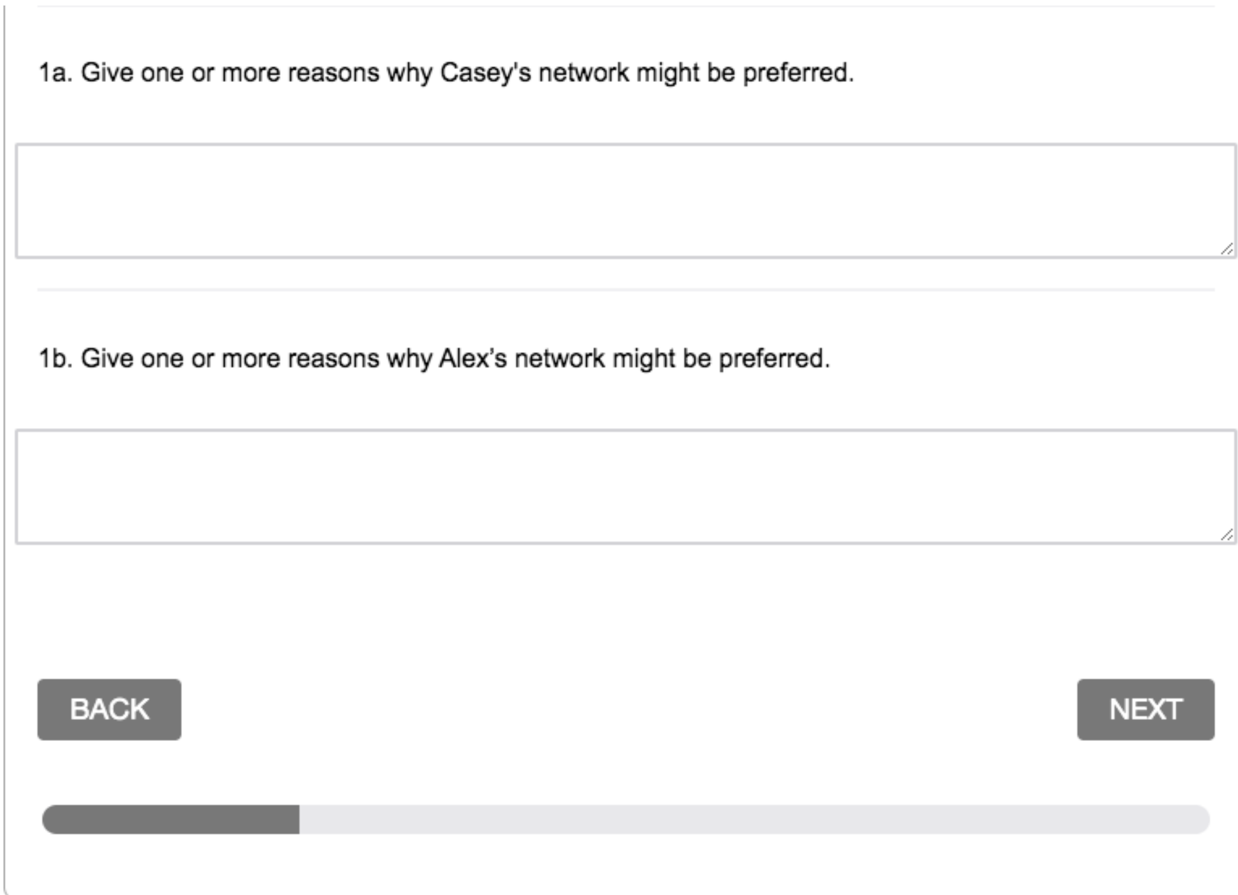
1. Four villages (I, J, K, L) are arranged in roughly a square (see below). Casey draws a network to connect them using links between I-J, K-L, and L-K. Alex draws a network to connect them with links between I-J, J-L, L-K, and K-I.

Casey:



Alex:





1a. Give one or more reasons why Casey's network might be preferred.

1b. Give one or more reasons why Alex's network might be preferred.

BACK

NEXT

Figure AH. Page 3, Item 1a and 1b of Post-task Questionnaire

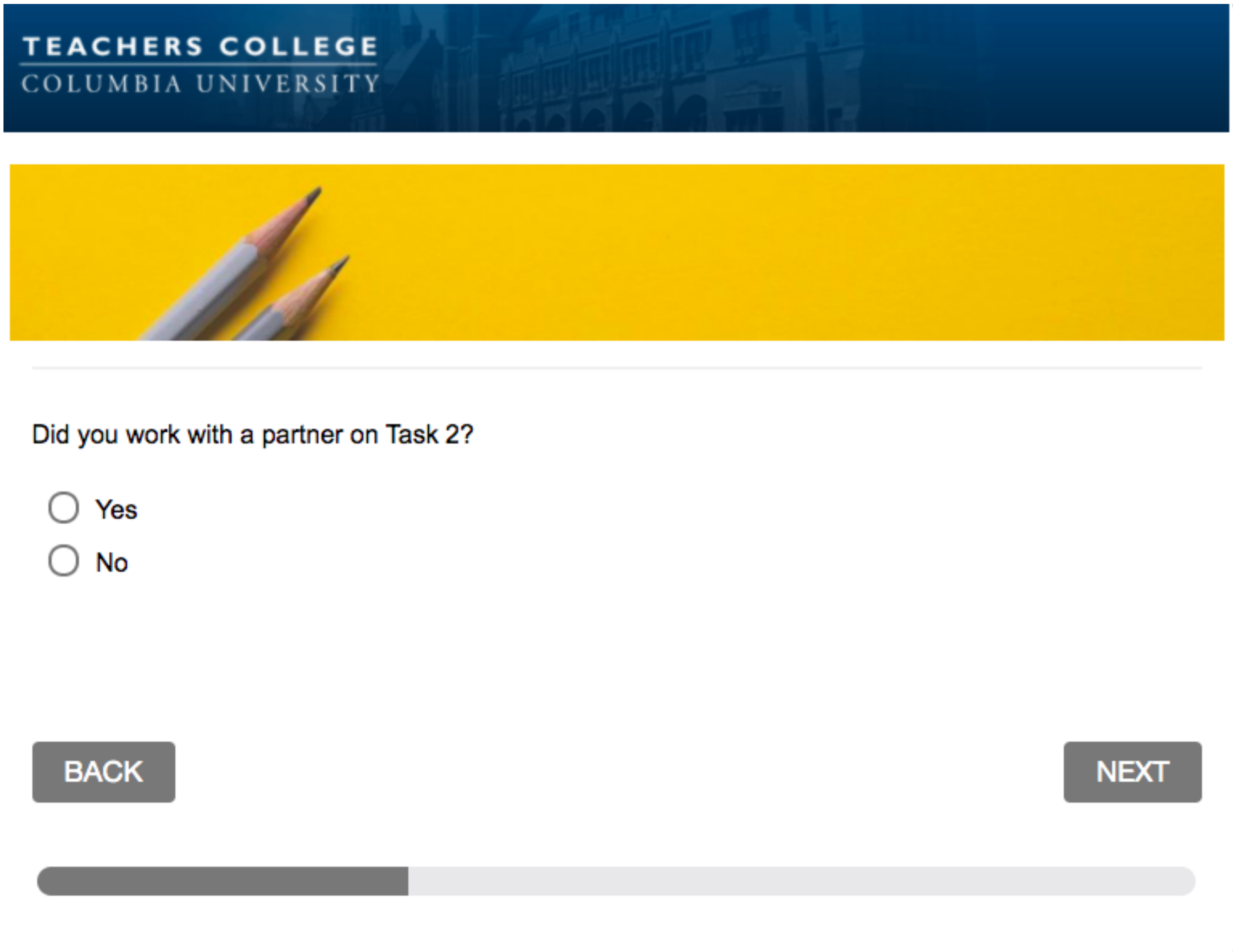
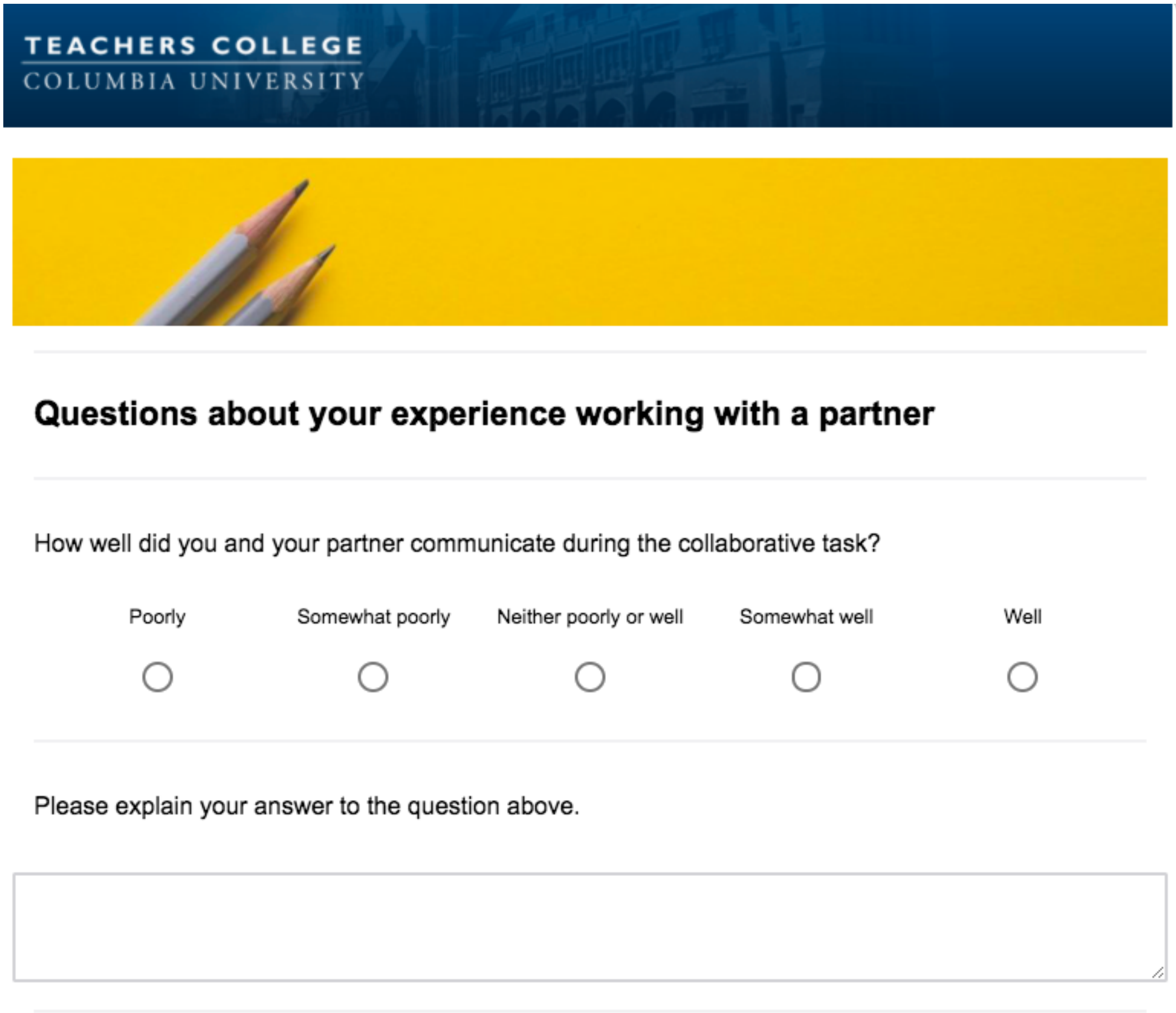


Figure AI. Page 4 of Post-task Questionnaire. This page included some logic. If participant answered "Yes", clicking NEXT would take them to Page 5, Item 2. If participant answers "No", clicking NEXT would take them to Page 6, Item 7.



TEACHERS COLLEGE
COLUMBIA UNIVERSITY

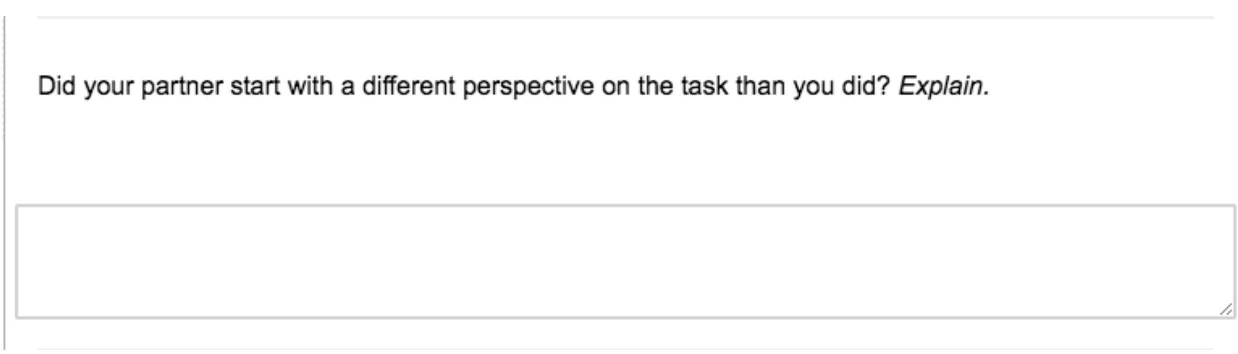
Questions about your experience working with a partner

How well did you and your partner communicate during the collaborative task?

Poorly	Somewhat poorly	Neither poorly or well	Somewhat well	Well
○	○	○	○	○

Please explain your answer to the question above.

Figure AJ. Page 5, Item 2 of Post-task Questionnaire.



Did your partner start with a different perspective on the task than you did? *Explain.*

Figure AK. Page 5, Item 3 of Post-task Questionnaire.

How would you compare your first task to your partner's first task?

- ◯ We had the same first task.
- ◯ Our first tasks were different.
- ◯ I don't know what my partner's first task was, so I can't compare mine to theirs.

Figure AL. Page 5, Item 4 of Post-task Questionnaire.

How would you compare your experience from your first task to your partner's experience from their first task? *Check all that apply.*

- ☐ My first task gave me more experience designing roads than my partner.
- ☐ My first task gave me more experience designing truck routes than my partner.
- ☐ My first task gave me the same experience designing roads as my partner.
- ☐ My first task gave me the same experience designing truck routes as my partner.
- ☐ I don't know what my partner's first task was, so I can't compare mine to theirs.

Figure AM. Page 5, Item 5 of Post-task Questionnaire.

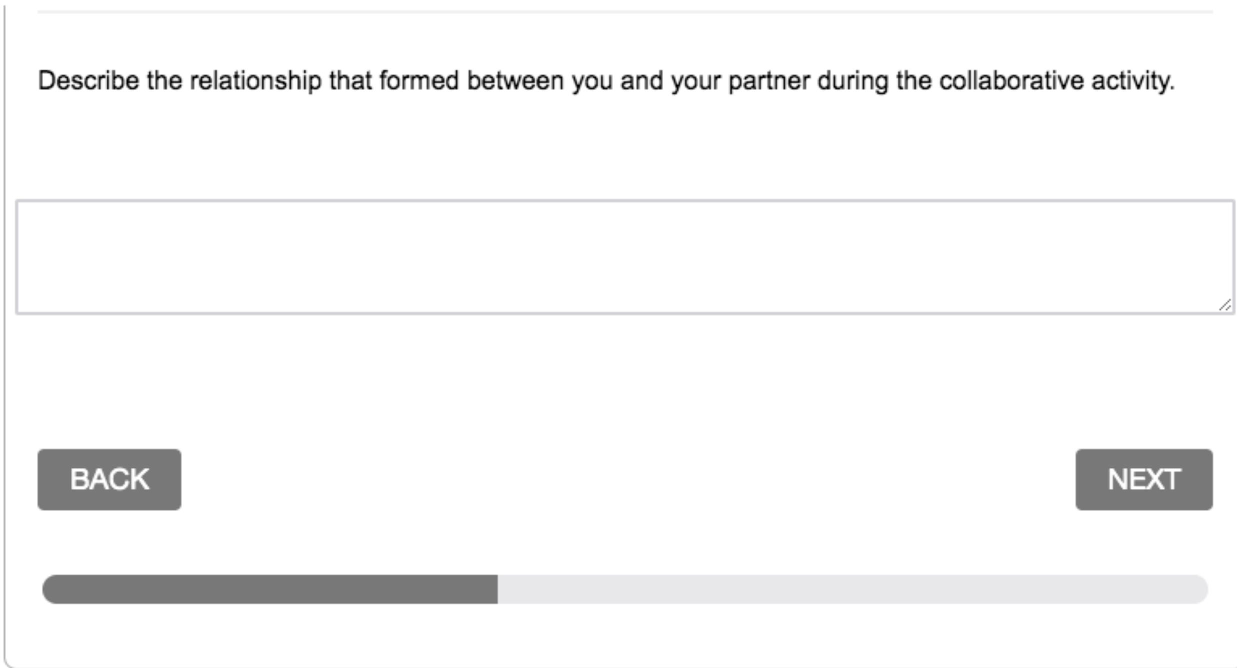
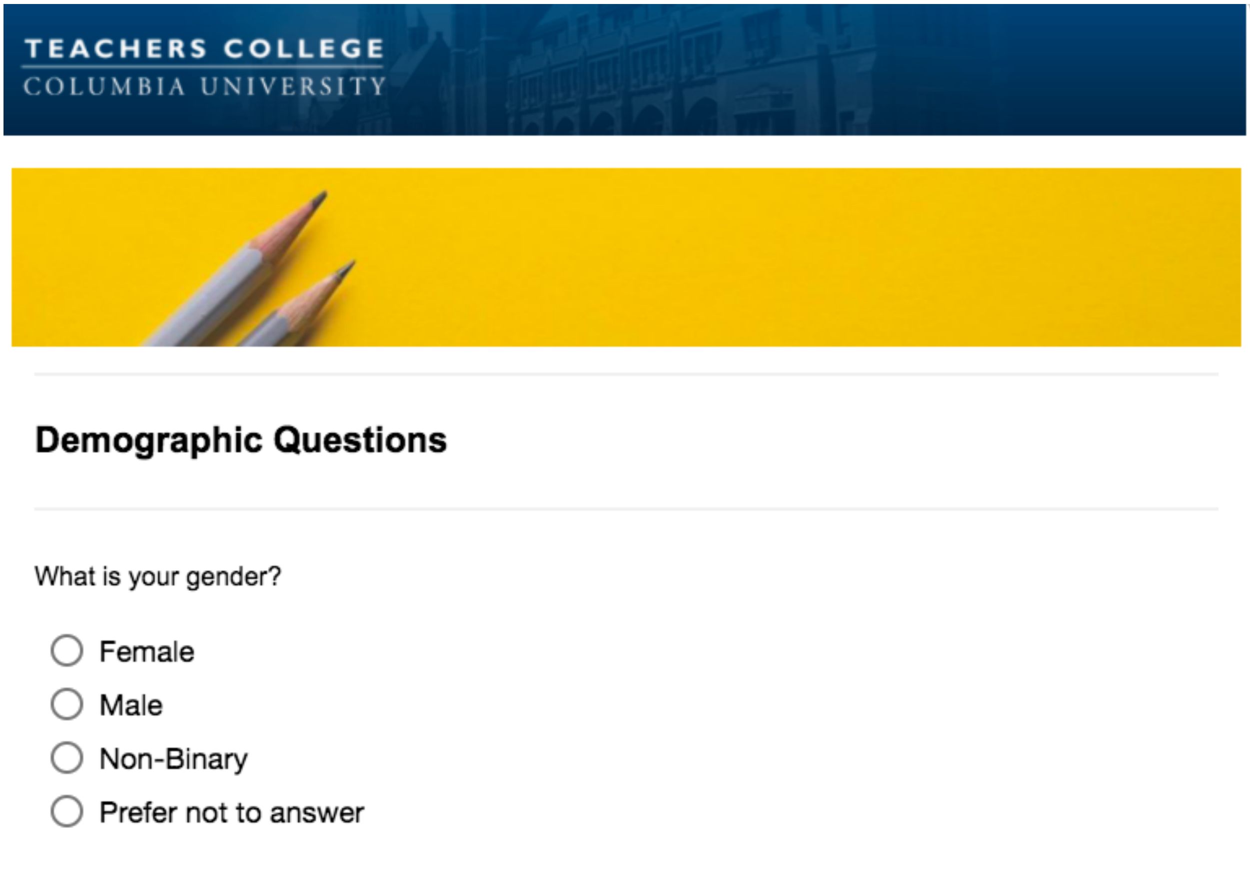


Figure AN. Page 5, Item 6 of Post-task Questionnaire.


TEACHERS COLLEGE
COLUMBIA UNIVERSITY

Demographic Questions

What is your gender?

- ○ Female
- ○ Male
- ○ Non-Binary
- ○ Prefer not to answer

Figure AO. Page 6, Item 7, Demographic Question within the Post-task Questionnaire.

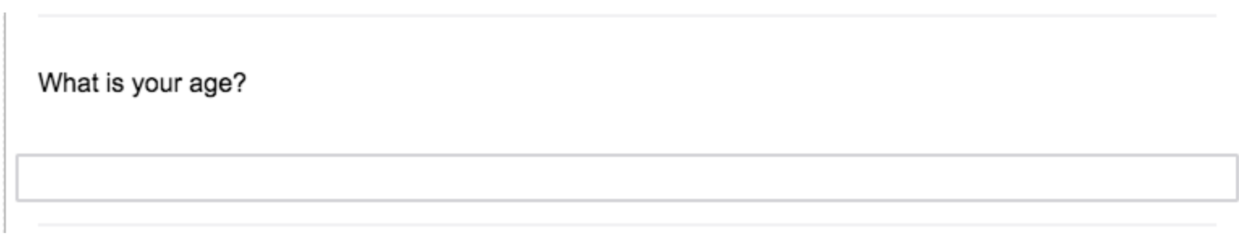
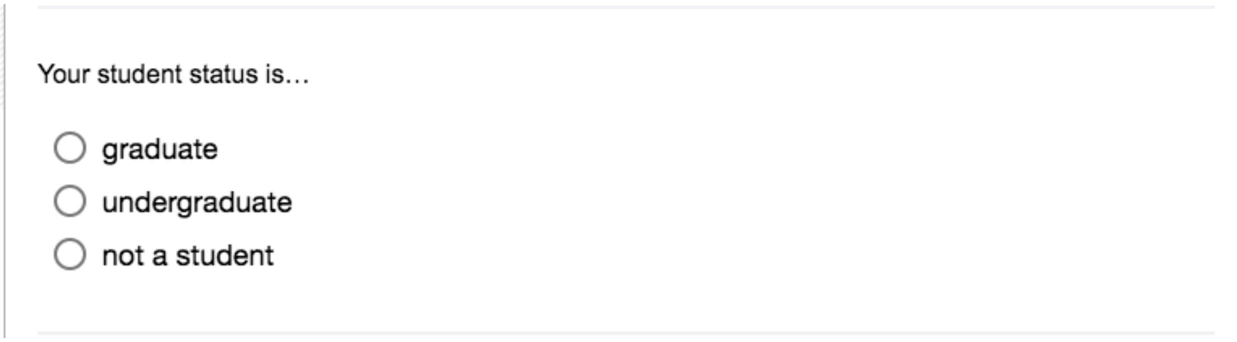

What is your age?

Figure AP. Page 6, Item 8, Demographic Question within the Post-task Questionnaire.


Your student status is…

- graduate
- undergraduate
- not a student

Figure AQ. Page 6, Item 9, Demographic Question within the Post-task Questionnaire.

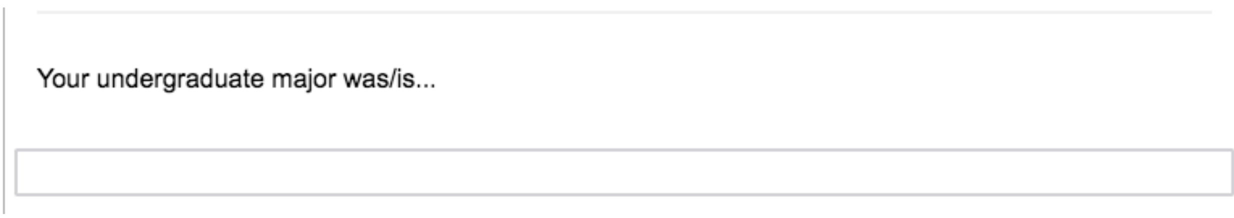
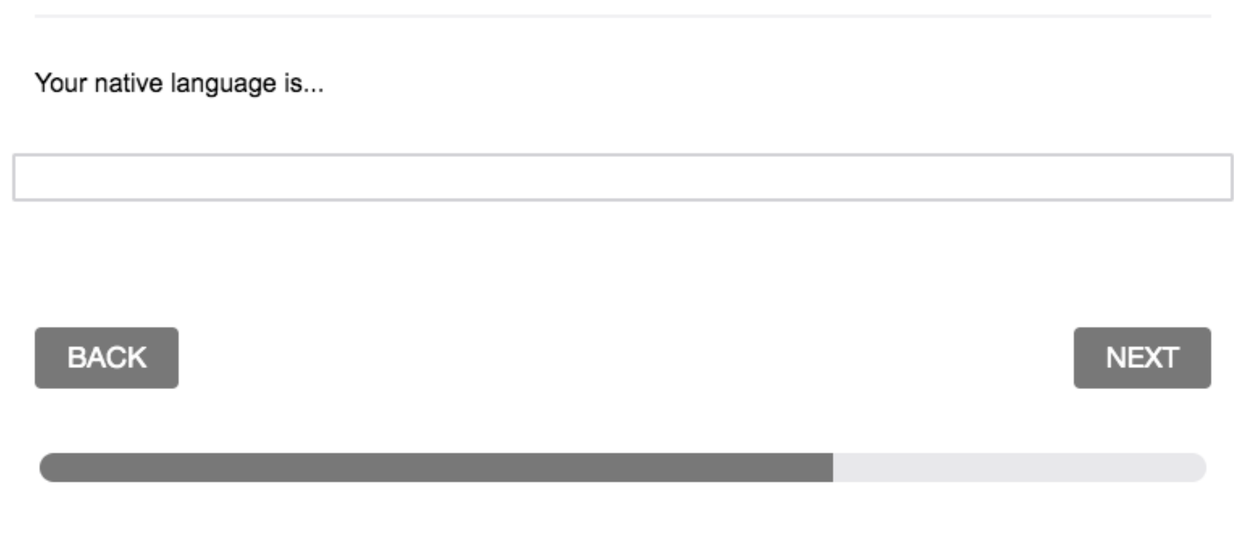

Your undergraduate major was/is...

Figure AR. Page 6, Item 10, Demographic Question within the Post-task Questionnaire.


Your native language is...

BACK NEXT

Figure AS. Page 6, Item 11, Demographic Question within the Post-task Questionnaire.

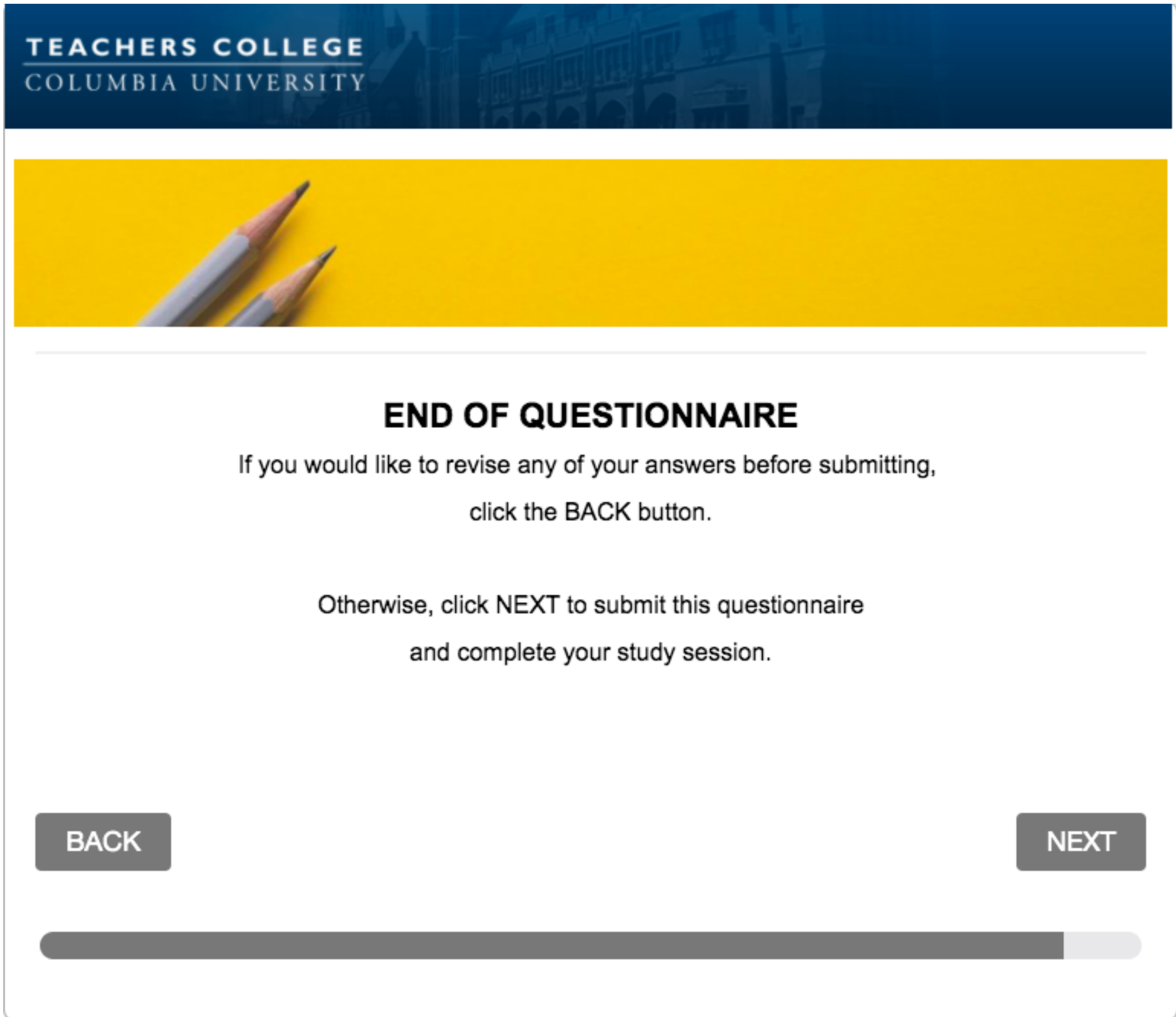


Figure AT. Page 7 of the Post-task Questionnaire.