ARE TWO HEADS BETTER THAN ONE? INVESTIGATING THE INFLUENCE OF COLLABORATION ON CREATIVITY

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Are two heads better than one? Investigating the influence of collaboration on creativity.

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MASTER OF SCIENCE

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ABSTRACT

Creativity and collaboration are considered fundamental skills for student success in STEM Education (Karimi & Pina, 2021) and are consistently among the top-ranked skills for employers (Flaherty, 2021). To assess creativity, the Remote Association Task (RAT) is an increasingly used tool to measure creative problem-solving (Wu et al., 2021). However, no research has systematically investigated the effectiveness of working collaboratively versus individually using this measure. The current research evaluates how collaboration impacts creative problem-solving using the RAT. Participants worked collaboratively or individually to solve 20 RAT problems (Experiments 1-2) and completed a later, individual test that involved the same 20 RAT problems and 20 novel RAT problems (Experiment 2). Outcomes suggest collaboration lowers performance during initial problem solving, but may benefit later, individual problem solving. Evaluating how best to support creative processes in the context of collaboration has implications for supporting student success and helping them develop highly applicable skills.

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RAT..Remote Associated Task

AUT ....Alternative Uses Task

PEQ..Post-Experiment Questions

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1. INTRODUCTION: CREATIVITY AND COLLABORATION

Creativity and collaboration are concepts that are a part of our everyday life. Indeed, we often engage in creative and collaborative processes in a variety of settings, ranging from home, to work, and to school. For example, in educational settings, students are often required to engage in creative processing, such that they are asked to generate new ideas, make connections between different concepts during class discussions, and problem-solve on class assignments (Hines et al., 2019; Hanif et al., 2019; Sirajudin et al., 2021). In addition, when considering educational contexts, students frequently work together with their peers when learning and studying class content (Premo et al., 2018; Wissman & Rawson, 2018). Importantly, a recent survey by the American Academy of Colleges and Universities (AACU) revealed that both creative thinking and the ability to work effectively with others are among the top-ranked skills for employers (Flaherty, 2021). Further, recent research indicates that creativity and collaboration are considered fundamental skills for success in STEM education with the potential to carry over to the workforce (Hanif et al., 2019; Karimi & Pina, 2021; Larkin, 2015; Sirajudin et al., 2021; Zeng et. al., 2011). As such, understanding how creative and collaborative processes interact with one another is important for preparing a skilled workforce.

The current study investigates how collaboration affects creative problem-solving using a commonly used measurement of creativity: The Remote Association Task (referred to as RAT; Bowden & Jung-Beeman, 2003; Cropley, 2006; DeHaan, 2009; Welling, 2007; Wu et al., 2020; Zhu et al., 2019). The RAT consists of presenting participants with three cue words that are remotely associated with a fourth word, and the goal is for the participants is to generate the fourth word.

To date, no other study has systematically assessed how performance on the RAT is affected when individuals work in a group compared to when individuals work alone. The current research examined the extent to which engaging in collaborative versus individual problem-solving impacts creativity. Outcomes from this research provide novel evidence for how best to support creative processes in the context of collaboration, which has implications for supporting students and helping them develop highly applicable skills.

1.1. Background on Creativity

Although creativity is a common construct, it is often misunderstood (Benedek et al., 2016; Patston et al., 2018). This misunderstanding, in part, is likely due to the fact that creativity is difficult to define and often described in different ways by different researchers. For example, Pang (2015) describes creativity as "a process to create something new and useful", Gilbert (2015) describes the concept as "the relationship between a human being and the mysteries of inspiration", and DeHaan (2009) says that creativity is "the ability of individuals to generate new ideas that contribute substantially to an intellectual domain." Of course, each of these different definitions involve some overlapping ideas (e.g., a novelty component), but nonetheless are not exactly identical. Despite slight differentiations in how creativity has been defined, research has been investigating this phenomenon for decades (Duncker, 1945; Guilford, 1966, 1967; MacKinnon, 1966; Mednick, 1962; Smith, 1995).

Historically, research has proposed two competing explanations for creative behavior: the psychometric approach and the creative cognition approach (Beghetto & Kaufman, 2009; DeHaan, 2009; MacKinnon, 1966; Smith, 1995). The psychometric approach posits that creativity is an innate quality an individual possesses, suggesting people are born with some pre-determined level of creativity (Smith, 1995). This perspective can be described in a range of two terms: very creative or very not creative. The psychometric approach remained the predominant perspective on creativity until the 1990s, with some contemporary creativity research remaining rooted in the psychometric perspective (Chen et al., 2023; Kaufman et al., 2016; Lebuda et al., 2021).

Researchers adopting the psychometric approach primarily focused on analyzing creative individuals, often referred to as creative geniuses, to better understand what makes a person creative. For example, in the 1960s researchers wanted to capture a precise picture of what makes a person creative (MacKinnon, 1966); to do this, they measured traits like intelligence, cognitive flexibility, and openness to experience in members of various professional groups (e.g., writers, architects, physicists, and engineers). Outcomes showed that individuals the professional groups identified as highly creative tended to score above average on IQ tests and were less likely to feel restricted to conform to ideas. These individuals also reported feeling more independent and more flexible in their thinking. One of the strongest correlations was observed for the relationship between creativity and openness to experience. The researchers hypothesized that a person's openness to experience make it possible for them to think differently about their life experiences, which allows them to generate new ideas based on their knowledge and experience. Since this early research, openness to experience has persisted as one of the most prominently studied traits when investigating creativity (Arden, et. al., 2010; Benedek et al., 2016; Runco, 2004; Silvia et. al., 2017; Zeng et al., 2011). Outcomes from this research consistently reveal a strong, positive correlation between openness to experience and creative ability.

In contrast to the psychometric approach, the creative cognition approach posits that creativity is a cognitive process that all individuals are capable of developing (Smith, 1995). This approach suggests that creativity is a learned process that individuals can spend time practicing to develop and improve upon. Smith (1995) notes that the creative cognition approach shifted the theoretical mechanism of creativity from who is creative to how can people develop the skill of creativity. To illustrate, if an individual wants to develop their drawing skills, they may begin by sketching various shapes every day for a couple of weeks; as their ability and confidence increases, they move onto more complex sketches by incorporating different techniques like shading. The view that creativity is a skill that can be practiced and refined has been supported by empirical evidence and is the most common approach to modern creativity research (Vandervert et al., 2007; Welling, 2007; Wu et al., 2020; Zeng, 2011).

With modern creativity research viewing creativity as a skill that can be learned and developed, research has shifted to focusing on creative thinking and creative processes themselves. The general creative cognition process is conceptualized as a two-stage process, which involves a generative phase and an evaluative phase (Ellamil et al., 2012; Zhu et. al., 2019). The generative phase is the process of developing multiple ideas, whereas the evaluative phase is selecting one of the ideas. To illustrate, imagine that an author is sitting down to write a story. To begin, the author must decide where they want to ultimately take the story, so they start at the generative phase by thinking of multiple possible pathways for their narrative. The author shifts to the evaluative phase when they select which narrative pathway is ideal to meet the goal of their story. Broadly speaking, the generative phase and the evaluative phase can be seen as mapping onto two types of thinking—divergent thinking and convergent thinking, respectively (DeHaan, 2009; Zhu et al., 2019)[1].

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[1] It is important to note that though the generative and evaluative phases are seen as mapping on to each type of thinking, this is not necessarily mutually exclusive. Creative problem-solving

Divergent thinking involves the generation of multiple solutions to a set problem. Originally outlined by Guilford (1967), divergent thinking tasks involve presenting participants with some type of problem and asking them to think of as many possible solutions to that problem (also see, Madore et. al., 2016; Reiter-Palmon et. al., 2019). Though research has used a variety of divergent thinking tasks to measure creativity (for the Droodle Task, see Nishimoto et al., 2010; for the Torrance Tests of Creative Thinking, Hee Kim, 2006), one of the most widely used tasks is the Alternative Uses Task (hereafter referred to as AUT; George & Wiley, 2019; Hass, 2017; Madore et al., 2016; sometimes referred to as the Unusual Uses Task (UUT); Baird et al., 2012; Ellwood et al., 2009; Silvia et al., 2017).

The AUT presents participants with commonly used objects (e.g., brick, paperclip, plastic bag), and then asks participants to generate as many creative uses they can think of for the object (Colzato et al., 2013; Forthmann et al., 2017; Plucker et al., 2011; Reiter-Palmon et al., 2019; Zhu et al., 2019). For example, for the prompt "brick," participants could suggest ideas to use it as a hammer, a stool, a weight for weightlifting, or a mortar and pestle. Measuring creativity for divergent thinking tasks, like the AUT, can be challenging, as this type of task often involves some subjectivity in terms of rating the creativity of the items generated.

Given the complexity and variety of responses that can be generated on divergent thinking tasks, two measures were developed to help standardize the assessment of creativity: the quantity of items generated (hereafter referred to as fluency) and the quality of the generated items (hereafter referred to as originality; Carroll, 1968; Guilford, 1967; Reiter-Palmon et al.,

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research suggests both divergent thinking and convergent thinking are likely required to solve a problem (Cropley, 2006; Zhu et al., 2019). During the creative problem-solving process, individuals must generate multiple solutions to a problem (divergent thinking) and then select the best option (convergent thinking).

2019). Fluency measures the number of ideas generated within a certain amount of time. For example, creative fluency would be higher for a participant who generated 10 ideas in 30 seconds compared to a participant who generated 3 ideas in 30 seconds. Though fluency provides a quantifiable way to score performance on divergent thinking tasks, simply generating a certain number of ideas is arguably only one part of creativity. The second dimension to measure creativity on divergent thinking tasks is assessing the originality of the generated items (Guilford, 1967; Reiter-Palmon et al., 2019). For example, if a participant is asked to generate new and unique uses for 'brick', suggesting it could be used as a 'cooking rock' would be considered less original than suggesting it could be used as a 'mortar and pestle' because bricks have more commonly been used as cooking rocks while camping, but are rarely used to grind herbs as a mortar and pestle. Originality can further be broken down into three dimensions: uncommonness, remoteness, and cleverness (for details on each of these dimensions see, Forthmann et al., 2017; Guilford, 1966; Reiter-Palmon et al., 2019; Wilson, et. al., 1953). Due to the wide variety of responses that participants may generate on the AUT, extensive rating training with multiple raters is typically required to ensure reliability and validity of the measure (Forthmann et al., 2017; Reiter-Palmon et al., 2019; Silvia et al., 2017).

Convergent thinking involves the generation of a single solution to a set problem. In convergent thinking tasks, participants are instructed to provide only one solution, with responses being measured as either correct or incorrect (Croply, 2006). Two of the most widely used convergent thinking tasks used to measure creativity are Analogical Reasoning Tasks and Remote Associates Task.

Analogical reasoning involves the ability to discern (and use) the similarity between two concepts, events, or situations (Gentner, 1983; also see Gentner & Smith, 2013). One of the most well-known analogical reasoning tasks is Dunker's (1945) radiation problem (Gick & Holyoak, 1980, 1983; Gray & Holyoak, 2021; Keane, 1988; Morsanyi et al., 2022). In this problem, participants are first presented with an expository text about a military general and his army attacking a fortress. To avoid detonating mines that surround the fortress, the general breaks his army into smaller groups and then sends them down different roads to capture the fortress. After reading this text, participants are presented with an expository text about medical problem in which a tumor must be destroyed using a ray while preserving the healthy tissue surrounding the tumor. Here, the solution is to use multiple, lower intensity rays to destroy the tumor.

The intention is that an individual completing an analogical reasoning task, will draw on the solution from one story problem and then apply it to solve another story problem. In the Gick and Holyoak (1980, 1983) example, the individual should use the solution from the first story problem (i.e., smaller armies being dispersed to capture the fortress) as an analogy to help them solve the second story problem (i.e., using multiple rays of low radiation to converge on the tumor). Research on these types of tasks has shown that individuals are able to solve the second story problem, though the likelihood of solving the problem is significantly greater when individuals are provided with a hint of using the first story as an analogy. (George & Wiley, 2019; Gick & Holyoak, 1980, 1983; Keane, 1988). Interestingly, some research conducted in more applied (design) settings suggests a hint may not be necessary for successful analogical reasoning (for architecture, see Ozkan & Dogan, 2013; for engineering, see Ball et al., 2004; for an exception, see Casakin & Goldschmidt, 1999; Vendetti et al., 2015). Specific to the concept of creativity, analogical reasoning tasks often require individuals to connect two (seemingly) dissimilar ideas in a novel way, such that the individual attempts to recall or generate possible ideas with the goal of selecting the best solution to apply to the current problem (Ozkan & Dogan, 2013).

1.1.1. Remote Association Task (RAT)

Another commonly used convergent thinking task used to measure creativity is the Remote Association Task (hereafter referred to as RAT; developed by Mednick, 1962; expanded by Bowden & Jung-Beeman, 2003). To review, this task consists of presenting participants with three cue words that are remotely associated with a fourth word, and the goal for participants is to generate the fourth word. For example, participants are presented with the cue words "Worm – Shelf – End", which would have a target solution of "Book." In this example, each of the three cue words are remotely associated with the target word because they form compound words (i.e., bookworm, bookshelf, and bookend).

One leading explanation for how participants solve RAT problems is the associative theory (Benedek et al., 2012; Collins & Loftus, 1975; Mednick, 1962; Wu et. al., 2017, 2020). The associative theory suggests that concepts organized in memory are part of an interconnected network and that each concept is connected to another concept in three ways: serendipity, similarity, and mediation. Serendipity is the association between different concepts because both were present in a similar environment or context. For example, the smell of cookies and the texture of a wooden table could be associated because they were both present in an individual's childhood memory at their grandparents' house. Similarity is the association between different concepts because they share certain traits that are alike. For example, rhyming words (e.g., pool and tool), could be associated because they share similar word structures. Finally, mediation is the association between two concepts through a third concept. For example, the concepts "stomach" and "rain" could be associated because a third concept "acid" creates the compound concept “stomach acid” and “acid rain.” As new concepts and ideas are incorporated into the associative network, new connections are made and the network grows in complexity, which in turn increases activation of and accessibility to concepts. The RAT is a useful measure of creativity as it maintains a similar format across sets and trials (e.g., all RAT problem sets involve presenting participants with three cue words), the difficulty of problem sets can be manipulated (e.g., the stronger the association between cue words and the target solution, the easier the RAT is to solve, and vice versa), and it has one expected correct solution.

1.2. Background on Collaborative Learning

A rapidly growing area of research within the domain of cognitive psychology is collaborative learning, which has primarily focused on costs and benefits that emerge when individuals work together in groups (for reviews, see; Rajaram, 2011; Rajaram & Pereira-Pasarin, 2010). Understanding how best to support collaborative processes is critical, as individuals are often asked to work together in a variety of settings (for education see, Premo et. al., 2018; for healthcare see, Rycroft-Malone et. al., 2015; for business see, Wang & Archer, 2004). In terms of educational settings in particular, research indicates faculty are increasingly incorporating collaborative learning into their classrooms (National Research Council, 2012) and that students report studying in groups to learn class content (Geller et. al., 2019; Hartwig & Dunlosky, 2012; Karpicke et. al., 2009; Wissman & Rawson, 2016).

A typical collaborative learning paradigm follows a common design, such that participants are asked to learn some type of to-be-learned information and then work either together (most often as a dyad or triad) or individually recall the information. Often times, participants complete a final, individual test after a delay to examine effects that follow collaboration. A robust, and arguably counterintuitive, finding in the literature is that individuals working together in a group, recall less information compared to individuals working alone (referred to as collaborative inhibition; Basden et al., 1997; Blumen & Rajaram, 2008; Finlay et al., 2000; Takahashi & Saito, 2004; Weldon & Bellinger, 1997; Wissman, 2020; Wright & Klumpp, 2004). To appropriately compare recall for individuals working collaboratively versus individually, performance is assessed by comparing the number of items generated by the collaborative group compared to the number of non-redundant items generated by the same number of individuals working alone (referred to as the nominal group). To illustrate, imagine participants are asked to learn a set of items: A, B, C, D, E, F, G, and H. The collaborative group includes two participants, who work together to recall A, B, D, E and F—a total of five items. The nominal group includes two participants working individually; Participant 1 recalls A, C, E, and G and Participant 2 recalls A, B, D, E, and H. Combining the recall from Participants 1 and 2 (and eliminating redundant items) results in the recall of A, B, C, D, E, G, and H—a total of seven items. The finding that recall is lower for participants working collaboratively versus individually is the phenomenon referred to as collaborative inhibition.

A majority of collaborative learning research has focused on collaborative inhibition, with outcomes demonstrating it is a robust effect. For example, research has shown that the effect emerges across of variety of to-be-learned information, such as unrelated word lists (Andersson & Meudell, 2006; Blumen & Rajaram, 2008), taxonomically related word lists (Basden et al., 2002; Wissman & Rawson, 2016), DRM lists (Roediger & McDermott, 1995), semantic and episodic tasks (Andersson & Rönnberg, 1996), and key-term definitions (Wissman, 2020). Research has also established that the effect emerges across different types of learners, such as children (Gummerum et al., 2013; Leman & Oldham, 2005), younger adults (Blumen & Stern, 2010; Harris et. al., 2008), and older adults (Blumen & Stern, 2010; Ross et al., 2004).

Finally, research has shown that how learners work together to recall information can impact the magnitude of collaborative inhibition, such that the effect is stronger when leaners openly recall information versus take turns recalling information (Barber et al., 2010; Harris et. al., 2012).

Given that collaborative inhibition is a well-established effect, research has also investigated underlying mechanisms of the effect to better understand when and why the effect occurs. Though a handful of explanations have been proposed (for part-list cueing, see Blumen & Rajaram, 2008; for social contagion errors, see Barnier et al., 2008) the leading theoretical account for collaborative inhibition is the retrieval disruption hypothesis (Basden et al., 1997; Finlay et al., 2000; Weldon & Bellinger, 1997). The retrieval disruption hypothesis suggests the output by one group member disrupts the way in which other group members have organized information in their memory, which in turn has a negative impact on recall. In other words, each individual develops a unique retrieval organization of information, which is disrupted during collaborative recall and in turn leads to decreased recall (i.e., collaborative inhibition).

Interestingly, particularly for current purposes, collaborative inhibition has also been shown in research focused on brainstorming (Diehl & Stroebe, 1987, 1991; Kohn & Smith, 2011; Schmidt & Hunter, 1999). This line of research has investigated the ability of groups to generate ideas when working together. Similar to the collaboration inhibition effect observed in collaborative learning research, research on brainstorming has also shown productivity deficits when individuals are working together to generate ideas. For example, Kohn and Smith (2011; Experiment 1) provided participants with a brainstorming topic, and then had participants work individually or collaboratively to generate ideas. Results revealed productivity deficits for brainstorming groups compared to nominal groups. More specifically, the researchers observed a lower fluency rate (i.e., generation of fewer ideas) and a lower originality rate (i.e., generation of ideas across fewer categories) for the brainstorming group compared to the nominal group.

Research in this area suggests two factors that could contribute to productivity deficits observed during brainstorming: production blocking and evaluation apprehension (Diehl & Stroebe, 1987, 1991; Kohn & Smith, 2011). Similar to retrieval disruption, production blocking refers to the idea that listening to a group member's ideas distracts and interferes with an individual's own thought process (Diehl & Stroebe, 1987), and in turn leads to decreased output in a collaborative group (as compared to a nominal group). The disruption to one's thought process also contributes to individuals fixating on generating ideas for one type of category, which in turn lowers the overall originality of the group. Evaluation apprehension refers to the idea that an individual feels as though other group members will judge their ideas. If an individual feel concerned that their output may reveal something socially undesirable or that they will be criticized, they are likely to withhold their answers, which in turn decreases the production output of the group.

1.3. The Current Research

To revisit, the goal of the current research is to evaluate the effects of collaboration when engaging in creative problem-solving. Of particular interest is investigating how collaboration impacts problem-solving using a commonly used creative measure: the RAT. The RAT is a reliable and valid measure of creativity, while also being convenient and objective (Bowden & Jung-Beeman, 2003; Lee et al., 2014; Mednick, 1962; Sio & Ormerod, 2015; Zhu et al., 2019). Further, a recent meta-analysis by Wu and colleagues (2020) indicates that research using the RAT to assess creativity has been steadily increasing in recent years. This meta-analysis focused on studies published between 2000-2019 that used the RAT to measure creative problem-solving. Results revealed that in those 20 years, approximately 170 studies used the RAT to measure creativity. Interestingly, only about 15% of this research occurred during the 2000-2009 timeframe, with 65% of these publications coming from the last five years (2015-2019) and 30% of these studies coming from the last two years alone (2018-2019). Outcomes from Wu et al. (2020) provide clear evidence that the RAT is an increasingly used tool by researchers for assessing creative problem-solving.

Of greatest interest for current purposes, the meta-analysis also revealed only two studies using the RAT involved collaboration (referred to as social interaction by Wu and colleagues). Weinstein et al. (2010) examined whether priming group members to have an autonomy (versus control) orientation would enhance RAT performance and task experience. Outcomes revealed that autonomy-primed dyads performed better on the RAT, with these participants reporting stronger connections with their partners (e.g., celebrating each other's successes) and greater task engagement (e.g., more guesses during the RAT). Colzato et al. (2013) assessed whether priming group members to think socially (versus individually) impacted performance on RAT performance and task experience. Outcomes revealed that when dyads were primed to feel integrated into the group (e.g., the dyads were primed to feel as if they were a team), they talked more to their group members. Critically, neither Weinstein et al. (2010) nor Colzato et al. (2013) included an individual comparison group. In other words, these studies were not equipped to compare how working collaboratively (versus individually) impacts performance on the RAT. As such, it is still an open question as to how engaging in collaborative versus individual problem-solving impacts creativity using the RAT.

How might collaboration impact creative problem-solving on the RAT? Interestingly, research from both collaborative learning literature and the creativity literature suggests factors that may promote or disrupt creative problem-solving in this context. On one hand, research from Colzato et al. (2013) and Weinstein et al. (2010) revealed that working in a group can have a positive impact on task engagement, which may in turn have a positive impact on RAT performance when working collaboratively. Research also suggests that working in a social setting can facilitate motivation, and that this increased motivation may lead to greater generation of ideas (for review, see Paulus & Dzindolet, 2008). In this sense, collaboration may promote creative problem-solving on the RAT.

On the other hand, research has shown that collaborative inhibition is a robust effect, which would suggest that working collaboratively may have a negative impact on RAT performance. For example, when attempting to solve RAT problems, each set of cue words will activate individuals' respective organizational networks, which presumably will be different for each learner. With different concepts and organizational structures being activated across different learners during collaborative problem-solving, there may be a greater likelihood for retrieval disruption (Basden et al., 1997; Weldon & Bellinger, 1997). Furthermore, brainstorming research suggests that production blocking (similar to retrieval disruption) and evaluation apprehension may hinder creativity in a collaborative context (Diehl & Stroebe, 1987, 1991; Kohn & Smith, 2011). Notably, when collaborating with others, a certain level of vulnerability should be considered, as each group member risks being viewed negatively when outputting information, which may lead to learners withholding their ideas. During creativity tasks in particular, learners are often required to generate unconventional or unique ideas, which means the necessary level of vulnerability may be even higher. Taken together, these lines of research suggest that collaboration may hinder creative problem-solving on the RAT.

1.4. Summary

To summarize, no research has systematically evaluated whether working collaboratively versus individually facilitates creative problem-solving on the RAT. Participants were asked to work either collaboratively (in dyads) or individually to solve 20 RAT problems. Of primary interest is to examine performance on the RAT for individuals who work collaboratively versus individually. Interestingly, existing theories and empirical evidence from collaborative learning research and creativity research for how collaboration might impact creative problem solving is mixed: some research suggests collaboration may be detrimental (Diehl & Stroebe, 1987; Finlay et al., 2000; Kohn & Smith, 2011; Rajaram, 2011), whereas other research suggests collaboration may be beneficial (Kohn & Smith, 2011; Paulus et al., 2011; Paulus & Dzindolet, 2008). Though existing research suggests potentially differential effects of collaboration, I believe research suggesting that collaboration will hinder creative problem-solving is more compelling and in turn predicted that learners who engage in collaborative (versus individual) creative problem-solving will perform worse on the RAT.

Of exploratory interest, I also wanted to gain insight on the interactions and experiences of individuals working collaboratively versus individually during creative problem solving. When solving the RAT problems, dyads were asked to indicate who had solved the problem (if applicable), as I believed having some information on group dynamics (e.g., if there was a domineering partner) may help understand the effects of collaboration in these contexts. After solving the RAT problems, all participants were asked to individually respond to four post-experiment questions (hereafter referred to as PEQs). These PEQs were of exploratory interest, and asked about motivation, engagement, difficulty, and withholding responses. I explored motivation, engagement, and difficulty because some research has shown that these factors can vary based on collaborative versus individual settings (Colzato et al., 2013 & Weinstein et al., 2010) and that creativity can be influenced by social settings (for review, see Paulus & Dzindolet, 2008). I was also interested in asking participants if they withheld any solutions during the RAT task, as a way to measure evaluation apprehension (Kohn & Smith, 2011). Though not of primary interest, exploring these factors may help inform and further our understanding of how collaboration influences creative problem-solving.

2. EXPERIMENT 1 METHODS

2.1. Participants

The sample included undergraduate students from a large midwestern university who participated for course credit. The targeted sample size was n = 128, based on an a priori power analysis using G*Power 3.1.5 (Faul et al., 2009), with power set at .80 and α = .05 to detect a medium effect of d = .50. I slightly oversampled by collecting n = 136 to account for the potential non-compliance (i.e., spending less than 2 seconds per RAT trial); no participants in Experiment 1 were removed based on the exclusion criteria. The final sample included n = 68 in the collaborative group and n = 68 in the individual group, resulting in 34 collaborative groups and 34 nominal groups. The experiment was pre-registered in Open Science Framework (OSF) https://doi.org/10.17605/OSF.IO/CUGSX. The experiment was approved by the NDSU Institutional Review Board for human subject research.

2.2. Design

How participants complete the creative problem-solving task (i.e., 20 RAT problems) was manipulated between subjects. Participants either worked to solve RAT problems collaboratively (as a dyad) or individually.

2.3. Materials

Materials included 20 compound RAT items[2] developed by Bowden and Jung-Beeman (2003) and selected from an open-source repository created by Sio (2020; https://osf.io/6cwgv/).

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[2] The original material set included 20 items divided into two RAT sets: 10 easy (mean solution rate of 74%) and 10 difficult (mean solution rate of 37%). Upon recommendation from the committee, RAT performance was examined after the first few sessions of data collection. Data for the first 10 participants revealed floor effects (i.e., average performance was 25% across all items). Thus, the final material set included 20 items at the same (easy) difficulty level. Given the change in material set, data for the first 10 participants are excluded from all analyses.

The 20 items had a mean solution rate of 75% based on the normed data from Bowden and Jung-Beeman (2003). Table A.1. provides the 20 RAT item sets. Materials also included a four-item post-experimental questionnaire (PEQ), which probed participants about their experience with the experimental task. PEQs 1-3 asked participants how motivated they were to solve the RAT problems, how engaged they were when trying to solve the RAT problems, and how difficult they found trying to solve the RAT problems. For these PEQs, participants provided responses ranging from 1 (not at all) to 3 (very). PEQ 4 asked participants whether they withheld of response when trying to solve the RAT problems. For this PEQ, participants indicated Yes, No, or Unsure, and given the opportunity to explain their answer.

2.4. Procedure

At the beginning of the experimental session, a research assistant read the following script to learners:

> "In today's experiment, you will complete a problem-solving task. For this task, you may be asked to work with a partner or you may be asked to work individually. This will be randomly decided shortly. If you do not wish to participate in this study or do not feel comfortable working in a group, please let me know."

Learners were asked to read and sign an informed consent form, and then seated at a computer to begin the experiment. Learners working individually were seated at their own computer. Learners working collaboratively were seated at a table with a plexiglass divider and one computer. All learners were asked to read through experimental instructions provided on the computer and asked to see the researcher when they were ready to begin. Task instructions were as follows:

"During today's experiment, you will be asked to solve a set of 20-word problems. Each problem will consist of three words. Your task in solving this problem is to come up with a fourth word that is related to each of the three words. The fourth word is part of a commonly spoken compound word or phrase with one of the three words.

For example: Worm, Shelf, End

Solution: Book. (This is the correct answer because Bookworm, Bookshelf, and Bookend are all common compound phrases.)

[Shown only to the collaborative group]: Please work together however you see fit to generate the solutions. The individual sitting at the keyboard will type in your group's answers.

You will have up to 30 seconds to solve each word problem. If you come up with an answer sooner, you can enter your response and advance to the next word problem.

[Shown only to the collaborative group]: Following each word problem, you will be asked to indicate who generated the answer. You will have the option to select '1' (participant sitting on the left), '2' (participant on the right), '3' (unsure) or 'N/A' (No answer was generated). Once you submit this answer, you will continue to the next word problem.

Please see the researcher now to begin the experiment."

After learners read through the instructions, the researcher asked them if they had any questions. After all questions were answered and learners were ready, the researcher advanced their computer to begin the experiment.

Presentation of the 20 RAT problems was randomized anew for each learner (or group). For each RAT problem, learners were given up to 30 seconds to respond. If a response is generated sooner, learners were able to submit their response and advance themselves. Following submission of target words for each RAT problem, learners in the individual group advanced to the next RAT problem. Following submission of target words for each RAT problem, learners in the collaborative group advanced to a screen that asks them to indicate who generated the response, with the option of entering a 'The participant sitting on the left (Who is typing)', 'The participant sitting on the right (Who is not typing)', 'Unsure (For example, we do not remember)', or 'N/A (For example, we did not come up with an answer)'. They then advanced to the next RAT problem[3].

After completion of the 20 RAT problems, all learners (individually) completed the PEQ. Learners in the individual group remained at their computers to complete the PEQ. Learners in the collaborative group were moved to individual computers to complete the PEQ.

2.5. Scoring

Performance on the RAT were scored as 0 (incorrect) or 1 (correct) for each problem set, for a total of 20 possible points. Performance is reported as the proportion of correctly solved RAT problem sets as a function of group (collaborative versus individual). Consistent with the collaborative learning literature, I report nominal recall (instead of individual recall) for RAT performance. Nominal groups consist of participants who completed the experiment in the same session or participants who completed the experiment on approximately the same day. Nominal

[3] Concerning outcomes of the follow-up question about which group member generated the solution, instances in which one member dominated providing responses (i.e., one group member generated a response on more than 50% of RAT problems) was rare, with this only occurring in 5 (of the 34) groups. As such, these outcomes are not discussed further and the follow-up question was excluded from Experiment 2.

recall was computed post-hoc by pooling non-redundant target responses on RAT problems from each participant within the nominal group.

For the open-ended PEQ in which learners had the opportunity to explain why they did (or did not) withhold an answer, a scoring key was developed based on participant responses. To establish inter-rater reliability, a subset of 20 protocols was scored by two raters. Overall agreement between the two raters was high (91% agreement); disagreements were resolved via discussion.

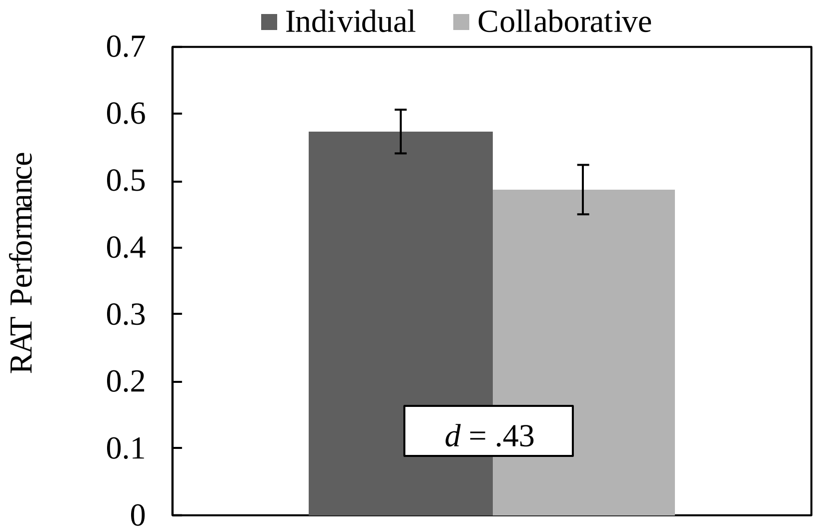
3. EXPERIMENT 1 RESULTS [4]

I used R Studio software (R Core Team, 2021) and IBM SPSS Statistics (Version 28) to conduct inferential statistics. In Experiment 1, the a priori directional prediction of primary interest (i.e., RAT performance for the individual versus collaborative group will be greater) was tested using one-tailed independent samples *t* test (see Judd & McClelland, 1989; Maner, 2014; Rosnow & Rosenthal, 1989; Tabachnick & Fidell, 2001; Wilkinson & Task Force on Statistical Inference, American Psychological Association).

As a reminder, the primary focus of Experiment 1 was to examine how working collaboratively versus individually impacts creative problem-solving on the RAT. Consistent with my prediction, results showed that the collaborative (M = 0.49, SE = 0.04) versus individual (M = 0.57, SE = 0.03) group solved significantly fewer RAT problems, $t(66) = 1.76$, $p = 0.042$, $d = 0.43$ (see Figure 1). This outcome provides initial evidence that working collaboratively does not benefit creative problem-solving, and in fact, may be disadvantageous. The finding that RAT performance was lower in the collaborative versus individual group also provides the first demonstration of collaborative inhibition (a robust effect in the collaborative learning literature; see Rajaram, 2011).

[4] The material in this chapter was co-authored by Alexander Knopps and Dr. Kathryn Wissman. Alexander Knopps had primary responsibility for designing, leading data collection, and analyzing the results. Alexander Knopps was the primary developer of the conclusions that are advanced here. Alexander Knopps also drafted and revised all versions of this chapter. Dr. Kathryn Wissman served as proofreader and checked the math in the statistical analysis conducted by Alexander Knopps.

Figure 1. Experiment 1: RAT performance



Note. Standard error is reported in parentheses in results. Cohen's d effect size is reported in the box.

Concerning outcomes of exploratory interest, I examined PEQ responses, which included participants' self-reported motivation (PEQ 1), engagement (PEQ 2), perceived difficulty (PEQ 3), and withholding responses during the experiment (PEQ 4). Table 1 provides the mean values for PEQs 1-3, with response categories ranging from 1 = very to 3 = not at all. Participants in the collaborative versus individual group showed no differences in their ratings of motivation (p = .762) or engagement ($p = 1.0$). The only significant difference between the collaborative and individual groups concerned self-reporting of task difficulty, such that participants who worked individually perceived the task as more difficult, $t(134) = 2.02$, $p = 0.045$, $d = 0.51$. Outcomes for PEQs 1-3 are discussed further in the Experiment 1 Discussion.

Table 1. PEQ 1-3 Responses for the Individual Versus Collaborative Group in Experiment 1

	Collaborative	Individual
Motivation	1.71 *(0.07)*	1.68 *(0.07)*
Engagement	1.21 (*0.05)*	1.21 *(0.05)*
Difficulty	1.76 *(0.06)*	1.59 *(0.06)*

Note. The table represents the mean results of the collaborative or individual groups response options on PEQs 1-3. The standard error is reported in parenthesis.

Concerning PEQ 4, only 15% (n = 10) of participants in the collaborative group reported withholding a response when attempting to solve the RAT problems. This result suggests evaluation apprehension (i.e., individuals withholding solutions because they are concerned about how their ideas may be perceived by a group member; Diehl & Stroebe, 1987, 1991; Kohn & Smith, 2011) was not present in the current research. To foreshadow, a similar pattern was observed in Experiment 2.

As a reminder, PEQ 4 also included an open-ended prompt which allowed participants to explain a rationale for their response. These responses were coded and analyzed in an attempt to better understand participants' reasoning for their PEQ 4 response. Of the 136 participants, 92 participants provided a response to the open-ended prompt. Unfortunately, a majority of responses to the open-ended question did not yield informative answers about why participants did (or did not) withhold responses. For example, of the relatively few numbers of participants who reported that they did withhold a response, a substantial number of participants responded by saying "they could not think of an answer", with approximately 79% of participants in the individual group and 56% of participants in the collaborative group providing this rationale. As an additional example, of the participants who reported that they did not withhold a response, a majority of participants responded by saying "I answered when I could", with approximately 79% of participants in the individual group and 85% of individuals in the collaborative group providing this rationale. It is perhaps worth noting that approximately 33% of collaborative participants reported withholding a response they thought were wrong, but this outcome should be interpreted cautiously given the extremely low number of participants who provided this explanation (*n* = 3). In general, a majority of participants provided non-informative responses to the open-ended prompt, with very few participants indicating that they withheld a response, which in turn resulted in a relatively small number of participants contributing to these exploratory analyses. As such, I do not discuss the PEQ 4 open-ended responses further for Experiment 1 or Experiment 2. For purposes of openness and transparency, Table A.2. & A.3. provides a breakdown of the open-ended coding and response rates for interested readers.

4. EXPERIMENT 1 DISCUSSION

The goal of Experiment 1 was to evaluate how collaboration impacts creative problem-solving. Participants worked either collaboratively (in a dyad) or individually to complete 20 RAT problems, with outcomes focusing on the proportion of correctly solved problems. Most importantly, results revealed that working collaboratively did not enhance creative problem-solving. In fact, the pattern of results was consistent with collaborative inhibition, such that participants working collaboratively versus individually solved fewer RAT problems ($d = 0.43$).

Why might collaboration not benefit creative problem-solving on the RAT? To review, the leading explanation for collaborative inhibition is the retrieval disruption hypothesis, which posits that when individuals are working together to recall previously studied information, the output of one group member disrupts the organization and retrieval process of another group member. It is worth highlighting that the design used in the current research differs slightly from more traditional collaborative learning research in that there was no initial learning phase. Thus, the opportunity for retrieval disruption (as typically thought of in the literature) is unlikely. One can imagine, however, that retrieval disruption may still be occurring in the current context albeit in a different way—namely, the disruption of group members' (non-overlapping) associative networks. According to associative theory, individuals organize ideas and concepts in their memory through associations, which leads to a uniquely organized set of concepts (Benedek et al., 2012; Collins & Loftus, 1975; Mednick, 1962). When attempting to solve RAT problems, individuals rely on these networks to generate a solution (Wu et. al., 2017). In a collaborative context, the activation of the unique, associative networks of each group member may disrupt the output during problem-solving. For example, imagine that Participant 1 and Participant 2 are attempting to solve the RAT problem 'Worm – Shelf – End'. Participant 1 might focus on the word “worm”, which in turn would activate similar ideas in their associative network, such as ‘nature’ and ‘tree’. In contrast, Participant 2 might focus on the word ‘end’, which in turn would activate ideas like ‘finish’ and ‘complete’. As the participants work together, their (non-overlapping) ideas that get output may disrupt the process of finding connections between the three items and in turn lead to an inability to get to a solution (in this illustrative example, ‘Book’). This (modified) retrieval disruption of associative networks across group members may help explain why individuals in the collaborative group solved fewer RAT problems and in turn why collaboration did not yield a benefit to creative problem-solving.

Another possible explanation for why collaboration did not benefit creative problem-solving concerns time on task. More specifically, some research has shown that collaboration may be less efficient, such that it takes participants more time to achieve similar levels of performance when engaging in collaborative compared to individual retrieval practice (Wissman & Rawson, 2018). Concerning Experiment 1, examination of time on task during RAT problem-solving showed no differences in average trial time for collaborative (M = 20.1 seconds, SE = 0.43) versus individual (M = 19.7 seconds, SE = 0.39) groups. This suggests that when learners have a set amount of time to complete RAT problems, working individually may be a more efficient and effective use of time. An open question, and potentially interesting direction for future research, would be to investigate collaborative versus individual problem-solving on the RAT when time on task is self (as opposed to experimenter) paced.

Concerning PEQs of exploratory interest, results showed that motivation and engagement did not differ across the collaborative and individual groups, whereas participants who worked individually reported greater perceived difficulty with the task. Prior research has shown that collaboration can increase task engagement (Colzato et al., 2013; Weinstein et al., 2010) and facilitate motivation (Blumenfeld et al., 2006; Järvelä et al., 2010), though this can depend on individuals' characteristics, goals, and situational demands (Boekaerts & Corno, 2005; Efklides & Volet, 2005; Järvenoja & Järvelä, 2005; Järvelä et al., 2010). Of relevance here, one situational factor that may have impacted engagement and motivation is the perceived difficulty completing the RAT. If the collaborative participants perceived the task as less difficult, this may reduce the extent to which they felt engaged and motivated to complete the task, which in turn could explain why differences between the collaborative and individual group did not emerge for these two factors. Continued exploration of how both situational factors and personal perceptions impact collaborative versus individual problem-solving will be important for furthering our understanding of how creativity is impacted in these contexts.

5. EXPERIMENT 2 INTRODUCTION

As a reminder, Experiment 1 showed no benefit of working collaboratively compared to individually for creative problem-solving on the RAT. Indeed, outcomes showed a pattern of results consistent with the collaborative inhibition effect such that problem-solving was worse when learners worked collaboratively versus individually. Given that this was the first evaluation of collaborative versus individual problem-solving using the RAT, the primary goal of Experiment 2 was to investigate this effect again. Indeed, scholars in the field increasingly emphasize the importance of replication, particularly for novel findings (see Fletcher, 2021; LeBel & Peters, 2011; Pashler & Harris, 2012; Plucker & Makel, 2021; Roediger, 2012; Schimmack, 2012; Simons, 2014). As such, the primary goal of Experiment 2 was to evaluate the effects of collaboration when engaging in creative problem-solving using the RAT for a second time. Similar to my prediction in Experiment 1 and consistent with Experiment 1 results, I predicted that participants who engaged in collaborative versus individual problem-solving would perform worse on the RAT.

The secondary goal of Experiment 2 was to investigate another common finding in collaborative learning literature: post-collaborative benefits. Post-collaborative benefits refer to the finding that individuals who previously engaged in collaborative (as compared to individual) recall perform better on a later, individual final test (Blumen & Rajaram, 2008; Congleton & Rajaram, 2011; Harris et. al., 2012; Wissman & Rawson, 2015; for a chapter overview, see Rajaram, 2018). Though explored to a much lesser extent than collaborative inhibition, post-collaborative benefits have been observed in a variety of settings. For example, research has shown that the effect emerges across different kinds of to-be-learned information, such as unrelated word lists (Blumen & Rajaram, 2008; Harris et. al., 2012) and taxonomically related word lists (Congleton & Rajaram, 2011; Wissman & Rawson, 2015). Post-collaborative benefits have also been shown when different retention intervals between practice and final test have been used, though the effect does tend to be stronger after short delays (Blumen & Rajaram, 2008; Blumen & Stern, 2011; Congleton & Rajaram, 2011; Harris et. al., 2012; Wissman & Rawson, 2015). Importantly, this effect suggests that though there may be an initial cost when working collaboratively (i.e., collaborative inhibition), there may also be a later individual benefit (i.e., post-collaborative benefits). Given that Experiment 1 revealed a pattern consistent with collaborative inhibition for creative problem-solving using the RAT, it is possible that post-collaborative benefits may also emerge for this type of material.

How might collaborative versus individual creative problem-solving on the RAT impact subsequent individual problem-solving? Collaborative learning research has investigated underlying mechanisms of post-collaborative benefits to better understand why the effect occurs. The two leading theoretical accounts for post-collaborative benefits are *re-exposure* (Blumen & Rajaram, 2008; Weldon & Bellinger, 1997) and *cross-cueing* (Harris et al., 2012; Meudell et al., 1995; Meudell et al., 1992). Re-exposure refers to the idea that when collaborative group members work together to recall the to-be-learned information, one group member may recall an item that the other group member would have otherwise forgotten, which provides the first group member with additional restudy of the item. Cross-cueing refers to the idea that when group members work together to recall the to-be-learned information, one group member may recall an item that cues the other group member to recall an item, which provides the second group member with additional retrieval practice. Though these mechanisms have been used to explain post-collaborative benefits, it is important to remember that the current research differs from a more typical, collaborative learning paradigm in one (potentially meaningful) way: there is no initial study phase. In a more traditional collaborative learning paradigm, participants first (individually) study some type of to-be-learned material, then engage in (collaborative versus individual) recall of that material, and then take a final (individual) test. In contrast, in the current research, all participants initially engage in collaborative versus individual problem-solving, which in turn means the opportunity for additional restudy (via re-exposure) and retrieval practice (via cross-cueing) may be unlikely. More specifically, without initial learning, there may not necessarily be an opportunity to re-learn otherwise forgotten information, which is presumably a leading explanation as to why post-collaborative benefits emerge. Furthermore, though post-collaborative benefits have been observed in the literature, it is worth noting that a majority of this research has used relatively simple to-be-learned material (i.e., word lists). In fact, some research using more complex material has not shown evidence of post-collaborative benefits (for lecture and statistical tests, see Pociask & Rajaram, 2014; for key-term definitions, see Wissman, 2020; Wissman & Rawson, 2018). This is particularly relevant for current purposes given that the RAT problems are identified as complex material (Wu et. al., 2020).

Investigating the downstream effects of collaborative problem-solving will provide insight into how working together affects the creative problem-solving process. Indeed, exploring how performance is affected both *during* collaborative problem-solving and *following* collaborative problem-solving has important implications for educational contexts (Premo et. al., 2018; Rajaram, 2011) and understanding creativity is a learned skill more generally (DeHaan, 2009; Wu et al., 2020). In addition, investigating whether post-collaborative benefits do (or do not) emerge for RAT problems will provide novel evidence to the collaborative learning literature.

5.1. Summary

The goal of Experiment 2 was to replicate and extend upon Experiment 1. Of secondary interest, I wanted to gain insight into creative problem-solving performance *following* collaboration. Thus, in Experiment 2, participants completed a final, individual test following the initial collaborative or individual problem-solving practice. On this test, all participants worked individually to solve the previously attempted RAT problems and a set of new RAT problems. Based on existing theories and empirical evidence from the collaborative learning literature, I predicted that the participants who previously worked in the collaborative group will perform worse on the reattempt of the 20 RAT problems than the participants who continuously worked individually. Of exploratory interest, I wanted to gain insight into how the collaborative learning paradigm (i.e., collaborative versus individual practice and an individual final test) influenced individual's creative problem-solving on a new set of RAT problems. After participants completed the 20 RAT problems for a second time, they were asked to complete a new set of 20 RAT problems. Concerning the outcomes of the new set of RAT problems, I did not have a directional hypothesis but was interested in exploring whether working collaboratively or individually facilitated transfer for creative problem-solving.

6. EXPERIMENT 2 METHOD

6.1. Participants

The sample included undergraduate students from a large midwestern university who participated for course credit. The target sample size was n = 136, based on an a priori power analysis using G*Power 3.1.5 (Faul et al., 2009), with power set at .80 and α = .05 to detect a medium effect of d = .43 (the effect size observed in Experiment 1). I slightly oversampled by collecting n = 143 to account for the potential non-compliance (i.e., spending less than 2 seconds per RAT trial). One participant from the individual group was removed from the final dataset to allow for an even number of participants for purposes of constructing nominal dyads. The final sample (n = 142) included n = 74 in the collaborative group is and n = 68 in the individual group, resulting in 37 collaborative groups and 34 nominal groups. The experiment was pre-registered in Open Science Framework (OSF) https://doi.org/10.17605/OSF.IO/D5JSC. The experiment was approved by the NDSU Institutional Review Board for human subject research.

6.2. Design

How participants complete the practice creative problem-solving task (i.e., 20 RAT problems on the practice phase) was manipulated between subjects. Participants worked either collaboratively (as a dyad) or individually to solve the problems only during practice problem-solving when completing the first set of 20 RAT problems (hereafter referred to as Phase 1). After a short delay, all participants worked individually to solve the 20 previously attempted RAT problems and 20 novel RAT problems (hereafter referred to as Phase 2).

6.3. Materials

Materials included 20 RAT problems used in Experiment 1 plus an additional 20 RAT problems. For Experiment 2, the RAT problems were divided into two sets of 20 (Set A and Set

B), with each set having a mean solution rate of 68% (See Table A.5). During Phase 1, participants completed Set A. During Phase 2, participants completed Set A followed by Set B.

6.4. Procedure

The procedure was the same as Experiment 1 with two exceptions. First, following collaborative versus individual problem-solving (Phase 1), all participants completed an unrelated distractor task for 5 minutes. Following the distractor task, all participants individually completed Phase 2. During Phase 2, participants were first asked to solve the same, previously attempted 20 RAT problems from Phase 1 (shown in a random order). Participants were then asked to solve 20 new RAT problems (shown in a random order). Similar to Phase 1, during Phase 2, participants were given up to 30 seconds to solve each RAT problem. If a response was generated sooner, participants were able to submit their response and advance themselves. The second change in Experiment 2 was the elimination of the question asking participants in the collaborative group to indicate who generated the solution was not included, as this measure yielded no meaningful information in Experiment 1. Excluding this follow-up question further ensured task expectations were equivalent across the two groups prior to completing Phase 2.

7. EXPERIMENT 2 RESULTS[5]

I used R Studio software (R Core Team, 2021) and IBM SPSS Statistics (Version 28) to conduct inferential statistics. In Experiment 2, the a priori directional prediction of primary interest for purposes of replication (i.e., Phase 1 RAT performance for the individual versus collaborative group) was tested using one-tailed independent samples *t* test (see Judd & McClelland, 1989; Maner, 2014; Rosnow & Rosenthal, 1989; Tabachnick & Fidell, 2001; Wilkinson & Task Force on Statistical Inference, American Psychological Association).

Consistent with my prediction, results indicated that the collaborative group ($M = 0.48$, $SE = 0.03$) versus individual group ($M = 0.54$, $SE = 0.03$) solved numerically fewer RAT problems $t(69) = 1.40$, $p = 0.084$, $d = 0.33$ (see Figure 2). Though this effect did not cross the threshold of statistical significance, it is important to note that the outcome is in the anticipated direction and similar to the pattern of results observed in Experiment 1. More generally, this outcome provides additional evidence that working collaboratively does not benefit creative problem-solving, and in fact, may be disadvantageous.

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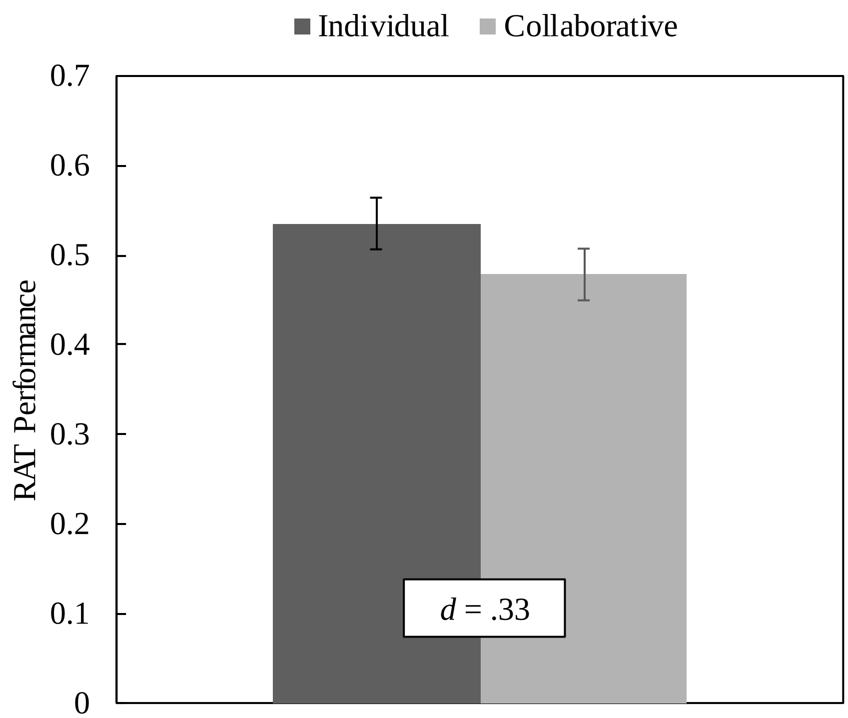
[5] The material in this chapter was co-authored by Alexander Knopps and Dr. Kathryn Wissman. Alexander Knopps had primary responsibility for designing, leading data collection, and analyzing the results. Alexander Knopps was the primary developer of the conclusions that are advanced here. Alexander Knopps also drafted and revised all versions of this chapter. Dr. Kathryn Wissman served as proofreader and checked the math in the statistical analysis conducted by Alexander Knopps.

Figure 2. Experiment 2: RAT Phase 1 Performance

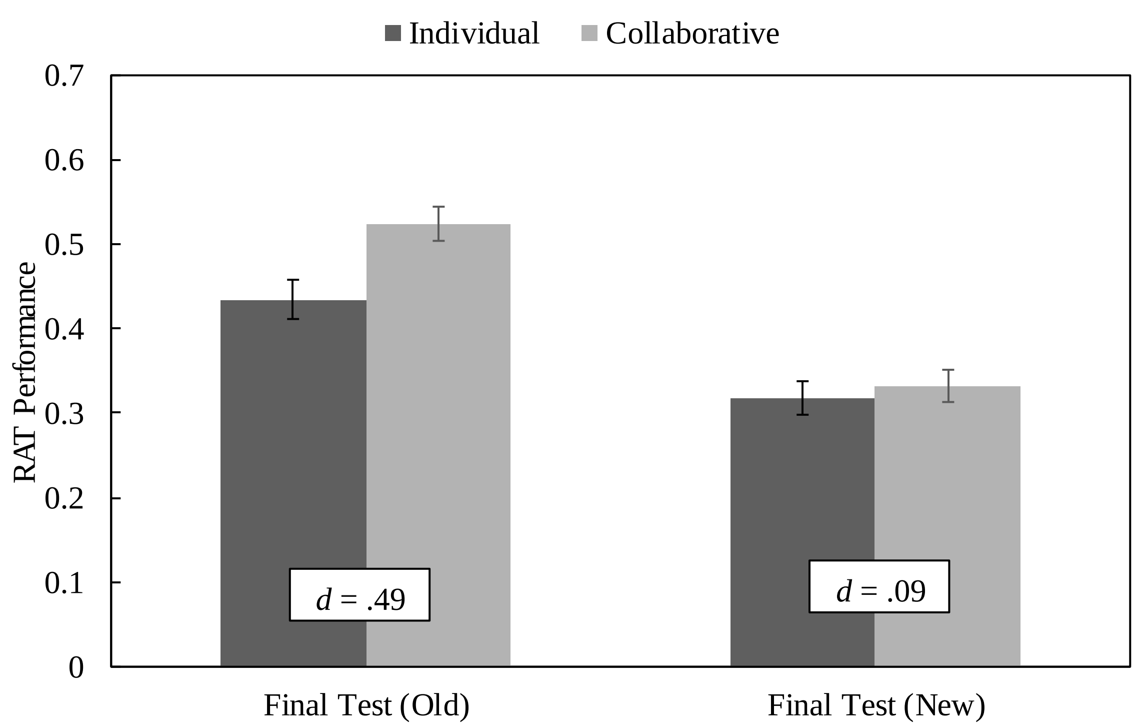


Note. Standard error is reported in parentheses in results. Cohen's d effect size is reported in the box.

Concerning outcomes of secondary interest, using a two-tailed independent samples *t* test, I examined how collaborative versus individual creative problem-solving on the RAT impacted subsequent individual problem-solving for both repeated and novel RAT problems. Concerning performance for repeated RAT problems, contrary to my prediction results showed that the participants in the collaborative group (M = 0.52, SE = 0.02) versus individual group (M = 0.43, SE = 0.02) solved significantly *more* RAT problems, $t(141) = 2.92$, $p = 0.006$, $d = 0.49$ (see left panel of Figure 3). This outcome provides initial evidence that although working collaboratively may not initially benefit creative problem-solving, it may benefit later individual problem-solving. This outcome also provides the first demonstration of post-collaborative benefits for creative problem-solving with the RAT material set (for similar findings see Blumen

& Rajaram, 2008; Congleton & Rajaram, 2011; Harris et. al., 2012). Concerning performance for novel RAT problems, results showed that participants in the collaborative group (*M* = 0.33, *SE* = 0.02) versus individual group (*M* = 0.32, *SE* = 0.02) solved a similar number of RAT problems, $t(140) = 0.52$, $p = 0.613$, $d = 0.09$ (see right panel of Figure 3). This result suggests that although collaboration may benefit later individual performance for re-attempted RAT problems, the benefit does not extend to novel RAT problems. Further discussion for how collaborative versus individual problem-solving impacts later individual problem-solving for both repeated and new RAT problems is provided in the Experiment 2 Discussion.

Figure 3. Experiment 2: RAT Phase 2 performance



Note. Standard error is reported in parentheses in results. Cohen's d effect size is reported in the box. The label "Final Test (Old)" refers to the performance on the repeated RAT problems. The label "Final Test (New)" refers to the performance on the new RAT problems.

Concerning outcomes of exploratory interest, I also examined PEQ responses, which included participants self-reported motivation (PEQ 1), engagement (PEQ 2), perceived difficulty (PEQ 3), and withholding responses during the experiment (PEQ 4). Table 2 provides the mean values for PEQs 1-3, with response categories ranging from 1 = very to 3 = not at all. Participants in the collaborative versus individual group showed no differences in their ratings of motivation, engagement, or perceived difficulty (all *ps* > .06). Concerning PEQ 4, only 23% (*n* = 17) of participants in the collaborative group reported withholding a response when attempting to solve RAT problems. When comparing PEQ outcomes across Experiments 1-2, it is important to highlight a slight discrepancy concerning when participants answered PEQ questions. More specifically, though PEQs were answered at the end of experimental tasks across both experiments, this resulted in PEQs being answered directly after collaborative versus individual problem-solving in Experiment 1 versus PEQs being answered after collaborative versus individual problem-solving (Phase 1) *and* individual problem-solving (Phase 2) in Experiment 2. Given this experimental design, Experiment 2 PEQ responses presumably reflect participants' task experience across both Phase 1 and Phase 2 problem-solving, which in turn means that comparison of PEQ responses across the experiments should be interpreted with caution.

Table 2. PEQ 1-3 Responses for the Individual Versus Collaborative Group in Experiment 2

	Collaborative	Individual
Motivation	1.64 *(0.07)*	1.80 *(0.07)*
Engagement	1.31 (*0.06)*	1.38 *(0.06)*
Difficulty	1.65 *(0.07)*	1.57 *(0.06)*

Note: The table represents the mean results of the collaborative or individual groups response options on PEQs 1-3. The standard error is reported in parenthesis.

8. EXPERIMENT 2 DISCUSSION

The goal of Experiment 2 was to replicate and extend on Experiment 1 by evaluating how creativity is affected *during* collaborative (versus individual) problem-solving and *following* collaborative (versus individual) problem-solving. To accomplish this goal, participants solved RAT problems across two phases; during Phase 1 participants worked either collaboratively or individually to solve 20 RAT problems and during Phase 2 participants worked individual to solve 40 (20 old and 20 new) RAT problems.

Most importantly, outcomes from Phase 1 showed that collaboration did not benefit creative problem-solving. Consistent with the results observed in Experiment 1, participants working collaboratively versus individually solved numerically *fewer* RAT problems (d = 0.33). Across Experiments 1-2, outcomes suggest a small-to-medium effect size for collaborative inhibition using the RAT material set, a discussion point I return to in the General Discussion.

Outcomes from Phase 2 showed that collaboration did benefit later, individual problem-solving for repeated items, providing the first evidence of post-collaborative benefits for creative problem-solving using the RAT. Indeed, performance on previously attempted RAT problems was significantly greater for participants who had engaged in collaborative versus individual problem-solving (d = .49). To review, the two leading explanations for post-collaborative benefits are *re-exposure*, the idea that one group member may recall an item that their partner would have otherwise forgotten (Blumen & Rajaram, 2008; Weldon & Bellinger, 1997), and *cross-cueing* (Harris et al., 2012; Meudell et al., 1995; Meudell et al., 1992), the idea that one group member may cue their partner to recall an item. Similar to retrieval disruption (as discussed in Experiment 1 Discussion), re-exposure or cross-cueing may not be directly applicable as the current research design did not involve an initial study period. However, thinking about modified versions of these accounts may offer explanations for the post-collaborative benefit observed for the repeated RAT items. In terms of re-exposure, Participant 1 may generate a solution for a RAT problem that Participant 2 was unable to solve, which in turn would enable Participant 2 to successfully solve this problem during Phase 2. For example, returning to the 'Worm – Shelf – End' example, Participant 1 might successfully generate the solution 'Book', which Participant 2 may have been unable to generate had they been working alone during Phase 1, but is now able to generate when working in Phase 2. In terms of cross-cueing, Participant 1 may say something during problem-solving that cues Participant 2 to generate the correct solution. For example, when Participant sees the word 'Shelf', it activates the idea of 'Paper', which in turn cues Participant 2 to generate the solution 'Book'. A fruitful direction for future research will be to explore underlying mechanisms of post-collaborative benefits when engaging in creative problem-solving.

Concerning novel RAT problems, outcomes showed no differences in performance for the collaborative versus individual groups. The finding that benefits did not emerge for novel RAT problems may support the (modified) re-exposure and cross-cueing explanations outlined above because these mechanisms may only function when participants attempt and then re-attempt each RAT problem. This finding has important implications for educational purposes, as the goal is to support students' ability to apply their learning and experiences to new situations (often referred to as transfer, Becheikh et al., 2010; Taylor & Jain, 2017).

9. GENERAL DISCUSSION

Collaboration and creativity are important skills in everyday life. The goal of the current research was to examine how collaboration impacts creative problem-solving using the RAT, a commonly used creative measure (Lee et al., 2014; Wu et al., 2020; Zhu et al., 2019). Importantly, the current study provides the first systematic investigation of how collaborative versus individual problem-solving impacts creativity using the RAT. Critically, outcomes indicate that collaboration did not enhance creativity. In fact, across Experiments 1-2, outcomes showed a deficit, providing the first demonstration of collaborative inhibition for creative problem-solving using the RAT and suggesting that collaboration may hinder creative problem-solving.

Given that this was the first demonstration of collaborative inhibition on the RAT, a critical next step will be continued investigation of the replicability of this effect with this material set. Indeed, research suggests running replication studies provides multiple effect size estimates to better inform conclusions (Fletcher, 2021; Freese & Peterson, 2017; Funder & Ozer, 2019; Lakens, 2023; LeBel & Peters, 2011; Lindsay, 2015; Maner, 2014; Plucker & Makel, 2021; Youyou et al., 2023). To get an estimate of the overall effect size here, I collapsed across Experiments 1-2 to compare performance on the 20 RAT problems that were solved either collaboratively or individually. Outcomes showed an overall significant collaborative inhibition effect ($t(137) = 2.27$, $p = 0.012$, $d = 0.39$). Given the small-to-medium effect size for collaborative inhibition, additional replication attempts will be particularly important. It is also worth noting that while findings indicate a statistically significant difference between working collaboratively compared to individually, the practical difference was arguably small, with the collaborative group (on average) only solving 3-4 fewer problems than the individual group.

This, coupled with the observed effect size, suggests that perhaps there are ways to overcome the collaborative deficit when engaging in collaborative creative problem-solving. Exploring factors that may enhance the effectiveness of collaborative problem-solving on the RAT will be a useful endeavor, particularly if initial collaboration produces downstream benefits, as suggested by Experiment 2 findings.

As previously discussed, the leading explanation for collaborative inhibition is the retrieval disruption hypothesis (Basden et al., 1997; Blumen & Rajaram, 2008; Wissman, 2020; Wright & Klumpp, 2004). As outlined above, I speculated that a modified version of this account may help explain the collaborative inhibition effect observed here, such that the disruption is caused by group members' non-overlapping associative networks. One possible way to test the extent to which non-overlapping associative networks influence disruption would be to manipulate group size. For example, you could have participants work in groups of two, three, or four to solve RAT problems, and then examine the magnitude of the effect. If non-overlapping networks result in greater disruption, one would expect collaborative inhibition to be stronger in larger (as opposed to smaller) collaborative groups. Investigating underlying mechanisms of this effect will further our understanding of how collaboration impacts creative problem-solving, which in turn can help inform how best to implement it in more practical environments, such as classroom settings.

Another interesting direction for future research would be to explore how group composition impacts the presence (or magnitude) of collaborative inhibition. Prior research has shown that collaborative inhibition is reduced when groups are comprised of individuals who know each other, such as married couples (Berg et al., 2003). One explanation for why collaborative inhibition can be attenuated in these groups is that individuals are able to more effectively organize their social and cognitive efforts given their familiarity with one another. In terms of RAT problem-solving, groups of individuals who know each other and spend time together likely result in shared experiences, and in turn, an increased likelihood of greater overlap in their associative networks. This may have the potential to reduce retrieval disruption and subsequently collaborative inhibition. Investigating how group composition impacts creative problem-solving could be particularly important for applied purposes, as students often work with peers whom they know in real-world settings. In general, additional exploration of collaborative inhibition will help uncover the nuances of how collaborative inhibition impacts creative problem-solving.

Although not of primary interest, the current research also investigated post-collaborative benefits for creative problem-solving using the RAT. Outcomes from Experiment 2 demonstrated post-collaborative benefits, such that performance during Phase 2 problem-solving on the repeated RAT problems was greater for the collaborative group compared to the individual group. As a reminder the two leading explanations for post-collaborative benefits are re-exposure (Blumen & Rajaram, 2008; Weldon & Bellinger, 1997) and cross-cuing (Harris et al., 2012; Meudell et al., 1995). One intriguing way to investigate either of these mechanisms for creative problem-solving with the RAT could be through the use of a confederate in the collaborative group. Concerning the former, a collaborative confederate could be trained to provide solutions to certain problems, in turn providing the opportunity for re-exposure for their partner. Concerning the latter, a collaborative confederate could be trained to provide ideas that are closely associated with the target, in turn providing the opportunity for cross-cueing for their partner. In either scenario, the control group would be a collaborative group comprised of two, true participants (i.e., no confederates). Outcomes would focus on later individual performance and examine if the presence of a confederate, trained to elicit re-exposure and/or cross-cueing, affected the magnitude of post-collaborative benefits.

Concerning the 20 novel RAT problems, outcomes suggest no benefit of prior collaboration—in other words, post-collaborative benefits were not observed for new RAT problems. The lack of post-collaborative benefits for novel problems suggests that the (modified) mechanisms responsible for the effect (i.e., re-exposure and cross-cueing) may only apply when for previously attempted RAT problems. For example, if an individual is re-exposed to the solution 'Book' for the problem 'Worm – Shelf – End', it may not provide any benefit to solving a different RAT problem (e.g., Cottage – Swiss – Cake; Cheese). If re-exposure and cross-cueing mechanisms do not extend to new problems, this will have important implications for educational purposes. Indeed, students are often exposed to one particular problem during learning and then asked to solve a different problem on a later test. In other words, to support learning, the goal is that students take information acquired in one setting and apply it to another. Further investigation of the extent to which collaborative creative problem-solving can facilitate transfer is an interesting and important direction for future research.

Another possible explanation for the lack of transfer concerns participant fatigue. When attempting to solve the 20 novel RAT problems, participants had already completed 40 RAT problems. For collaborative participants, 20 of these problems involved coordinating social and cognitive efforts, which uses a large portion of working memory capacity (Hood et al., 2022) and subsequently, working memory capacity under a high cognitive load can lead to fatigue (Westbrook et al., 2018). Notably, research suggests when fatigue sets in, participants perceive future tasks as requiring an even greater effort (Iodice et al., 2017) and has a negative impact on performance (Ackerman & Kanfer, 2009). The suggestion that fatigue may be at play in the current research is supported by the fact that Phase 2 performance on the new items (i.e., Set A) is lower than Phase 1 performance (i.e., Set B problems), despite the fact that difficulty was equated across these two sets of RAT problems. One experimental design to reduce the impact of participant fatigue could either have participants solve the 20 new problems prior to the re-attempted problems during Phase 2 or insert a delay between Phases 1 and 2. Outcomes from either hypothetical design would provide important information on whether the lack of transfer for novel RAT problems may have resulted from participants being too fatigued to perform well at the end of a lengthy experiment. Conducting either of these hypothetical experiments will provide important information on whether working collaboratively versus individually improves or hinders creative problem-solving performance on later, individual novel RAT problems.

The present research provides the first systematic investigation of how collaboration impacts creative problem-solving using the RAT, with outcomes establishing novel effects and providing fruitful avenues for additional investigation of these effects with this material set. Of course, as noted in the introduction, the RAT is but one creativity measure, so investigating the impact of collaboration using different creativity materials is also important. For example, evaluating the impact of collaborative versus individual problem-solving on divergent thinking tasks, such as the Alternative Uses Task (AUT). As a reminder, the AUT asks participants to generate as many uses for ordinary objects (e.g., a brick) as possible that are not within the scope of the object's typical use. In contrast to convergent thinking tasks (such as the RAT), the AUT only involves generating ideas (as opposed to generating and evaluating ideas), which has the potential to increase collaborative inhibition. On the one hand, collaborative inhibition could be present because the participants are tasked with outputting as many ideas as possible, which increases the opportunity for modified retrieval disruption to occur. As such, each time one member outputs an idea, it disrupts the thought process of the other group member. On the other hand, collaborative inhibition could be absent because the participants are not attempting to search for one solution, but instead trying to generate as many ideas as possible, so the output of one group member could cue another member to suggest similar solutions. Additional research using different material sets will provide important information on the extent to which collaboration impacts the generative phase of the creative process.

For educational purposes, evaluating how collaboration impacts creative problem-solving in more authentic contexts with more authentic materials will be important. Indeed, one could imagine investigating collaboration and creativity in the classrooms across STEM disciplines, such as Biology, Chemistry, Physics, and Psychology. To accomplish this goal, a researcher could work with STEM instructors to identify creativity tasks in their curriculum. For example, in a physics classroom, students might be asked to work collaboratively or individually to complete word problems on electromagnetic energy that require connection of prior information on particle waves and movements to the current problem to reach the solution (Maulidah & Prima, 2018). In a psychology classroom, students might be asked to work collaboratively or individually to solve Duncker's candle problem (Duncker, 1945), which requires students overcoming functional fixation by thinking of certain items (e.g., a matchbox) in a different way. Examining how collaborative versus individual problem-solving affects creativity with authentic, learning materials in real-world, classroom settings will further our understanding of how collaborative creativity operates in educational environments and help support student success in STEM education.

9.1. Conclusion

The RAT is an increasingly utilized creative problem-solving measure, which is both a reliable and valid measurement of creativity (Bowden & Jung-Beeman, 2003; Lee et al., 2014; Mednick, 1968; Sio & Ormerod, 2015; Zhu et al., 2019). The current study provides the first systematic exploration of collaborative versus individual creative problem-solving using the RAT, with outcomes showing no benefit of collaboration, but instead evidence suggests a disadvantage. Given the relevance of collaboration and creativity in our everyday life, future work should continue to evaluate the effects observed here and investigate the potential underlying mechanisms of these effects. More generally, this research provides foundational findings for how collaboration impacts creative problem-solving, which has the potential to help inform educational recommendations to support the success of students and contribute to the preparation of a skilled workforce.

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APPENDIX

Table A.1. RAT Materials for Experiments 1 & 2

	Experiment 1			Experiment 2 Set A			Experiment 2 Set B		
	RAT Cue Words	RAT Solution	Solution Rate	RAT Cue Words	RAT Solution	Solution Rate	RAT Cue Words	RAT Solution	Solution Rate
1	Cottage Swiss Cake	Cheese	0.64	Night Wrist Stop	Watch	0.97	Duck Fold Dollar	Bill	0.92
2	Aid Rubber Wagon	Band	0.69	Cream Skate Water	Ice	0.9	Measure Worm Video	Tape	0.87
3	Sage Paint Hair	Brush	0.69	Date Alley Fold	Blind	0.85	Nuclear Feud Album	Family	0.85
4	French Car Shoe	Horn	0.69	Cracker Fly Fighter	Fire	0.85	Food Forward Break	Fast	0.82
5	Hound Pressure Shot	Blood	0.72	River Note Account	Bank	0.79	Fur Rack Tail	Coat	0.79
6	Basket Eight Snow	Ball	0.72	Print Berry Bird	Blue	0.77	Show Life Row	Boat	0.79
7	Safety Cushion Point	Pin	0.74	Fish Mine Rush	Gold	0.74	Safety Cushion Point	Pin	0.74
8	River Note Account	Bank	0.79	Basket Eight Snow	Ball	0.72	Hound Pressure Shot	Blood	0.72
9	Fur Rack Tail	Coat	0.79	Aid Rubber Wagon	Band	0.69	Mouse Bear Sand	Trap	0.72
10	Show Life Row	Boat	0.79	French Car Shoe	Horn	0.69	Sage Paint Hair	Brush	0.69

Table A.1. RAT Materials for Experiments 1 & 2 (continued)

	Experiment 1			Experiment 2 Set A			Experiment 2 Set B		
	RAT Cue Words	RAT Solution	Solution Rate	RAT Cue Words	RAT Solution	Solution Rate	RAT Cue Words	RAT Solution	Solution Rate
11	Pike Coat Signal	Turn	0.64	Pike Coat Signal	Turn	0.64	Cottage Swiss Cake	Cheese	0.64
12	Way Board Sleep	Walk	0.64	Opera Hand Dish	Soap	0.62	Way Board Sleep	Walk	0.64
13	Mouse Bear Sand	Trap	0.72	Knife Light Pal	Pen	0.62	Keg Puff Room	Powder	0.62
14	Fish Mine Rush	Gold	0.74	Eight Skate Stick	Figure	0.59	Wet Law Business	Suit	0.59
15	Print Berry Bird	Blue	0.77	Dream Break Light	Day	0.56	Carpet Alert Ink	Red	0.59
16	Food Forward Break	Fast	0.82	Cat Number Phone	Call	0.54	Horse Human Drag	Race	0.56
17	Date Alley Fold	Blind	0.85	Down Question Check	Mark	0.54	Boot Summer Ground	Camp	0.54
18	Nuclear Feud Album	Family	0.85	Master Toss Finger	Ring	0.51	Type Ghost Screen	Writer	0.54
19	Cracker Fly Fighter	Fire	0.85	Wagon Break Radio	Station	0.51	Mill Tooth Dust	Saw	0.51
20	Measure Worm Video	Tape	0.87	Palm Shoe House	Tree	0.51	Dress Dial Flower	Sun	0.51

Note. RAT Cue Words refer to the three words learners were provided with to solve the RAT. RAT Solution refers to the correct answer. Solution Rate refers to the rate at which learners from the original normative study (Bowden & Jung-Beeman, 2003), were able to accurately solve the RAT. The RATs & solution rate were compiled by Sio (2020; https://osf.io/6cwgv/).

Table A.2. Open-Ended Responses for Experiment 1 PEQ 4

	Yes		**No**		**Unsure**	
	Individual	**Collaborative**	**Individual**	**Collaborative**	**Individual**	**Collaborative**
Response	n = 28	n = 10	n = 33	n = 53	n = 7	n = 5
Open-ended	n = 28	n = 9	n = 17	n = 27	n = 6	n = 5
"I answered when I could"	4%	11%	79%	85%	0%	60%
"The time limit stopped me"	29%	11%	12%	4%	17%	20%
"I couldn't think of an answer"	79%	56%	29%	15%	50%	20%
"I thought I was wrong/ dumb"	11%	33%	0%	0%	0%	20%
"I was confused and didn't understand"	29%	11%	6%	11%	33%	0%
"I skipped problems"	21%	0%	6%	0%	0%	0%
"My partner and I worked together to figure it out"	0%	11%	0%	19%	0%	0%
Other	0%	0%	6%	4%	0%	0%

Note: The table represents the percentage of responses from the collaborative and individual groups as a function of the response to PEQ4 that asked if the participants withheld any responses during the RAT problem-solving process. The response row indicates the number of responses the collaborative and individual group reported for each response option. The open-ended row indicates the number of responses the collaborative and individual group provided an open-ended response per response option. Across all open-ended responses, participants sometimes provided responses that were scored across multiple categories. As such 22 participants in the "yes" category, 15 participants in the "no" category, and 3 participants in the "unsure" category provided responses that were scored in more than one category.

Table A.3. Open-Ended Responses for Experiment 2 PEQ 4

	Yes		**No**		**Unsure**	
	Individual	**Collaborative**	**Individual**	**Collaborative**	**Individual**	**Collaborative**
Response	n = 21	n = 17	n = 40	n = 50	n = 8	n = 6
Open-ended	n = 21	n = 17	n = 14	n = 17	n = 8	n = 5
"I answered when I could"	10%	0%	36%	65%	25%	0%
"The time limit stopped me"	24%	6%	36%	18%	25%	80%
"I couldn't think of an answer"	76%	65%	43%	12%	50%	20%
"I thought I was wrong/ dumb"	19%	24%	7%	0%	0%	0%
"I was confused and didn't understand"	5%	6%	0%	0%	25%	0%
"I skipped problems"	5%	6%	7%	0%	13%	0%
"My partner and I worked together to figure it out"	0%	6%	0%	0%	0%	0%
Other	0%	6%	0%	6%	0%	0%

Note: The table represents the percentage of responses from the collaborative and individual groups as a function of the response to PEQ4 that asked if the participants withheld any responses during the RAT problem-solving process. The response row indicates the number of responses the collaborative and individual group reported for each response option. The open-ended row indicates the number of responses the collaborative and individual group provided an open-ended response per response option. Across all open-ended responses, participants sometimes provided responses that were scored across multiple categories. As such 11 participants in the "yes" category, 7 participants in the "no" category, and 3 participants in the "unsure" category provided responses that were scored in more than one category.