The Effects of Collaboration on Spatial Reasoning Task Performance

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Abstract

In the current study, I aimed to investigate the effect of children's collaboration on a spatial reasoning task as part of a larger study on spatial reasoning in the primary school*. Existing research on collaboration show both advantages and disadvantages of working with other people. From a cognitive science perspective, research investigating the influence of collaboration on cognitive processing shows potential costs. This research has typically focused on adult populations and using encoding and retrieval paradigms to assess performance. None has focused on children performing other ecologically valid tasks, such as spatial reasoning tasks. Educational research into collaboration is broader in scope and most comes from mathematics education research, showing predominately advantageous outcomes for collaborators across a range of settings, but no research has investigated the effect on spatial reasoning. Spatial reasoning is, among other things, the ability to mentally form and rotate images and objects and it has been positively linked to STEM outcomes.

The participants comprised 76 primary school students from Years 1 and 2 (6-8 years). Students were drawn from a metropolitan school and classes were allocated within Year group to one of two conditions: individual or collaborative. Scores on Raven's Progressive Matrices were used to ensure both that the groups were equivalent in spatial reasoning skills, and to pair students of similar ability in the dyads. The researcher observed students solving two spatial reasoning tasks; tower and bridge constructions. Data were collected in the form of measurements and photographs of the constructions and audio recordings of the dyads' conversations. On the first testing occasion, all students in both conditions individually solved the task. During the second testing occasion, half of the students worked individually (individual condition) while the other half worked in their dyads (collaborative condition). In the analysis, the students in the individual condition formed nominal dyads for comparative purposes between the conditions. A mixed method ANOVA (2x2x(2) was conducted indicating overall significant differences in favour of the collaborative group, and in particular for Year 2, as well as a 3-way interaction with Condition by Year by Task. Follow-up simple effects analysis indicated a positive significant difference for collaborating Year 2 students on the second task but not for Year 1.

A secondary analysis of the data was conducted for qualitative differences in the students' levels of spatial structure in their construction process. Photographs were coded for one of four spatial structural levels: pre-structural/emergent, partial structural, structural and advanced structure. The analysis indicated the relative proportion of students at each level; Prestructural/Idiosyncratic, Emergent or Partial Structural, Structural, and Advanced Structural respectively. The findings support the notion that spatial structural development progresses from Years 1 to 2 and that collaboration did not effect the level of structural development i.e., students at each level were represented equally from both groups, dyads and individuals. The findings are discussed in relation to theoretical and pedagogical approaches to developing spatial reasoning and implications for mathematics education and cognitive science research.

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Keywords: Spatial reasoning, collaboration, primary school, mathematics education, cognitive science

Authorship Statement

I hereby certify that this thesis, titled "The Effects of Collaboration on Spatial Reasoning Task Performance" is an original research thesis based on data collected and interpreted by me for the purposes of completing the Master of Research degree at Macquarie University.

I further certify that this thesis has not previously been submitted as part of requirements for a degree at Macquarie University or any other university, and that all sources used in the thesis are cited.

This research was approved by the Macquarie University Faculty of Human Sciences Subcommittee, reference number: 5201832664870 (Appendix A). Approval was obtained from Arden Anglican School to conduct the research at the school (Appendix B).

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Chapter 1. Introduction

> "Over a decade even the profoundest thinkers never questioned the assumption; they never entertained the notion that what children can do with the assistance of others might be in some sense even more indicative of their mental development than what they can do alone."
>
> Vygotsky, 1997, p.32

Despite the prevalence of collaboration as a strategy in teaching and learning across a range of domains, understanding the effects of collaboration on task performance in young students has not to date been well researched, especially within the area of spatial reasoning. Spatial reasoning has been linked to a range of academic benefits, particularly in STEM (Science, Technology, Engineering, and Mathematics). This study adopts a cross-disciplinary approach, combining the fields of cognitive science, spatial reasoning and mathematics education. The research utilises mixed methodologies drawn from these disciplines to investigate the effect of peer collaboration with Year 1 and Year 2 students on a spatial reasoning task.

1.1. Collaboration

Collaboration occurs when two or more people work together to achieve a common goal or outcome, and it is crucial to numerous aspects of human society. Schools and work places often incorporate collaboration in their daily activities (e.g., Blumen, Young, & Rajaram, 2014; Gummerum, Leman, & Hollins 2013), and there is a common lay understanding that people working together should achieve better outcomes than those working alone, which is partially supported by research (e.g., Butler & Walton, 2013; Olsson, Juslin, & Olsson, 2006; Plötner, Over, Carpenter, & Tomasello, 2015).

Cognitive studies have shown that when collaboration is successful, it leads to at least equal task performance compared to what participants could have achieved individually (e.g., Blumen & Stern, 2011; Olsson et al, 2006). There may also be social and motivational benefits collaboration can provide (Butler & Walton, 2013; Plötner et al., 2015). When collaboration is unsuccessful, however, collaborators do not perform as well as individuals (e.g., Abel & Bämul, 2017; Basden, Basden, Bryner, & Thomas, 1997). Research in cognitive science and mathematics education is divided on whether or not collaboration leads to performance gains.

In educational research, studies investigating children's knowledge acquisition, social awareness, and motivation for task completion have demonstrated potential advantages for students who collaborated with one another (e.g., Butler & Walton, 2013; Fung, Hung, & Lui, 2018; Plötner, et al., 2015). In cognitive science, research on collaborative remembering instead indicates that collaboration between adults often produces poorer performance for those collaborating compared to those working alone (e.g., Barber, Harris, & Rajaram, 2015; Sjolund, Erdman, Kelly; 2014). These discrepancies in findings between fields may be due to the nature of the cognitive task (e.g., remembering vs. problem solving vs. spatial reasoning), to the methodologies used to assess collaboration, or to developmental differences between participants. In the cognitive sciences, for example, there is limited research examining peer collaboration of children. In one of the few studies to date, however, Gummerum et al. (2013) find evidence for possible developmental differences on a word recall task. Their finding suggested that older children (age 9) perform worse when working together, but younger children (age 7) showed no difference between working alone and collaborating (but see Andersson, 2001, for contrasting findings).

Research on collaboration provides mixed evidence as to its effectiveness and investigating collaboration across different domains and in specific types of problem-solving tasks is important in order to understand when collaboration is beneficial. Findings gaps in research allows for new research to be undertaken, and for collaboration to be investigated and understood in a variety of specific contexts: that is, with specific participants and for specific tasks.

1.2. Collaboration and Spatial Reasoning

Although there are many different definitions of spatial reasoning, the definition used within this thesis is the following: spatial reasoning is the ability to mentally manipulate and predict spatial aspects of the world, including mental rotation of objects and figures, structure, stability, and more abstract problem solving. It is an important area of research, but no known research to date has examined the influence of collaboration on spatial reasoning performance. There is also currently no research examining whether children's existing spatial skills influence their collaborative success. Spatial reasoning has historically received little attention in educational research (Lowrie, Logan, Harris, & Hegarty, 2018). Yet spatial reasoning permeates many areas of life in and out of school, including giving and receiving directions, playing games and team sports, or working with classmates to problem solve. Spatial reasoning has further been linked to school performance, and particularly strong associations exist between spatial reasoning and Science, Technology, Engineering, and Mathematics (STEM) performance (e.g., Newcombe, 2013; Uttal, Miller, & Newcombe, 2013; Wai, Lubinski, & Benbow, 2009). Bruce et al. (2017) and Newcombe (2013) both argue that improvement in spatial reasoning skills early in school lead to improved outcomes a few years later in a child's academic achievement, and there is research demonstrating that this skill is malleable and thus can be improved.

1.3. Aims and Research Questions

While no identified research has considered the effects collaboration on children's spatial reasoning performance, both collaboration and spatial reasoning are featured in learning contexts (e.g., Lowrie, Logan, & Ramful, 2017; Andersson, 2001). Indeed, educational research shows some benefit to collaborating with peers, such as improved knowledge acquisition (e.g., Fung et al., 2018). There are also some studies in which spatial reasoning tasks are used to assess other learning outcomes: for example, Butler and Walton (2013) provided children with a puzzle task that required spatial reasoning and found that children who were in the collaborative condition reported enjoying the task more. Other research investigate pedagogical processes through intervention studies looking at spatial problem solving with other aspects of learning (Casey, Andrews, Schindler, Kersh, Samper & Copley, 2008).

This study aims to extend and combine previous lines of inquiry by investigating the effect of children's collaboration on a spatial reasoning task. The aspects of spatial reasoning applicable to this research include mental manipulation and problem solving. It further aims to consider developmental differences for young students across Year 1 and Year 2 by allocating students to either a collaborative or individual condition. The research questions guiding the study are as follows:

1. Do collaborating dyads perform differently from individuals on spatial reasoning tasks?
2. Is there a difference in the performance outcomes, and levels of spatial structure evident in task solutions, for students in Year 1 and Year 2?

1.4. Thesis Structure

This thesis is divided in to five chapters. Chapter 1, the current chapter, introduces the research aims and questions and provides an overview of the study. Chapter 2 describes the theoretical framework and provides a literature review of pertinent studies. This includes an outline of Vygotsky's sociocultural theory (focusing on social and developmental learning trajectories) in education and of extended mind theory in cognitive science, as well as a literature review which underpins this study. Chapter 3 outlines the methodology of the current study, in which students in Year 1 and 2 were asked to construct solutions to a spatial task to help the fictional cat Alex through obstacles on adventures. Chapter 4 reports the results of the study. Finally, Chapter 5 is dedicated to the discussion of the results and how they advance our understanding of collaboration and spatial reasoning. Chapter 5 also discusses the limitations and implications of the study, followed by a conclusion. A reference list and appendices are included at the end of the thesis, followed by the appendices.

Chapter 2. Theoretical Framework and Literature Review

2.1. Theoretical Framework

This research draws on two theories in particular; Vygotsky's sociocultural theory and extended mind theory. The combination of educational theory and theories drawn from cognitive science provide a foundation on which this research can stand and allows for results to be interpreted across the two fields.

2.1.1. Sociocultural Theory and Vygotsky

This research draws upon Vygotsky's sociocultural theory which is in turn a prominent social constructivist theory (Newton & Alexander, 2013; Powell & Kalina, 2009). The modern social constructivist approach incorporates a focus on social relations (Detel, 2015). One of the central ideas of this theory is the notion that our social interactions shape our perceptions and knowledge of the world around us. As Detel (2015) outlines, social constructivism permits for human action to influence circumstances which may not initially seem flexible. Vygotsky's social constructivist perspective is focused specifically on how children come to acquire new knowledge and skill. His work is now more than 100 years old, with the vast majority taking place in the early 1900s. Nonetheless, his ideas have remained both relevant and influential. At the core of Vygotsky's theory is the notion that a person has a zone of actual development (ZAD; Shabani, Khatib, & Ebadi, 2010), which is referred to as an actual development level in his translated writings from 1997b, and a zone of proximal development (ZPD). The ZAD refers to the skills the individual has mastered and can complete on their own, and a ZPD, which are skills not yet mastered but which can be completed with assistance from interactions with others, who are often considered more experienced (Vygotsky, 1997b). By practicing skills within the ZPD, with the assistance of more experienced others (Vialle, Lysaght, & Verenikina, 2005; see Wood, Burner, & Ross, 1976 for first use of term scaffolding), Vygotsky suggests that the act of collaboration temporarily extends an individual's competencies to mimic mastery. Further, working with others should, ultimately, allow those skills to be internalised and become part of the ZAD: thus, results in a long-term cognitive change (Shabani, et al., 2010).

Vygotsky believed that the competence afforded by the ZPD needs to be taken in to account when measuring a child's ability, not just what a child has achieved in their ZAD (Vygotsky, 1997b). Shabani et al. (2010) further argues that the ZPD should be seen as an interaction between the learner and the learning environment, and that techniques such as scaffolding allows the learner to be in control of their own learning more so than traditional teacher-instructed learning.

From an educational perspective, sociocultural theory offers a parsimonious explanation for learning, and Vygotsky himself wrote a book called Educational Psychology, which was originally printed in Russian in 1926, and reprinted in English in 1997 (Vygotsky, 1997a). In this book, Davydov introduces Vygotsky's ideas as useful for educators wishing to take scientific findings in to the classroom. Finally, and more recently, Mercer and Howe (2012) and Smith and Mancy (2018) have highlighted the influence aspects of sociocultural theory, such as social interaction, can have on research concerned with learning. However, Mercer and Howe (2012) also argue that adopting Vygotsky's approach, while effective for explaining and understanding the learning process, will only be beneficial if social interaction is viewed and recognised as a factor in conceptual knowledge acquisition and change. These ideas are also touched on in Vygotsky's own work (Vygotsky, 1962, 1997a, 1997b).

2.1.2. Vygotsky's Theory Applied to Education

Within education, Vygotsky's sociocultural theory has often been used as a framework for advancing individual students' abilities. Teachers typically have the role as the more experienced other, as do more experienced peers (e.g., Vygotsky, 1997b; Wood, et al., 1976). The individual student is still seen as a person with agency, however, and therefore actively contributes to the social interaction. Thus, the learning takes place through interaction with others in a co-dependent relationship with both parties contributing.

Sociocultural theory from Vygotsky's perspective provides a framework in which development of skills like spatial reasoning are supported. Because spatial reasoning is a malleable skill that can be improved with the right activities and assistance (e.g., Casey et al., 2008; Ramani, Zippert, Schweitzer, & Pan, 2014), and because of the links between spatial reasoning and other academic outcomes, such as STEM related outcomes (e.g., Lowrie et al., 2017; Newcombe, 2013; Wai et al., 2009), it is important to understand the educational contexts that will best support the acquisition of spatial reasoning skills in the classroom. Social constructivist theories like Vygotsky's sociocultural theory offers explanations for this growth by emphasising the importance of interactions, including social interactions. For children working on a spatial reasoning task, this might be expressed through the conversation between them, as they cannot reason for one another but they can discuss features like pattern or symmetry which may challenge existing mental images and allow for growth in understanding.

The social interaction aspect may be one of the reasons educational research has increasingly drawn on social constructivist, and in particular sociocultural theory to enhance learning. As a result, Vygotsky's work has become part of larger volumes aimed at future educators, enabling them to maximise learning outcomes for their future students (Gindis, Agevyev, Miller, & Kozulin, 2003; Grouws, 1992; Moll, 1990; Saxe, 1991; Slavin, 2009;

Vialle, et al., 2005; Vygotsky, 1997a, 1997b). These volumes also emphasise the critical role of the teacher and peers in the child's learning.

Looking beyond Vygotsky, sociocultural theory emphasises learning with others, and peer collaboration in school-aged children is more thoroughly researched in the mathematics education literature than in any other discipline. Although much of the research on collaboration in education has considered collaborative learning amongst classroom peers, and sometimes without any apparent structure behind placing students in groups (i.e. without deliberately placing one peer with a more advanced peer), collaboration has nonetheless been proven successful on many such occasions, in particular where measures and outcomes are directly related to learning. Thus, although not focused on spatial reasoning tasks, the educational evidence to date provides broad support for sociocultural theory as an approach for teaching and learning (e.g., Fung et al, 2018; Ng & Sinclair, 2015).

2.1.3. Application of Sociocultural Theory in the Current Study

This study investigates the individual child's problem-solving ability and how that ability is modified when working with a peer; rather than focusing on scaffolding which adults or more experienced peers could potentially provide. It adopts the perspective that children do not learn in isolation and this is something Vygotsky emphasised heavily in his writing on the topic. The premise of this research incorporates Vygotsky's ideas of social interaction as necessary for mental development and the acquisition of knowledge, as well as the idea that knowledge extends beyond what a child has completely mastered.

Overall, this study adapts the aspects of sociocultural theory that propose that children are more capable than their individual performance would suggest. Social interaction is considered as part of the learning experience and to influence performance-related outcomes, but not that one collaborator necessarily needs to be more advanced than their peer. As mentioned previously, Vygotsky suggested that the abilities that are part of the child's ZPD (i.e., what a child is able to achieve with guidance from others) should also be considered when determining the child's capabilities, as the child is able to perform the task even if not mastered to the level of independence. This notion influenced the design of the study to include peer collaboration in studying spatial problem solving. For children collaborating on a spatial task, the outcomes may be better for collaborators, indicating that student collaboration may bring forth skills that are not yet mastered and by practising these skills with a partner, in social interaction, the same skills should eventually come to be internalised. In contrast to Vygotsky's original notions of a more experienced partner, however, the current study examines the influence of collaboration when the collaborator is not more advanced than their peer (e.g., Andersson, 2001). As discussed in the next section, extended mind theories suggest that even collaborators with similar levels of expertise bring with them a range of diverse skills, and can therefore each make important contributions to the group effort.

2.1.4. Complementary theories

Complementing Vygotsky's sociocultural theory of learning is the "extended mind" theory of contemporary cognitive science research. Extended mind theory emphasises the role the environment (including, but not limited to, other human beings) can have on our learning and information processing. Our environment, for example, may support new knowledge acquisition. In education, this may include prompts from peers or teachers which allow a student to bring new information and skills into their ZPD, leading to knowledge gains. In addition, according to extended mind theory, sharing the cognitive load with others during difficult tasks may allow for more efficient processing and for shared planning.

Wegner, Giuliano, and Hertel (1985) describe the "extended mind", which is a mind-network between two or more people acting as one interdependent cognitive system (or "transactive memory system"). To be successful, this requires partners who are aware of each other's cognitive capacities (skills, beliefs, or knowledge). This higher-order information and lower-order information is then used when determining when to trust a partner's contributions to the cognitive task and how to integrate them (Wegner et al., 1985). As in Vygotsky's sociocultural theory (1978; Mercer & Howe, 2012), Wegner, et al. (1985) suggest that the key to accessing the cognitive systems of other people lies in conversation. The importance of conversation is further explored by Rajaram (2018), who highlights that knowing about other people's experiences and knowledge tend to collaborate better than those who do not know much about their collaborator's knowledge. For example, people who are old friends appear to collaborate better than complete strangers. These ideas are similarly touched on in Clark and Chalmers (1998) as well as more recently in Sutton, Harris, Keil, and Barnier (2010). The extended mind is useful for individuals who share aspects of their lives, such as families, classmates, or work colleagues, as it allows for minimal duplication of information; if one family member is responsible for remembering to pay the electricity bill, for example, the other person does not need to allocate space in their individual memory store to remember when that bill needs to be paid because they know the first individual is responsible for that information. This frees up cognitive capacity for the second person to remember to pay the internet bill. Importantly, according to extended mind theory, people who interact frequently with one another naturally become more cognisant of each other's abilities and knowledge over time.

Extended mind theories feature a cognitive connection and utilisation of several memory systems working together as one. If, through working with someone else and using an extended memory, a student is able to learn more than what they can achieve on their own then the outcome of collaboration may be an excellent tool to understand student capabilities. For skills such as spatial reasoning, which is a malleable skill, these theoretical perspectives may offer insights into how collaboration can effect problem-solving performance. Students who work together on a spatial reasoning construction task may have an advantage if they are able to communicate their thinking about the task to the other person and as such allowing their combined skills to be divided up, or combined, for more efficient work.

2.2. Literature Review

So far, this chapter has provided an overview of two theoretical frameworks: Vygotsky's sociocultural theory and extended mind theory and how they may contribute to our understanding of the collaborative problem- solving process. Both theories predict benefits for collaborators, not only in spatial reasoning but for a range of cognitive tasks. As noted in Chapter 1, no research to date has empirically examined the effects of collaboration for spatial reasoning. It is important to do so, however, as spatial reasoning tasks differ from other types of cognitive tasks in a range of ways relevant to collaboration. Much research in cognitive science with children concerns for example, word list recall, which relies simply on recall, and participants may differ in capacity for recalling words but not necessarily in conceptual understanding. Such difference may be present on a micro-level, even when standardised tests such as Raven's Progressive Matrices (Raven, 2000) is administered.

Given the lack of research examining the influence of collaboration on spatial reasoning performance specifically, the following literature review outlines what *is* known. In this section, pertinent studies from both mathematics education and cognitive science are therefore reviewed in relation to spatial reasoning and collaboration. This section will first discuss the importance of spatial reasoning in our lives and what learning this skill might mean for individuals in school and beyond. Second, it will also outline the impact collaboration can have on a variety of outcomes, including performance but will also briefly discuss the social benefits. Specifically, it will compare findings in mathematics education research, which typically finds benefits for collaboration, with those in cognitive science, which often (but not always) finds cognitive costs.

Collaboration may provide opportunities to complete tasks which are impossible on one's own. Working together can afford performance related gains, but not always, and depends on a variety of performance-related factors. Mathematics education research into peer collaboration offers a variety of research contexts and studies across age groups (see for example Smith & Mancy, 2018). Often, school-aged students are the primary participants, and there are comparative and mixed methods described in the literature. These include comparing against a control group, measuring improvements between two test times, and comparisons directly between collaborating groups. The tasks are often similar to mathematics problem-solving tasks which students encounter in schools, providing a high ecological validity to the research outcomes (e.g., Fung et al. 2018; Ng & Sinclair, 2015).

In contrast to mathematics education research, the cognitive science field concerned with collaboration, offers mixed results. Cognitive studies on collaboration focus predominately on adult participants, with children very rarely considered. One of the most common comparative methods in collaborative research in cognitive science is the collaborative inhibition paradigm, in which nominal groups (combined results of two individuals at post-task) compared to genuinely collaborating groups.

2.2.1 Spatial Reasoning

As more research is conducted into spatial reasoning, it is becoming clearer what role this process plays in our daily lives as well (e.g., Lowrie et al., 2017). Spatial reasoning requires both spatial visualisation, and mental rotation skills (Bruce & Hawes, 2015; Casey et al., 2008; Lowrie et al., 2017; Lowrie et al., 2018; Uttal, Meadow et al., 2013), enabling us to mentally rotate 2D and 3D objects and to make inferences about these objects. By using spatial reasoning, for example, it is possible to estimate distances between objects (Uttal, Miller et al., 2013), to construct 3D objects with mathematical nets, and mentally take someone else's visual perspective. These skills in turn make it possible to read maps and give directions, to build houses, and see the world from someone else's visual perspective (Newcombe, 2013). In our increasingly technological world, some apps on our smartphones may also require spatial reasoning skills (e.g., Bruce & Hawes, 2015; Mulligan, Woolcott, Mitchelmore, & Davis, 2018). The real-world applications of spatial reasoning are extensive and there is evidence spatial reasoning ability can be improved (e.g., Ng & Sinclair, 2015).

When discussing spatial reasoning, implications for education and practice are important. Spatial reasoning can improve across childhood and beyond. There is a particularly strong association between the level of spatial reasoning skill and academic achievement in STEM (Newcombe, 2013; Uttal, Meadow et al., 2013), and that earlier spatial reasoning skills positively correlate with school performance and outcomes in mathematics approximately two years later (Bruce et al., 2017; Newcombe, 2013).

Spatial reasoning, thus, features heavily in human life. The skill also increases across childhood and can influence subsequent careers (Wai et al., 2009), as discussed later in this chapter. This section will review pertinent studies on the development of spatial reasoning, and the role of spatial reasoning in cognitive development.

2.2.1.1 Development of spatial reasoning across childhood. Young children experience rapid cognitive development in spatial reasoning across the school years. The development of spatial reasoning in children is supported by the development of visualisation skills, executive function, structural thinking (recognising and operating within a known structure or pattern to understand and ultimately solve a problem), working memory speed and capacity, and previous learning experience (e.g. Bruce & Hawes, 2015; Cheng & Mix, 2014; Lowrie et al., 2017). These influences in turn are supported by brain maturation and scaffolding as well as learning. During their time in school, students are inevitably part of a larger group (their class) and while whole-class collaboration may be unusual, especially in mathematics, the classroom environment may influence learning. It is, as emphasised by the principles of scaffolding (e.g., Wood et al., 1976), important to take into account, the general skills and abilities that children possess at various times prior to and throughout their schooling to make teaching appropriate for the learner. Mercer and Howe (2012) highlight the importance of speech in their writings, and specifically argue that classroom dialogue may influence the development of self-regulation in the child and their learning. This is only possible, according to the authors, if it is recognised as beneficial to children's learning, and it would appear that this aspect can be valuable when the education is also teacher-led so long as the teacher is aware of the student's cognitive abilities and limitations. These cognitive abilities develop gradually, and while there is individual variation in acquisition, these develop along the same trajectory. To demonstrate such a developmental trajectory, Dempster (1981) shows a steady increase in child working memory capacity across childhood and into adolescence and adulthood. The development of spatial reasoning through childhood can have positive influences beyond school as well. Below continues a review of studies focused on the relationship between spatial reasoning and children's STEM outcomes in greater detail. Following this, the review highlights the possible influences of early spatial reasoning performance on later career choices

2.2.1.1.1 Prior to primary school. As already mentioned, children prior to school undergo rapid cognitive development, in particular in areas like mentally holding information which is dependent on development in the prefrontal cortex (Diamond, 2002). Nonetheless, spatial reasoning performance is relatively poor at this age. Younger children may find it difficult to simply be informed of procedures and follow complex instructions, for example, with implications for a range of tasks including spatial reasoning which may be a multi-step process and thus too complex for the child's current developmental stage. Elia, Gagatsis, and van den Heuvel-Panhuizen (2014) suggest that children prior to formal schooling are able to link verbal information and learning, but are able to learn more through imitation to solidify what they are being taught than just verbal tuition. Executive functions develop rapidly before school, especially relation to attention, including self-regulation and inhibitory behaviours (Anderson, 2002). While information processing speeds and working memory capacity are typically very low – working memory holds just 2-3 pieces of information at this age (Dempster, 1981) – children experience gradual gains in both speed and capacity through this period (Anderson, 2002).

Young children do show early evidence of structural thinking, and an ability to reason about how the world works. Vasilyeva, Gopnik, Lombrozo (2018) suggests that children from around the age of 3 can think in a structural manner, and that children about 5-6 years old are showing evidence of discrimination between structural and non-structural thinking. Studies focused on spatial structuring have also found that children as young as four years can develop patterning skills and structural thinking across a range of concepts (Mulligan, English, Mitchelmore & Crevensten, 2013). Not surprisingly, children do have the mental ability to learn in a structured setting prior to formal schooling and are able to learn concepts which may benefit the students later in life.

Mathematics education studies of children's early learning have investigated the acquisition of specific skills, including spatial reasoning, which can benefit later knowledge acquisition. Hawes, Tepyolo, and Moss (2015) outline the benefits of early spatial reasoning skills, and emphasises the links between level of spatial reasoning and positive academic outcomes upon entry in to school. Several studies have demonstrated that early intervention and purposeful instruction of spatial reasoning can improve students' spatial reasoning skills (e.g., Clements, Sarama, Spitler, Lange, & Wolfe, 2011; Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2017).

In their block-building intervention study, Casey et al. (2008) identified that the most beneficial improvements for children in preschool involved a relevant context, in this case a story and a character, to which they could relate their building. Similarly, Clements et al. (2011) investigated gains by block-building interventions for preschool children, but on a larger scale than Casey et al. (2008). This study investigated if the spatial reasoning intervention group would learn more mathematics than those in the control condition, and the study found that those in the intervention condition demonstrated larger gains, although in mathematical concepts, and not necessarily spatial reasoning.

Verdine, Golinkoff, Hirsh-Pasek, Newcombe, Filipowicz and Chang (2014) also view block-building as an opportunity to understand children's spatial reasoning abilities, and they highlight the inequity that exists between high and low socioeconomic status children. Studying 3-year olds skills, the authors concluded that children from lower socioeconomic status demonstrated poorer performance, reportedly heard fewer spatial words at home, and are likelier to have poorer mathematics performance upon school entry.

2.2.1.1.2. During primary school. Children in the primary school experience important maturational gains in their cognitive capacities that are of relevance to spatial reasoning performance. At this stage, for example, most children have developed the ability to mentally hold increasing amounts of information (Diamond, 2002; Anderson, 2002), including spatial information, such that there is now greater opportunity to manipulate multiple pieces of information simultaneously. They also experience increasingly rapid gains in processing speed (Diamond, 2002). According to Anderson (2002), children would also most likely be moving towards completing more complex and multidimensional task-switching at this age, making them increasingly capable of following more complex instruction and improve in mathematics learning by being able to perform more multifaceted tasks.

Over and above maturational gains in cognitive capacities through the primary school years, children in early primary school are also exposed to many new formal learning experiences that may support spatial reasoning development. They may, for example, benefit from increased spatial tuition within formal mathematics education. Ideally, these lessons would be adapted to their ability and mental development. Supporting the importance of formal spatial tuition is evidence from recent intervention studies.

Within educational settings, Lowrie et al. (2018) conclude that spatial reasoning interventions can fit within existing educational frameworks. Specifically, the authors refer to the Experience-Language-Pictorial-Symbolic-Application learning framework (Lowrie & Patahuddin, 2015), which outlines student knowledge development and views learning as an active process. The framework was used to develop and trial a spatial reasoning intervention program. The outcome of the intervention showed positive effects on mathematics learning. Lowrie et al. (2017) similarly ran a study which involved a 10-week spatial reasoning intervention program for grade 6 students, replacing the existing curricula for that time. The researchers found that improvements in spatial reasoning as a result of this intervention also resulted in improvements in mathematics. Cheng and Mix (2014) had a similar finding on a smaller scale, after asking students to either complete mental rotation tasks or crossword puzzles. Children trained with mental rotation tasks improved in mathematics, whereas those with crossword puzzles stayed the same across the pre-and post-test scores. Though both studies found that their interventions improved spatial reasoning and mathematics ability, Cheng and Mix (2014) point out that their spatial improvements were only seen on a mental rotations test and not spatial relations, limiting the generalisability of this finding. Lowrie et al. (2017), who compare their results to Cheng and Mix (2014), conclude that they also found that students' mathematics performance improved across concepts and sub-strands, and found that their mental rotation and spatial visualisation scores improved as well. They did not find this for spatial orientation, however, which may also limit the conclusions that can be drawn. Nevertheless, the findings of both of these studies indicate that a variety of spatial reasoning interventions benefitted children's mathematical acquisition, and that they may be used within the existing educational programs.

These studies represent a shift in mathematical education research. Mulligan (2015) asserts that STEM subjects may have relied previously on more traditional modes of learning, but that there is a move in STEM learning towards developing visuospatial skills. As such, an argument could be made that school curricula should involve more spatial reasoning training. Newcombe (2013) also highlights the usefulness of spatial reasoning as a tool for increasing STEM performance among students.

Clements et al. (2011) further highlight that choosing the right tasks might be more important than the total time spent trying to learn an activity. Hawes, Moss, Caswell, Naqvi & MacKinnon (2017) implemented a variety of spatial tasks to improve young school students' mathematics performance. Their results revealed that there were several benefits to learning spatial skills, including foundation skills like numerical comparisons and geometry sub-strands.

Focusing on specific conceptual areas, for example, in mathematics allows for more specific understanding of how spatial reasoning influences learning outcomes. Geometry is an area of mathematics where spatial reasoning skills are integral to learning (Clements & Battista, 1992). Several studies highlight the importance of early geometry to increase mathematical performance (e.g., Hawes et al., 2017). Research such as that by Ng and Sinclair (2015) also emphasise this connection. The authors focus their research on symmetry acquisition, something also related to geometry and spatial reasoning. By changing the environment of geometry learning to be more dynamic than the curriculum specified, Ng and Sinclair (2015) demonstrated that young students were able to produce novel and dynamic communications of symmetry. Much geometry also relies on visualisation and rotational skills, which are part of spatial reasoning skills (e.g., Casey et al., 2008; Hawes et al., 2017), as well as both 2D and 3D objects, which are often involved in spatial reasoning tasks (Bruce & Hawes, 2015).

In an attempt to bridge the gap between cognitive science and mathematics education, Bruce and Hawes (2015) provide children with mental rotation tasks for 2D and 3D objects, another important aspect of geometry. Analysing the results of the task's impact, among other aspects, it was concluded that their research also supports the claim that improving spatial reasoning in students can positively affect mathematics performance.

2.2.2.2. Beyond school. Longitudinal research has also investigated the effects spatial reasoning may have in the long term, post mandatory education. This includes studies concerned with spatial reasoning's connection to career prospects, such as Wai et al. (2009). Their article summarises the results of two longitudinal studies which followed high school students in to adulthood to track whether level of spatial reasoning related to latter entry in to STEM careers. The first study lasted 14 years, while the second one started in 1971 and was ongoing as of 2009. The results indicate that spatial reasoning skills in high school was predictive of subsequent STEM-related careers; i.e., those with higher spatial reasoning skills in high school are more likely to pursue STEM careers. Further, Uttal, Meadow, et al. (2013) highlighted the strong connections between spatial reasoning and STEM through their review of literature, and suggested that if more importance was given to spatial reasoning in schools, more students would most likely seek careers in STEM related fields later in life. Their conclusion suggests that research can help inform the circumstances under which spatial skills can be improved, to allow students the benefits associated with improved spatial reasoning skills. Spatial reasoning skills could therefore have flow-on effects that permeate people's whole lives, and not just choice of subjects in school.

2.2.3. Summary

The links between spatial reasoning and achievement in STEM, particularly mathematics and science, are becoming increasingly clear and is increasingly supported by the literature (e.g., Lowrie et al, 2017; Newcombe 2013; Uttal, Meadow, et al., 2013). The existing research demonstrates the importance of spatial reasoning and the benefits it provides, in particular for certain aspects of academic performance. Understanding this is important, and it highlights that spatial activities improve student performance in spatiallyoriented academic areas, which can be translated to other general skills which may benefit individuals throughout life.

However, while this research accentuates the importance of spatial reasoning skills and the role they play in a variety of aspects, it does not refer to the influence of other people in learning. The research on spatial reasoning takes an individual approach, and there is no research investigating the effect collaboration can have on these skills. Children learn from collaboration with others, but none of the research mentioned in this section studied collaborative effects. In the next section, this literature review explores outcomes of studies on collaboration.

2.2.4. Studies on Collaboration and Cognition

Collaboration is utilised in many areas of life, both among children and adults, and they can be found anywhere from casual every-day activities to guided academic tasks (e.g., Blumen, et al., 2014; Butler & Walton, 2013). Collaboration in mathematics education research relies predominately on research paradigms within the classroom with a variety of tasks, while cognitive science research in to collaboration, with child-participants, rely predominately on memory recall tasks in laboratories.

Collaborating with others may result in greater performance than working alone. Indeed, in accordance with sociocultural theory, collaboration potentially allows for completion of tasks which may be unattainable on one's own. Consistent with this theory, educational research has focused on improving learning outcomes for students in collaborative settings. Fung et al. (2018) discuss the benefits of collaboration, and the subsequent performance gains afforded to students who collaborate in science to learning new scientific concepts. The authors do not elaborate or provide examples of scientific concepts, but do highlight that the collaborative experience facilitated joint construction of these new conceptual knowledge between students.

Further, Butler and Walton (2013) demonstrated that when children believe they are collaborating they report enjoying a spatial reasoning puzzle tasks more than children who believe they are working alone. By leading half the children to believe they were working with a peer (who participants were told was located in a separate room, but was in fact non-existent), the authors found that working together is intrinsically motivating for children because they found the task more enjoyable. Although the primary focus for this study was not performance-related outcomes, the authors do address other aspects, such as motivation, which may in turn influence the outcome on a collaborative task. Similar benefits were found by Gilles (2004) who distributed students' geometry-related problems and a mathematics questionnaire to assess cooperative learning effects on problem solving activities. The author's conclusions were that students assigned in groups and a structured environment (i.e., everyone is aware of the task, the expectations and are aware that they need to contribute) tended to behave in more prosocial manners, and resulted in higher learning outcomes.

Over and above the benefits of collaboration for shared knowledge construction, educational research demonstrates benefits of collaboration for motivation.

When studying problem solving with young children, collaboration in cognitive science and mathematics education research present competing views. In mathematics education research, collaboration has shown positive outcomes while cognitive science typically (but not always) shows a trend of collaborative inhibition. Fung et al., (2018), found that collaboration was beneficial to student's conceptual understanding and increasing knowledge, while Plötner, et al. (2015) and Ng and Sinclair (2015) similarly found positive outcomes in the mathematics research. Gummerum, Leman, & Hollins. (2014), on the other hand, compared collaborative recall performance of 7- and 9-year olds, and found negative effects from the collaborative experience when testing in a laboratory setting. Similarly, in a comparison of 7- and 15-year old students Andersson (2001) identified worse performance for collaborators. This finding was particularly strong for 7-year olds. These outcomes point to complexities within the collaborative research, and suggests that there are certain circumstances which may facilitate collaborative inhibition, while certain situations may benefit collaborative work.

2.2.5. Discrepancies in the Research

2.2.1.1. Why might collaboration be beneficial? Mathematics research has provided evidence which suggests that children may benefit from interactive interventions. For example, a study by Ng and Sinclair (2015) into student's geometry acquisition highlights that when students receive such interventions, which include social interactions, more complex material can be communicated and learned. In this study, the researchers suggest that the collaborative component (the teacher-student exchange) helped facilitate the increase in geometric acquisition. This intervention study featured both a computer- based interactive learning experience and traditional pencil-and-paper tasks in addition to the social interactions between teacher and student. The authors believe that a combination of these were responsible for the improvements seen in the students.

Although the predominant finding of cognitive science research into collaboration shows inhibition occurs (e.g., when information recall processes are disrupted and thus slowing down the recall process), studies concerning specific groups of adults offer insights into when and why collaboration may be useful. This is consistent with extended mind theory, where being aware of one's collaborators cognitive abilities allows individuals to use those sources of information to benefit from collaboration. Research with adult participants, such as Rajaram (2018) and Harris, Keil, Sutton, Barnier and McIlwan (2011), suggests that collaboration between individuals make use of techniques like those outlined in extended mind theories to successfully collaborate during memory retrieval tasks. Further, Blumen and Stern (2011) investigated slightly prolonged effects from collaborating adults on collaborative recall tasks, and found benefits in memory and recall up to a week post-testing for those who had repeated collaborative trials, compared to repeated individual trials.

Olsson, Juslin, and Olsson (2006) and Harris, Barnier, Sutton, Keil and Dixon (2017) both look to cognitive science to explain benefits to collaboration. Note that although both investigate the influence of collaboration on memory recollection tasks, their explanations apply broadly to multiple kinds of cognition. Olsson et al. (2006) describe an exemplar pooling effect, whereby the authors mean that collaborators have an extended knowledge base from which useful information can be accessed for task completion. They highlight that social interaction allows the participants to outperform nominal groups (which are described later in this chapter). Harris et al. (2017) instead point to transactive memory: the notion that collaborators who are close with one another may pool their cognitive resources to allow for more efficient cognitive processing and performance. They too emphasise that communication is key for collaboration to be successful and for participants to access their shared cognitive resources. These similar interpretations each predict that the benefits of collaboration are accessed through successful communication, whereby all group-members are aware of the cognitive resources which exist in the group.

If effective collaboration depends on knowledge of others' cognitive capacities, then groups whose members are already familiar with one another are likely to also perform better collaboratively (Andersson, 2001; Harris et al., 2011; Harris et al.,2017; Rajaram, 2018). Such groups are likely to have greater knowledge of the cognitive tasks that their partners have successfully completed before, greater understanding of each other's strengths and weaknesses, and more effective communication strategies. Most cognitive science research where collaborative costs are shown has paired strangers together, which might account for the negative effects exemplified in the research.

A final explanation for the benefits of collaboration seen in some research studies, including educational studies, is that working with others may enhance intrinsic motivation. As mentioned previously, experimental research by Butler and Walton (2013) has shown that children who thought they were collaborating – despite never having met a fictional peer - still enjoyed completing a spatial reasoning puzzle task more than did children who were told they were working alone. Although this evidence is limited, it would suggest that collaboration leads to motivation and could also underlie prosocial learning. If collaborating with peers makes the experience more pleasant for the learner, it should in turn encourage further interaction and learning. Consistent with this possibility, motivation has been shown in previous research to underpin learning for primary and secondary school students (e.g., Butler & Walton, 2013).

2.3.1.2. Why might collaboration fail? Very little research in mathematics education shows performance loss following collaboration. In cognitive science, however, and despite the exceptions noted above, the majority of studies examining the influence of collaboration on performance shows potential cognitive costs. In other words, working together actually results in poorer performance than working alone would have afforded (e.g., Barber et al., 2015; Sjolund, Erdman, & Kelly 2014). One explanation for these findings is that the optimal collaborative strategies shared by some groups are not shared by everybody. Consistent with this explanation, Gummerum et al. (2013) point out that "to recall as much accurate information as possible, group members should pool their unique information" (p. 303). They go on to identify that this does not appear to happen often, either with children or adults.

Other research suggests that retrieval disruption is at the cause of collaborative inhibition (Basden, et al., 1997; Barber et al., 2015; Blumen & Stern, 2011; Harris et al., 2013), where the problem lies not in the encoding phase but when the person later tries to access the information again. For example, a student who constructs a tower out of building blocks may not remember how to do so two weeks later. It may not be that the student did not process what they were doing at the time, but when they go to reconstruct the tower at a later event, they cannot access the relevant information and attend to it. Barber et al. (2015) suggest that collaborative inhibition may have several sources, as their research implies that the inhibition may be retrieval based, and highlights that their findings seem congruent with both retrieval disruption and retrieval inhibition. Although most of this research is done with adults, research with children shows similar trends. In such child-centric research, older children show worse collaborative performance than younger (but see Andersson, 2001, for exception). This is because they have more sophisticated strategy use: thus, there is more to be disrupted than there is amongst younger children.

The explanation for collaborative success or failure appears to be complex. Looking yet again to Rajaram (2018) and Harris et al. (2011), there appears to be certain circumstances that can help or hinder these kinds of interactions to be successful. For example, knowing the fellow collaborators well will make it likelier that the group performs well together compared with if the collaborators are unknown to each other when being grouped together, as mentioned previous. In their study on academic achievement, Fung et al. (2018) highlight various environmental influences positively affected performance. This included more teacher-guided use of effective collaborative strategies such as trust and respect, classroom set up, and tasks promoting interaction. These aspects, it would seem, were not as evident in student-directed collaboration, or what traditional whole-class approaches provided, and lead the authors to conclude that successful collaboration needs structuring.

To further complicate matters, collaborative learning performance gains have also been demonstrated for categorisation tasks, where Richey, Nokes-Malach, and Cohen (2018) compared working in dyads versus working alone. Their study showed greater performance gains for the dyads, but only for certain categories. One study by Blumen et al. (2014) compared collaborative and individual recall to attempt to understand what allows for more accurate recall. Comparing the effects of different learning and recall modes (different combinations of collaborative and individual work), the researchers looked at effects of retrieval disruption, re-exposure to information, and cross-cueing of information (recall by one member causes another member to recall even more) to assess retention rates. The results of this study were complex and would suggest that the learning goals need to guide the type of learning mode, to allow for maximum recollection later.

These studies provide a glimpse in to the complexity of collaborative research and suggest that consequently, there may be certain circumstances which would allow collaboration to be more effective than others.

2.3.1.3. Confounding findings. Taking the findings together, it is clear that the answer may be more complicated than simply suggesting that collaboration does or does not work. Understanding the circumstances under which collaboration is successful is equally important as understanding the reasons behind collaborative inhibition, to ensure a collaborative experience is successful, but it also leads to complex findings in the research. How to successfully collaborate is therefore not very clear and more research is needed to understand the process better. As Harris et al. (2017), Harris et al. (2011) and Rajaram (2018) point out, certain circumstances facilitate learning.

One possible explanation for these confounding results may be the difference in methodologies. In mathematics education, the collaborative performance is measured with participating children. Casey et al. (2008), Fung et al. (2018), Ng and Sinclair (2015), and several others utilise children as their participant pool. They cover a range in age, with the youngest children being tested prior to primary school (e.g., Verdine, et al., 2017). There are also, for example, several investigations of collaboration amongst primary and secondary school students (e.g., Battista, 1999; Ellis, 2011; Kotsopoulos, 2010). This is expected, as mathematics education research is concerned with children's mathematical and problem-solving skills acquisition.

Currently, children are largely overlooked in cognitive science research on collaboration. To date, only five studies have investigated school-aged children's collaborative performance. Andersson (2001), Gummerum et al. (2013; 2014), Leman (2015), and Leman and Oldham (2005) all investigated the outcomes of collaborative tasks in children, and most of these focus on word-recall tasks (with the exception of Andersson, 2001). Gummerum et al. (2013; 2014) and Leman and Oldham (2005) all looked at collaborative recall in children under the age of 10, while Leman (2015) compared differences in group reliance for word recall between 8 years old and 13 year old children. Similarly, Andersson (2001) compared collaborative effects of spatial and collaborative memory performance between students aged 7 and 15, though this did not include word recall, and included factors such as age, gender, and friendships to investigate moderating effects such variables may have on the students' results. Some research, such Plötner et al. (2015) and Butler and Walton (2013), have incorporated children prior to formal schooling, but as discussed earlier, this research investigates social benefits from collaboration but use spatial reasoning tasks as part of their study, and did not focus on learning outcomes of their tasks.

The research on collaborative effects emerging from the field of cognitive science appears largely focused on collaborative memory research, and the majority of this specific research is done with adult participants, with the exceptions noted above. In research by, for example, Richey et al., (2018), Barber et al. (2015), and Sjolund et al. (2014) all relied on undergraduate participants or their research, while Harris et al. (2017) used older adults. Blumen and Stern (2011) relied on a combination of older and younger adults. As memory is a large component of human life, this research is important and highlights how adult collaboration unfolds but neglects the importance of collaboration in childhood and the part it plays in the academic domain.

Most studies using stringent collaborative inhibition paradigms in cognitive science use adult populations, and it is not clear how it influences children as that research shows mixed findings across age (e.g., Andersson, 2001). These studies allow for inferences to be made regarding adult cognitive functioning, and while valid conclusions were drawn within the framework of their research, the outcomes of these studies may not reliably represent child-populations whose brains are still in development. For example, the prefrontal cortex is not fully developed until around 20 years of age, and although Diamond (2002) reports that much of this prefrontal cortex development occurs prior to 11 years of age, it is an ongoing process. Diamond (2002) further suggests that children aged 3-5 undergo a lot of cognitive development, in particular with regards to holding information in the mind and inhibiting behaviours which initially have a high cognitive load. It is not until about 7 years of age that children improve in areas like information processing speed, and simultaneous holding and manipulating multiple pieces of information in the mind. While this development generally starts at the age of 7, it continues until the prefrontal cortex is fully developed (Diamond, 2002). Children are therefore unlikely to possess the abilities required to perform certain tasks or perform them effectively to the same extent as adults. Due to this, it is important to test children's abilities separately and provide ample opportunities to test with a variety of ages to infer when certain abilities may be formed. Research on adult collaboration provides a strong foundation on which to start testing with children, but must be careful when comparing and contrasting between child and adult populations.

2.3.1.3.1. Tasks and testing environment. The second possible reason for the discrepancy between mathematics education research and cognitive science research relates to the tasks used and the testing environment. In the mathematics education research, collaboration was researched using tasks that pertained to for example, curricula outcomes (e.g., Lowrie et al., 2017; Sinclair & Bruce, 2015) or tasks with more relevance to the daily activities of school children (e.g., Cheng & Mix, 2014; Lowrie et al., 2017; Ng & Sinclair, 2015). These studies often take place in school, during children's normal school day (e.g., Fung et al., 2018; Lowrie et al., 2017). Lowrie et al. (2017) introduced their spatial reasoning intervention in the place of the curriculum.

The tasks used in collaboration research form the field of cognitive science often have little ecological validity and are often carried out in laboratory settings. Research by, for example, Gummerum et al. (2013; 2014) tested children's collaborative memory skills with word lists. Again, the only research which could be considered ecologically valid was the study by Andersson (2001) who carried out the research in the participants' schools.

Mathematics education and cognitive science appears to differ not only in the level of real-world application the outcomes may carry as a result of the type of task employed, but also differ in their approach to testing environment, where the mathematics education research is conducted in environments familiar to children and cognitive science uses more controlled environments.

2.3.1.3.2. Comparative methods. Yet another reason may involve the way in which performance gains are measured. A common theme in mathematics education is the use of quasi-experimental classroom research, and the most common comparison is of collaborating groups and individuals. Thus, rather than asking about cognitive processing costs, researchers are instead able to ask about whether a single student will perform better on their own or with someone to help them. Outcomes of interest (e.g., knowledge, motivation) are compared between the participants in two different classes, one of whom is asked to collaborate, or between collaborating- and non-collaborating students in the same class.

As an example of this, Fung et al. (2018) allocated teachers, along with their classes, to either an experimental or control condition in order to assess the outcomes of collaboration. The outcomes of an individual knowledge test post intervention reflected that students who worked individually performed worse than collaborating students in the experimental condition. The outcomes published in the mathematics education journals are therefore broader than those in cognitive science, and their research paradigms do not typically call for the same tightness of experimental design.

Cognitive science, however, appears mainly interested in the cognitive load of collaboration, and thus adopt the use of nominal groups. Nominal groups involve creating fictitious groups of the same size as the group size compared against, and combining individuals' scores post-testing to be able to compare between individual and group conditions (Abel & Bämul, 2017). For example, if the collaborators worked in triads, a nominal group would have to be created using the scores of three people working on the same task individually. By averaging these three scores to create a nominal group score, comparisons and conclusions can be drawn based on collaborative performance vis-à-vis individual performance. The use of nominal groups is quite common, in particular in cognitive science research, and it is an effective way of comparing maximum individual gains against the effect of collaboration. However, when this method was used with research on children (e.g., Gummerum et al. 2014; Leman, 2015) the outcomes were that students were less capable when working together with peers than when students worked individually. However, the research is too limited to draw any definitive conclusions.

Much of the research in cognitive science employ dyads (e.g., Olsson et al., 2006; Richey et al., 2018) or triads (Barber et al., 2015) in their research and compare that to nominal groups (e.g., Sjolund et al., 2014) to measure the effect from, for example, an intervention. The use of nominal groups thus allows for a comparison between, for example, the combined output of two people working individually versus the output of two individuals actually collaborating to assess benefits or drawbacks from collaborative work compared to what the individuals may have completed on their own.

2.2.6. Summary

The research on whether collaboration helps or hinders performance is divided, especially in research involving children. In the mathematics education field, including spatial reasoning, collaboration appears to produce positive outcomes (e.g., Ng & Sinclair, 2015). In cognitive science, however, findings are mixed. Although the precise reasons for these discrepant findings are not clear, approaches to researching collaboration vary greatly between the two disciplines. While mathematics education approaches the problem with broader but more realistic settings and tasks, cognitive science takes a more controlled approach. In addition, while children are the primary participants in mathematics education research, adults are most often tested in the cognitive sciences. Finally, the two disciplines take very different approaches to comparing gains. Research in mathematics education typically compares individual and group performance outcomes, for example, while cognitive science uses nominal groups rather than individuals to examine the cognitive costs of collaboration.

2.3. Conclusions and Gaps

As discussed through this literature review chapter, there are clear links between spatial reasoning and other aspects of academic and every-day life. The ability helps us perform daily tasks, and this reasoning can be improved upon across the lifespan, and in particularly through childhood. Casey et al. (2008) demonstrate that these skills can be acquired from a young age, while Wai et al. (2009) highlight that spatial reasoning can have long-lasting effects, including career choices, later in life. Importantly, however, no research has yet considered the influence of children's collaboration on their spatial reasoning performance. Furthermore, existing research on collaboration shows both benefits and costs. Research in mathematical education typically describes collaborative benefits, whereas research in cognitive sciences is more mixed. Because of the different research traditions used in these two disciplines, the reasons for these discrepancies are unknown.

The current research aims to investigate the effect of collaboration on children's spatial reasoning performance. By doing so, it will also bridge the existing gap between mathematics education and cognitive science approaches to studying of collaboration. Drawing on sociocultural and extended mind theory, students will be asked to complete two spatial reasoning tasks. The next chapter outlines the methodology of this research including the tasks and procedures used to collect data.

Chapter 3. Methodology

3.1. Project Description[1]

An exploratory empirical study of 40 Year 1 and 36 Year 2 students' spatial reasoning performance adopted a quasi-experimental design. Whole classes were assigned to one of two conditions (collaborative dyads or individual) and participated in two spatial reasoning construction tasks. Thus, as classes and not students were allocated to conditions, this is not a true experimental design. The students participated in two tasks on two separate occasions, comparing both within and between conditions. The students in the collaborative condition worked individually on the first task but collaboratively on the second task, while students in the individual condition worked individually on both occasions and were paired into nominal dyads after testing concluded. This was done to be able to compare the results between the two conditions more accurately. The quantitative analysis involved a 2 x 2 x (2) ANOVA to analyse the possible effect of collaboration across two Year levels. The photographic images of the students' constructions were analysed for one of four levels of spatial structure: Prestructural/Idiosyncratic, Emergent or Partial Structural, Structural, and Advanced Structural. A repeated measures ANOVA was run on the coding of the tower and bridge images, with a Raven's score as a covariate followed by a descriptive analysis of the structural levels by Year level and condition.

The research paradigm was undertaken to combine aspects of cognitive science research and mathematics education research. As the use of nominal groupings and mixed methods quasi-experimental design often features in cognitive science research, it seemed appropriate to implement them in environments which commonly features in mathematics

[1] This project contributes to, and complements the design of a larger study on spatial reasoning (Australian Research Council Discovery Project DP170101588; Mulligan, et al., 2018)

education research; classrooms. This marrying of research methodologies strengthen the inferences which can be drawn from these findings and allows future research to combine these two fields for further research.

3.2. Participants and Recruitment

The participants were 35 boys (46%) and 41 girls (54%) in Year 1 (6yrs 8mths – 7yrs 10mths) and Year 2 (7yrs 7mths – 8yrs 7mths) who attended a metropolitan private school. The setting was chosen as this is a place where children are often engaged in collaborative tasks. The participants were drawn from two Year 1 and two Year 2 classes at the same school and the sample were from households with high socioeconomic backgrounds.

Ethics approval was obtained from Macquarie University Faculty of Human Sciences Subcommittee, reference number: 5201832664870 (Appendix A). Teachers distributed and collected the consent forms among the students on behalf of the researcher, and the forms were collected from the teachers by the researcher prior to the testing sessions. As this was a classroom experiment, a total of 91 students participated in the activity itself but data were only collected from the 76 students whose parents had provided consent. Data were only collected from students who also verbally agreed to participate, and (for those in the collaborative condition) had a partner who also fulfilled the first two criteria. All students verbally agreed to participate.

Students were allocated to one of two groups (collaborative dyad or individual). The allocation was based on the proportion of consent, where the classes with proportionally more consenting students were paired into dyads to allow for maximum viable data. To pair students in the dyadic condition, a measure of Raven's Progressive Matrices (Raven, 2000) was used. Raven's Progressive Matrices (Raven, 2000) is a test which assesses a student's ability to mentally manipulate information to find a missing piece of an image. This test relies on mental rotation and visualisation, which features heavily in the type of construction tasks this study employed, and allows students to think ahead, predict and develop strategies for construction to achieve their goal. Students with similar scores on this test were paired together as it indicated they were of similar spatial reasoning level for the purposes of this task. The students in the collaborative condition were paired up prior to the second task while students in the individual condition were paired up during the data analysis phase in identical ways to the collaborators. Most students had been previously tested during kindergarten so their Raven's scores were obtained from the school. Some students who were allotted the dyad condition did not attend kindergarten at this school and did not have Raven's results. The researcher therefore tested the Raven's Progressive Matrices (Raven, 2000) on those students prior to the second test time. Some students in the individual condition did not have Raven's scores either for the same reason and the researcher also tested these students.

3.3. Spatial Reasoning Task Design and Materials

The spatial reasoning tasks consisted of two different construction activities, where the students built either a tower or bridge-like structure. These types of construction tasks would rely on students' spatial reasoning abilities as they did not have a model or instructions. This type of task relied on some aspects of spatial reasoning, such as mental rotation, structure, stability, and problem solving, as students had to mentally predict, plan and adjust the constructions themselves mentally and (for the collaborators in the second task) communicate with their peers to successfully complete the construction tasks.

The students were each given a bag of materials. On the first occasion, each student received 40 paddle pop sticks (approximately 11 cm long each) and a piece of plasticine (approximately 2-2.5 cm^3), and on the second occasion, the students received 50 paddle pop sticks and approximately the same amount of plasticine in each bag. As the second task was collaborative, extra paddle pop sticks were provided from the start to ensure that collaborators would not run out of paddle pop sticks too quickly. Extra plasticine and extra paddle pop sticks were available from the researcher if the students needed additional supplies. In each bag there was also a sheet of A4 paper on which to write a recollection of their task completion (Appendix E). The 25 cm tall cat Alex (See Figure 1) was presented as an adventurer who had come to the school to ask the students for help to complete adventures, and gave the students prompts on computer typed notes that were carried in the attached backpack.

Figure 1

Images of Alex.

Note. The backpack is on the cat's back but is not very visible.

3.4. Data collection

During both test times, data were collected on the height and length of the constructions. As the students had been instructed to build their constructions as tall or as long as possible, this measure was useful to see how capable students had been in following instructions. Students were then asked to recall and write down the construction process for Alex to replicate (see Appendix E for template), and photographs were taken of the constructions as soon as possible after the construction phase was finished (during the students' recall phase) to capture the structural level of the constructions. This measure was useful to assess whether students had understood the task, but also how structurally advanced their constructions were. At the second test time, a GoPro camera with a covered lens was placed at each dyad's table to capture the conversation between the dyads to ensure collaboration took place. The camera lens was covered up as we did not have approval to visually record the students collaborating but consent was given to audio-record their conversations. The second test time for the individual students was not recorded. For students in the dyad condition, a slip of paper was also provided which asked them to rate on a Likert scale how good a friend they considered themselves to be with the person they worked with (Appendix G). The teachers in the classrooms of the dyads were similarly asked to fill out some information about the student's social interactions at other times, including both playing at recess and classroom collaborations (Appendix F).

3.5. Procedures

3.5.1. Pilot Testing

Alex's instructions and the tasks used in this study were pilot tested with students between the ages of 5 and 8. Four students participated in the pilot testing sessions which were held in their home environments. Only the protocol for the individual testing settings were pilot tested for potential difficulties and drawbacks. As a result of the pilot testing sessions, the wording of the instructions was altered to allow for a more open interpretation of the requirements of the construction.

3.5.2. Testing Schedule

The students were asked to participate on two occasions, on two consecutive weeks, during their regular mathematics lessons. For the first occasion, the researcher administered the task to both Year 1 classes simultaneously on one day and both Year 2 classes simultaneously on the following day. The testing took place in the last month (last two weeks) of the school year. Testing sessions were of 20 minutes duration. All testing sessions took place in the morning except for one Year 2 class which was tested at 2pm.

3.5.2.1. Test time 1. During test time 1, both Year 1 classes were briefed together and then all students in both classes completed the task individually, in their respective classrooms. The same process was completed for the Year 2 classes, but a day later. All classes were tested during the morning. The testing times varied from 8.30am to 9.30am.

Students sat on the floor in the front of the classroom, and the researcher introduced Alex to the students as a friend who had visited the researcher at the university to ask for help. The researcher explained that she had brought Alex to meet the students at the school and to ask them for help. At test time 1, Alex introduced a problem encountered during an adventure; Alex was lost in a forest and couldn't find his way. The cat asked the students to help by constructing something which allowed Alex to see above the tree tops (see Appendix D for more details). Below is an excerpt from the note Alex brought to the classes.

[…]I was travelling through a forest with many trees standing really close to each other, and I got lost. I came upon a clearing but didn't know where to go. I tried climbing the trees, but I couldn't get high enough to see where I needed to go.

So I have come to ask you for your help, as I have heard you are very clever children. I would like you to construct something for me that I can use in the clearing. I need you to make it as tall as you can so I can see above the tree tops. […]

The task was intended to evoke the idea of a tower-like structure. Prior to commencing the task, the students all verbally agreed to partake in this task. The students were then given a bag of material and directed to their desks for a 20-minute construction session. Time was recorded using a timer on a phone. After the session, the students were asked to recall and write down what they did during the construction phase so that Alex could replicate it during the adventure (see Appendix E for template). While the students were writing, the researcher, with assistance from staff at the school, photographed and recorded measurements of the constructions.

The students asked if they could keep their constructions and were told that if it was okay with their teacher they could keep them. The remaining materials were packed away and the forms collected by the researcher.

Upon completion, each student was presented with a certificate of appreciation, signed by Alex, as a thank-you token for participating and helping Alex (Appendix H).

3.5.2.2. Test time 2. At test time 2, each class was briefed individually. Year 1 students were tested in the morning (11am on two separate days) while the Year 2 classes were tested in the afternoon (between 1-3pm on the same day). One of the Year 1 classes and one of the Year 2 classes were allocated to the collaborative condition, being paired up by the researcher in to dyads based on the similarity in Raven's Progressive Matrices scores. The remaining Year 1 and Year 2 classes completed the second task individually yet again. Students in the dyadic condition comprised both same and mixed gender pairings and the individuals who were paired in to nominal dyads post-test also comprised both types of pairings.

All students were instructed in the same way as for test time 1. Alex the adventurer visited with another letter in the backpack and the instructions were read aloud to the students. At the second test time, the students were instructed to create something to help Alex cross a multi-lane road with heavy traffic and no pedestrian crossing. They were asked to make their creation as long as possible, and the only criteria their construction needed to meet was for a cardboard car (10 cm tall) to be able to pass under their construction. The aim was to evoke the idea of a pedestrian bridge, but the students were free to construct as they wished. Once instructions had been communicated, the students again verbally agreed to participate in the activity. Below is another excerpt from the letter Alex brought for this task. See Appendix D for full note.

[...]I made it through the forest thanks to the constructions you built last time, but I had another problem.

When I came out of the forest, I adventured on for a bit but then I came upon a really wide road with many lanes. I could not cross it because there was constant traffic and there was no pedestrian crossing in sight. I am also a bit frightened of cars.

Because you helped me so much last time, I was hoping I could ask for your help again. Can you please help me build something I can use to cross the road? I would like you to work in pairs. The construction needs to be as long as possible so I can cross all the lanes, and it needs to be high enough from the ground so that this car can fit under it. [...]

Please note that this is the note brought to the collaborating classes, and the note for the individual constructors excluded the line about working in pairs.

For the collaborative condition, the students were paired up during the distribution of materials according to the dyads the researcher had compiled, and were seated with their partner at a table decided by the teacher. Each pair was given one bag with paddle pop sticks and plasticine. Following this, the timer was set and the students once again constructed for 20 minutes. During the construction phase, the teachers in the collaborative condition classes were asked to fill out a quick survey for each dyad regarding their perception of the dyad's contact and collaboration during school time (See Appendix E for survey). The individual condition followed an identical procedure to testing time 1. After agreeing to participate in the activity, materials were distributed and each student returned to their own seat with one bag each. These students were not audio recorded. They were also given 20 minutes to complete their task. These results were later compiled in to nominal group scores (explained in Chapter 2). The nominal dyads were, as mentioned previously, also based on the students' Raven's Progressive Matrices scores.

Similar to the previous testing time, there were extra materials available for students if they required these. Post-construction, both students working individually and in dyads were asked to recall and write down how they had completed their constructions for Alex to read later. While the students were occupied with the writing task, the researcher measured the height and length of each construction, took photos, and tested whether the car could fit underneath their construction (as required by the conditions of the task). Students in the dyads were also asked to rate their perceived level of friendship to the person they worked with (Appendix G). Students were allowed to keep the constructions and materials they had built with if their teacher permitted it.

In addition to the individual thank-you certificate, each class also received a thank-you certificate at the end of the second test time, which they could display in the classroom if they wished (See Appendix I).

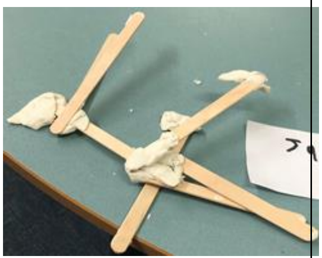
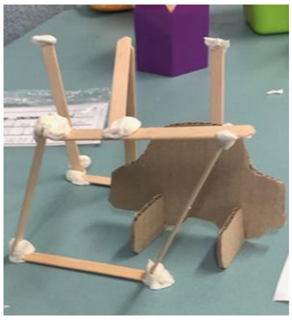
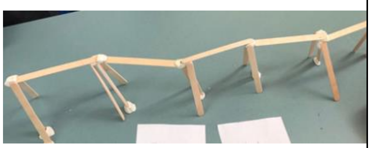
3.6. Analysis of Data

A 2 x 2 x (2) mixed model ANOVA was used to investigate if collaboration and year at school effected outcomes on the spatial reasoning tasks. The data were analysed for successful criteria using dichotomous codes and entered into an SPSS spreadsheet. Each student was assigned a 1 or 2 for a correct or incorrect response (completed the task according to instructions or not) respectively. Dyads were coded in the same way. Students' scores on Raven's Progressive Matrices (Raven, 2000) were used as a covariate.

Secondary coding was allocated to photographs of the constructions using a four-point scale. This coding scheme was based on the levels of structural awareness developed by Mulligan and Mitchelmore (2013). Their coding scheme was originally developed to measure levels of awareness in pattern and structure in early mathematics according to broad stages of structural development. As the current coding scheme focused on determining emergent awareness levels, it appeared appropriate to modify Mulligan and Mitchelmore's (2013) coding scheme to assess emergent structural awareness also. Mulligan and Mitchelmore's (2013) levels of patterning and structural awareness were based initially on the Structure of Observed Learning Outcomes (SOLO) taxonomy used widely in categorising students' responses to a range of mathematical problem (e.g., Mulligan & Watson, 1998; Watson & Chick, 2001). The coding scheme aimed to classify the students' constructions based on their level of spatial performance according to the descriptors used to identify the structural level. As the purpose of the SOLO taxonomy is to identify the level of complexity within the performance, it seemed an appropriate framework to base the levels of this coding scheme on. This coding scheme divided children's constructions based on four levels of structural complexity and images were double coded to ensure reliability in structural levels. These levels are described as follows (see Table 1 below).

Table 1

Coding Scheme: Level of Structure in Task Response

Level of structural response	*Descriptor*	*Exemplar (photograph) Tower*	*Exemplar (photograph) Bridge*
Prestructural/ Idiosyncratic	Demonstrates none or little understanding of structural elements • Construction does not meet relevant criteria • Idiosyncratic features in solution • Does not demonstrate structural elements • Completed task with redundant or irrelevant elements according to outcome May focus on one dimension but redundant/unnecessary elements		
Emergent or Partial Structural	Understands some structural requirements but focuses only on one aspect at a time • Focuses on one dimension of the construction • Repeats one structural feature e.g., height/length/stability • The construction meets criteria • Partially completes construction • Demonstrates emergent structural awareness		
Structural	Focuses on multiple structural aspects • Demonstrates awareness of relevant structural features • Uses stability		

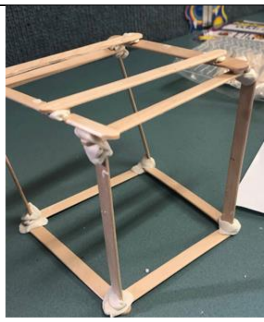
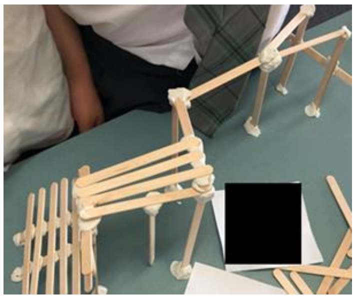
	• Awareness height/length dimensions • Evidence of symmetry		
Advanced Structural	Meets task design specifications at superior level • Integrates height/length dimensions • Repetition of form • Evidence of symmetry and efficiency • Explains and justifies structural features • Views construction process in a holistic way • Generalises features of the construction		

Table 1 describes the coding scheme comprising four categories, ranging from prestructural/idiosyncratic to advanced structural level. Students at the prestructural/idiosyncratic level often constructed with little understanding of what was necessary to successfully complete the task. Those at the emergent or partial structural level constructed with emergent structural awareness, but only focused on one dimension of the construction process. Students in the structural response category were able to focus on, and attend to multiple aspects of the construction to build something that met the criteria. Those at the advanced structural level constructed in a more holistic way, and used superior knowledge of spatial features of the construction. They also completed the construction within 20 minutes.

As required by ethics, all images were stored on the university's cloud storage drive. Unfortunately, 30 of 133 images stored on this drive were lost or corrupt. Despite engaging the support of university IT staff, these 30 images could not be recovered. As a result, only 44 students had images saved from both test times.

The coding scheme was applied to all remaining 103 images. All the images were coded by the researcher. Following this, 16 images from the tower construction task and eight images from bridge construction task were randomly selected and double coded by an independent coder. This represented 20% of the images from each group. The interrater reliability was calculated at 92%. There were initial discrepancies between the coding by the researcher versus the independent coder, attaining an initial 63% reliability. These discrepancies were resolved by discussion and by asking a second independent coder to double code the images in question, and with those responses, the interrater reliability increased to 92%.

A repeated measures ANOVA was run on the coding of the tower and bridge images, with a Raven's score as a covariate. A descriptive analysis of the levels of spatial structure was conducted for each Year level and condition.

3.7. Student's Conversations and Written Recollections

Data were collected on student's conversations during the collaborative activity to ensure the engagement of both parties in the collaborative process. All of the audio recordings were transcribed and reviewed by the researcher. The transcripts revealed that the collaborating students discussed the construction process and in all cases developed some form of dialogue focused on their instructions, justifications or arguments about the construction process. It was confirmed that all students in the collaborative condition did indeed collaborate. Student's written recollections about the construction process, intended to communicate to the fictional cat Alex, were collected from each student. These recollections were used to support the coding and analysis of images where necessary.

The student's conversations, written recollections for Alex and the friendship scores were not analysed as it was not within the scope of this thesis, but may be analysed in future for further analysis.

Chapter 4. Results

This chapter presents the results of the two types of analysis used in this study. This includes the quantitative analyses aimed at comparing between and within condition and Year group level, as well as the qualitative analysis concerning the spatial structural levels by condition and Year group level. As described in Chapter 3, all students constructed individually for the tower task, and collaborators were only paired up prior to the bridge task. Thus, while groups will be referred to as either collaborative or individual, no collaboration took place during the first task.

A 2 x 2 x (2) mixed model ANOVA was used to investigate if collaboration and year at school effected outcomes on a spatial reasoning task as described in Chapter 3. The between subjects-variables included Condition (collaboration vs. individual) and Year (1 vs. 2), and the within-subjects variable was Task (tower vs. bridge). Note that because the tower -building and bridge-building tasks had different demands, with one focused on height and one on length, we would not necessarily expect performance to be the same across tasks. Thus, while the task main effect is reported for completeness, the influence of collaboration can only be determined by examining the interaction between task and condition. The coding and method of analysis is reported in Chapter 3.

4.1. Effects of Task and Condition

There was a significant main effect for Task, $F(1, 72) = 36.091$, $p < .001$, $\eta_p^2 = .334$, modified by a significant Task x Condition interaction, $F(1, 72) = 12.374$, $p = .001$, $\eta_p^2 = .174$. Figure 2 depicts the difference in task performance between the two conditions overall.

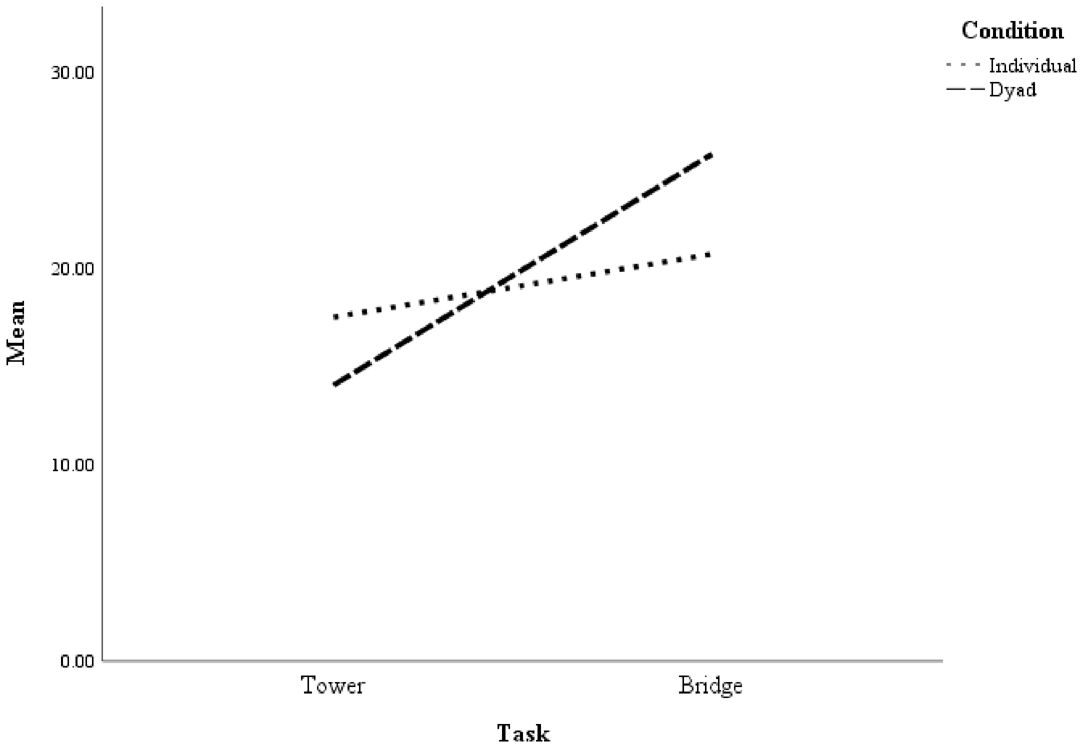


Figure 2. Between Group Differences. Mean depicts mean construction height/length in cm.

Follow-up tests of simple effects showed that students in the collaboration condition built significantly shorter towers than their individual counterparts (*M* = 14.053, *SD* = 5.918 vs. *M* = 17.513, *SD* = 9.144). However, they also built longer bridges (*M* = 25.816, *SD* = 14.918 vs. *M* = 20.724, *SD* = 11.859). The between-subjects effects analysis revealed that these differences were significant, both for the tower, $F(1, 72) = 6.044$ $p = 0.016$, $\eta_p^2 = .077$, and the bridge, $F(1, 72) = 4.037$, $p = .048$, $\eta_p^2 = .053$. Means and Standard Deviations for the data are found in Table 2 and are valid for the primary and follow-up analysis.

Table 2

Means and Standard Deviations

		Mean Tower Height			Mean Bridge Length		
Numeric Condition	Year	Mean	Std. Deviation	N	Mean	Std. Deviation	N
Individual	1	16.333	6.301	18	25.333	6.949	18
	2	18.575	11.171	20	16.575	13.872	20
	Total	17.513	9.144	38	20.724	11.859	38
Dyad	1	17.591	4.434	22	20.682	9.877	22
	2	9.188	3.907	16	32.875	17.903	16
	Total	14.053	5.918	38	25.816	14.918	38
Total	1	17.025	5.319	40	22.775	8.892	40
	2	14.403	9.832	36	23.819	17.587	36
	Total	15.783	7.846	76	23.270	13.629	76

Note. Mean and Std. Deviation measured in cm. All decimals rounded to 3dp. Dyad represents the collaborative condition.

4.2. Changes across Year Group

There was not a significant main effect for Year group, $F(1, 72) = .129$, $p = .720$, $\eta_p^2 = .002$. This means that the performance between Year 1 and Year 2 overall did not differ significantly. Although there was also no significant Task x Year interaction, $F(1, 72) = 2.913$, $p = .092$, $\eta_p^2 = .039$, or a significant Condition x Year interaction $F(1, 72) = 1.848$, $p = .178$, $\eta_p^2 = .025$, there was a significant three-way interaction between Task x Condition x Year, $F(1, 72) = 31.58$, $p < .001$, $\eta_p^2 = .305$. This result would suggest that Year 1 and Year 2 students approached the tasks differently, and these results were further investigated.

The follow-up simple effects analysis showed that for students in Year 1, there were no significant differences between the conditions for either task, $p = 0.582$ and $p = 0.247$ for tower and bridge respectively. For students in Year 2, however, there were significant differences between the conditions both in tower height and bridge length, with dyads performing significantly worse in the tower task, but significantly better in the bridge task, *p*

= .001 and p < .001 respectively, compared to the individual condition. Figure 3 and 4 depicts the difference within Year 1 and Year 2 respectively, between conditions for each task.

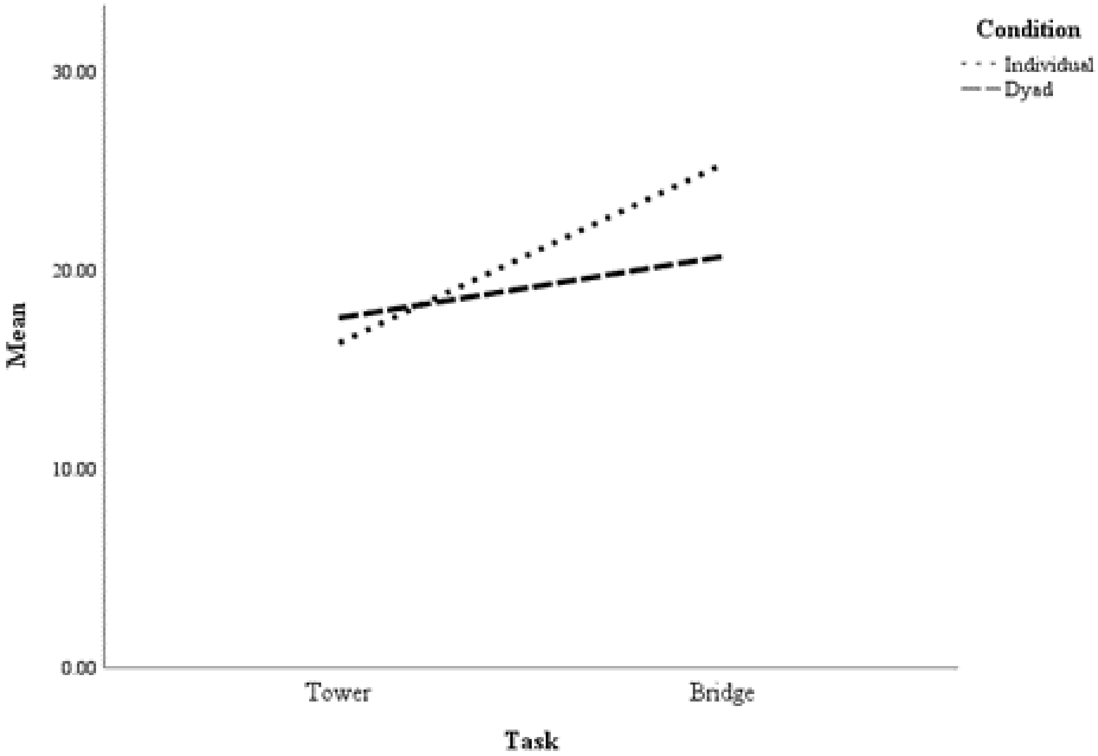


Figure 3. Year 1 differences. Mean denotes mean height/length in cm. Dyad represents the collaborative condition.

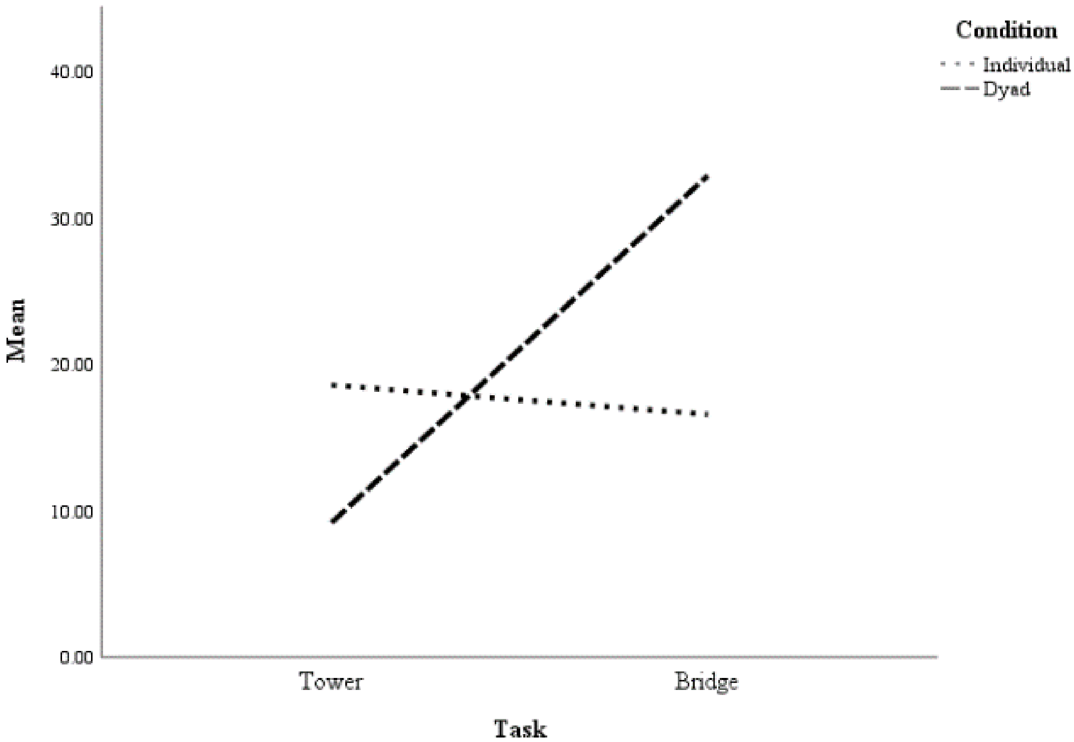


Figure 4. Year 2 differences. Mean denotes mean height/length in cm. Dyad represents the collaborative condition

Further examination of the simple effects for conditions revealed that there was a difference between the collaborative group scores for the tower-building task, where the Year 1 students in this condition performed significantly better than those from Year 2, $p = .001$. This was not the case for the students in the individual condition where the groups performed more equally, $p = .338$. This difference is visualised in Figures 3 and 4 above.

When actual collaboration took place, the simple effects analysis for the bridge length showed within-condition differences between Year 1 and Year 2 for both the individual and collaborative groups. The students in the individual condition in Year 1 performed significantly better than the Year 2 students, $p = .035$. The students in the collaborative condition performed better in Year 2 than in Year 1, $p = .004$. This is also depicted in Figures 3 and 4.

Overall, there was no significant main effect for the Condition $F(1, 72) = .215$, $p = .644$, $\eta_p^2 = .003$, or Year $F(1, 72) = .129$, $p = .720$, $\eta_p^2 = .002$.

4.3. Structural Levels

The coding scheme of structural levels that was developed and applied to the images of the students' constructions were analysed in an ANOVA. The within-subjects effects analysis revealed that the main effect of Task was non-significant, $F(1, 41) = .264$ p = 0.610, $\eta_p^2 = .006$, and the Task x Raven's Score interaction was also non-significant $F(1, 41) = 0.490$, p = .848, $\eta_p^2 = .012$.

Tables 3 and 4 report the percentage of student constructions that were coded for each level based on the coding scheme for the different years and condition. Examples of students' constructions and description of the data are continued below. The tasks were set in a context (outlined in Chapter 3) whereby students were asked to help Alex the Adventurer in a specific situation. See Chapter 3 for more details.

Table 3

Percentage of Students at Each Structural Level for Tower Task

		Individual		Dyad	
		Year1	Year 2	Year 1	Year 2
Tower	Prestructural/Idiosyncratic	28.6%	20%	41.7%	16.7%
	Emergent and Partial Structural	57.1%	60%	33.3%	50%
	Structural	14.3%	0%	25%	25%
	Advanced Structural	0%	20%	0%	8.3%

Note: These calculations are based on the subsample which had image data for both tasks. *n* = 44

Table 4

Percentage of Students at Each Structural Level for Bridge Task

		Individual		Dyad	
		Year1	Year 2	Year 1	Year 2
Bridge	Prestructural/Idiosyncratic	14.3%	40%	33.3%	25%
	Emergent and Partial Structural	64.3%	20%	66.7%	25%
	Structural	21.4%	40%	0%	33.3%
	Advanced Structural	0%	0%	0%	16.7%

Note: These calculations are based on the subsample which had image data for both tasks. *n* = 44

Table 3 denotes the distribution of the coded images on the tower construction task. There appears to be a similar distribution within each year for the conditions, suggesting that there was an equal distribution across classes. All students completed constructions individually, and the data indicate that the majority of students are operating at the lowest two levels (Prestrucutral/Idiosyncratic and Emergent or Partial Structural levels). These students often produced collapsed constructions, or constructions where they understood the task but struggled to take into account all structural elements necessary to complete the construction according to the instructions. Figures 5 and 6 are exemplars of these levels.

Figure 5. Tower at Prestructural/Idiosyncratic Level

Figure 6. Tower at Emergent or Partial Structural Level.

Few students demonstrated skills in the higher categories (Structural and Advanced Structural levels) for these tasks, but of those who did, their construction took on a holistic approach to solve the task. Examples of this are seen in Figures 7 and 8.

Figure 7. Tower at Structural Level.

Figure 8. Tower at Advanced Structural Level.

In Table 4, there is a similar distribution within the individual condition, and for the Year 1 collaborating dyads. For the Year 2 collaborating dyads, 50% of their constructions still fell in the first two levels. This represents a large group in these two categories, but their spread over the four categories might suggest that collaborators were able to better express their skill level when working with a peer. This limitation also found in the other task and groups may be due to the time limit. This is discussed further in Chapter 5. The spread across the categories for the collaborating dyads in Year 2 is perhaps a representation of the difference in performance according to the simple effects analysis. While there were non-significant differences in the results seen in the quantitative analysis for Year 1 and for the individual condition, in Year 2 collaborating dyads (who demonstrated a significant difference both to their Year 1 counterparts but also against the individual condition) are captured in the spread across the levels.

The students in the two lowest levels often presented constructions that attempted to fulfil the task criteria but did not complete their constructions according to the requirements outlined in the instructions. Examples of this can be seen in Figures 9 and 10.

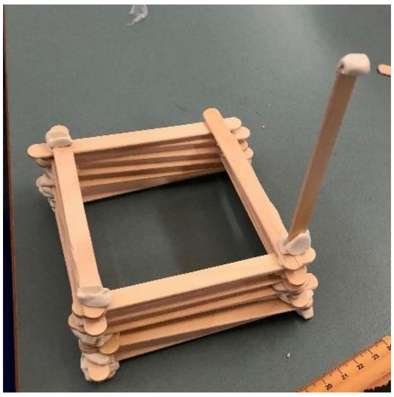


Figure 9. Bridge at Prestructural/Idiosyncratic Level.

Figure 10. Bridge at Emergent or Partial Structural Level.

For the few students operating at the two higher levels, (similar to the first task), the constructors built more complete constructions which appeared to meet the criteria to varying degrees. These can be seen in Figures 11 and 12.

Figure 11. Bridge at Structural Level.

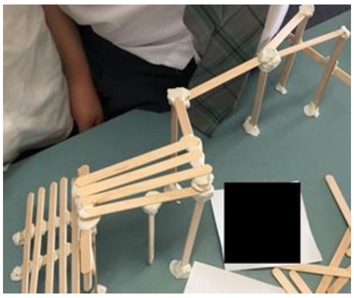


Figure 12. Bridge at Advanced Structural Level.

While the results in Tables 3 and 4 are interesting, it is important to keep in mind that these results were obtained with a subsample of students (n = 44), and that more research is needed to evaluate if the proposed explanations for the results are true.

In the next chapter, the results are discussed further and explanations suggested for the results obtained in this study.

Chapter 5. Discussion, Implications and Conclusions

This chapter will discuss the findings presented in Chapter 4 and will summarise the conclusions of the study. Limitations of the research will be outlined as well as the implications for theory, and future research.

The aim of this research was to investigate broadly the role of peer collaboration in young children's problem-solving performance during a spatial reasoning task. Another purpose of the research was to potentially inform pedagogical practice and gain insight into student learning. The study was designed to explore the effect of peer collaboration on students' performance and use of spatial structure when solving two construction tasks.

The first research question was — "Do collaborating dyads perform differently from individuals' on spatial reasoning tasks?" There was an overall advantage found for the collaborative group compared to the individual group. This result was expected, especially in light of the positive outcomes for collaborators found in some mathematics education research (Fung et al., 2018; Ng & Sinclair, 2015), and to some extent from findings in cognitive science research showing collaborators perform better under certain circumstances (e.g., Rajaram, 2018).

The finding that collaborators performed better than nominal groups consisting of individual constructors is consistent with both sociocultural theory and extended mind theory (e.g., Wegner, 1985). Recall that sociocultural theory asserts that social interaction advances knowledge and allows peers to access information in their ZPD which can be applied in problem- solving tasks. Extended mind theory suggests that collaboration can be beneficial to the task solution process if collaborators are aware of the knowledge available and mentally connect ideas as a mind-network, as described by extended mind theory, accessible through communication. Adopting a Vygotskian approach, the findings suggest that working with another individual to achieve a common goal should result in better performance than working alone. The students in the collaborative group showed poorer performance on the initial tower task (where they worked individually) relative to the students in the individual group, but when collaboration ensued in the bridge-building task the collaborating students performed better than those in the individual group. This suggests that they were able to use their combined knowledge and skills and communicate effectively in accordance with extended mind theory. It can be implied that collaborators were able to access and use their cognitive structures effectively to maximise the task solution. This is contradictory to the findings of studies on collaborative inhibition which is prominent in cognitive science research on collaboration (e.g. Gummerum et al.,2013; 2014). In addition, and notwithstanding the reduced sample size for the test of structural levels, the enhanced performance of the collaborating dyads did not come at the cost of quality. Because nominal groups were used as the comparison group for collaborators, providing a measure of cognitive processing costs and benefits by assessing performance, the findings in this research which demonstrated collaborative advantage are particularly robust.

The review of the literature highlighted some differences in methodology between this study and previous research, including research settings, tasks, and comparative methods. Some differences were described not only in approach but also in the expected outcomes (related to knowledge gains versus understanding cognitive impacts of collaboration). The findings of mathematics education research, including spatial reasoning were generally positive for collaborators (e.g., Ng & Sinclair, 2015), with learning advantages to those who collaborate, while cognitive science research showed contrasting findings. For example, school-aged children in studies by Gummerum et al. (2014) and Leman and Oldham (2005) showed disadvantage when collaborating.

The difference in the approach in this present study relates to the aims of the research. Mathematics education research is aimed at performance-related outcomes, where the goal is to improve learning for students, while cognitive science is generally focused on mental processing, and understanding the mental processing costs or benefits that collaboration can afford. These differences are also reflected in the design and types of environments and tasks the research uses, where mathematics education research tends to use more ecologically valid tasks, and research in classrooms, compared to cognitive science research on collaboration, which often relies on memory tasks in laboratory settings.

Further, the use of nominal groups in the cognitive science research is designed to capture and assess processing costs and benefits. The analysis in itself is rigorous and accounts for much variation in results, but it may not be as ecologically valid as the mathematics education approach which usually adopts individual assessment of mathematical concepts and processes, including types of mathematical thinking such as spatial reasoning.

Findings in child-centric cognitive science research on collaboration such as Gummerum et al. (2014) and other research which uses the collaborative inhibition paradigm in their methodology have demonstrated that collaboration actually fosters worse performance than working alone. As this study used the same collaborative inhibition research paradigm as Gummerum et al. (2013; 2014) with the use of nominal groups to account for cognitive advantages or disadvantages, there may be several explanations for why this sample showed better performance when in collaborating dyads.

First, the tasks involved in the cognitive science research investigating children's collaborative performance predominately asked children to memorise and recall word lists: a task which requires markedly different cognitive abilities than the tasks used for this study. While children may differ in recall capacity, those task solutions are not influenced by conceptual understanding and the development of mathematical structures, integral to the construction tasks in this current study. This may be one reason to account for the results which are markedly different. Practical spatial reasoning performance, while still influenced by cognitive development, may use a more complex network of skills that are less reliant on a child's ability to recall and express information verbally and accurately. Performance on these tasks might instead be influenced by experiences in construction, which a child may or may not be able to recall precisely, and have internalised the knowledge gained through those experiences.

Second, the students in this sample may have extensive previous experience collaborating in a range of learning experiences which may have influenced their performance on these tasks. Engaging the students in collaborative experiences through enquiry-based, or problem-based learning as opposed to teacher-directed instruction may have fostered their collaborative skills and reasoning abilities relative to children of the same age at a different school. These children may have also experienced the advantages of collaborating with peers or siblings in the out- of-school or home environment, something which was not controlled for in this study.

Further, the grouping method used in the current study may have facilitated collaborative success. In cognitive science research, the research on collaborative inhibition suggests that as a person develops and implements specific cognitive strategies in order to perform a task, it is easier for these strategies to be disrupted (e.g., Basden et al., 1997). This interruption may account fully for the collaborative inhibition found in many cognitive science studies, both amongst adults (e.g., Abel & Bämul, 2017) and children (e.g., Leman & Oldham, 2005). The design of our study ensured that the students would have to rely on their own cognitive retrieval strategies for this task, and that the students in the collaborative dyads would need to do so as well, plus communicating their knowledge and reasoning. The results demonstrated that the students in the dyads, and in particular Year 2, were able to prevent the inhibitions from taking place and excelled in their construction process as a result. Students were also matched based on their similar Raven's score. The similar Raven's score may reflect a similar level of spatial reasoning and thus it could be predicted that a similar level of spatial structure, and/or type of problem-solving strategies would be used. If collaborators use the same level of spatial structuring and problem-solving strategies, then these strategies may be harder to disrupt, and collaboration may be facilitated.

Fung et al. (2018) have exemplified this by comparing different levels of rigor placed on collaborative conditions. The students in their study who had the most stringent control also exhibited greater collaborative advantages. It could be that students were directed towards similar strategies when placed in the most rigorous condition and thus experienced the collaborative advantage. Their study, along with the findings in this study support the idea that collaboration affords educational advantages.

Last, there could also be an environmental effect to explain why these differences occur in our study compared to the cognitive science research on collaboration, which is the testing environment. As mentioned previously, cognitive science uses laboratories to study their participants, while this study and mathematics education frequently use classrooms. It could be that the familiar environment helped facilitate collaboration, but this is not clear from this research.

The second research question — "Is there a difference in the performance outcomes, and levels of spatial structure, for students in Year 1 and Year 2", aimed to investigate developmental differences (Year level differences) and any potential advantages of the two conditions with one Year level compared with the other. Again, the predicted outcome was confirmed when significant differences were found in favour of collaboration for Year 2 students but not for Year 1 students. This finding suggests that for Year 2 students there may be a general benefit to collaboration in this type of practical construction tasks and possibly across other learning experiences and challenges. It could be inferred that students begin to take advantage of collaboration more so by the time they enter Year 2 but this advantage is not necessarily present in Year 1. The differences found for each Year level may also be related to the range of individuals' ability level rather than age-based allocation to Year levels.

These differences between Year levels may also result from the previous pedagogical and learning experiences of the students in the school context; in particular that Year 2 students may have had more opportunity to learn to collaborate than Year 1 students related to teacher pedagogical approach. These differences are explored in more detail below.

5.1. Developmental Differences between Year 1 and Year 2

While the overall finding of this study indicated the benefits for collaboration, interactions were present and followed up with simple effects analyses. These analyses showed that these collaborative benefits were present for the Year 2 students. One important question, therefore, is why the Year 2 students show differences, but not the Year 1 students, on the bridge-building task. There may be several explanations for this beyond the reasons given for the overall findings previously.

The main aspect that divides the two years relates to the fact that Year 2 has had an additional year of formal schooling. This might translate into better collaborative performance because they are more familiar with their peers, and they have had more opportunities to collaborate with them through the additional year. Mathematics education research in collaboration frequently describes the classroom as a collaborative environment where students develop familiarity with the way that their peers think and cooperate. Andersson (2001) and Rajaram (2018) both suggest that familiarity and friendship may make the collaboration more successful. However, this factor of familiarity is not often present in cognitive science research which may rely on strangers collaborating, especially when some cognitive science research emphasises that collaboration may not be successful if individuals are strangers (e.g., Rajaram, 2018). Year 2 students by default have at least one year more in their classroom environment compared to Year 1 students and they may have benefitted from that extra degree of familiarity.

Further, the Year 1 students in this study produced similar results to Gummerum et al (2013), and this could be explained through both extended mind and sociocultural theory. Students in this Year group may not have developed enough strategy knowledge to use an extended mind-network, or express their knowledge in such a way that collaboration could succeed. This may also be influenced by experience and familiarity, however, the results do not show that students at this age may not benefit academically from collaborative experiences.

It is of course also possible that there may be differences in such things like class cohesion, and one class may have had more practice than another, such as building with blocks (e.g., Casey et al., 2008; Ramani et al., 2014), or extracurricular play. However, as there were no significant differences within Year 1, and the Year 2 showed a positive improvement in performance across the tasks relative to the individual condition, this does not seem to be the case. The Australian Curriculum (Australian Curriculum Assessment and Reporting Authority [ACARA], 2019) is implemented equally in the same depth across the classes, and should therefore result in the same prior learning opportunities.

5.2. Influences of Task and Timing

Despite the initial poor performance by the individuals in the collaborative group in Year 2 on the tower task (the first task), their performance improved on the second test task (bridge task). One of the reasons this difference was seen within the group could be related to the timing of the task. All students were given 20 minutes to complete their constructions, but the Year 2 students unexpectedly exhibited significantly different results on the first task, where students in the collaborating condition constructed significantly shorter towers (recall that all students constructed individually for the tower task). It was not possible to directly compare performance scores between the bridge and tower tasks in this study because each task had different demands. Rather, the influence of collaboration was determined by examining the interaction between task and condition. It could have been 'the luck of the draw' that the students in the collaborative condition represented the worst performing builders, as their mean score on the tower task was significantly lower than for the individual group. Upon inspection of the construction records, it was noted that although none of the students presented a collapsed construction, and none of the constructions were particularly tall at the end of 20 minutes. The photos from this task revealed that all structures were sound, and since all buildings were still standing, and since their collaboration lead to significantly better performance than the Year 2 individual condition, it could be concluded that the difference may not have been the result of their ability. If the students had been given more (or unlimited) time to construct, this difference may not have been so pronounced, and therefore the timing could have affected their performance.

Further, it may be the case that existing spatial skills did not influence performance or collaborative success on this task when pairing students on their Raven's score. As the ANOVA for the coding scheme applied to the images of the constructions (presented in Chapter 3) revealed no significant differences, this is one possible explanation. However, it may be the case that student's full range of spatial reasoning abilities were not captured within this coding scheme or accessed due to the timing factor. Students in the Year 2 collaborative condition did show a greater distribution across the spatial levels on the bridge task than any other group. This may indicate that they were able to collaborate advantageously, and they may have been able to better express their spatial and reasoning skills. The analysis of spatial structure was conducted on a subsample (recall that only 44 students had images from both tasks), and no definitive conclusions can be drawn at this stage. Further analysis would be needed to determine if this effect was reliably measured or if these results were in part due to the time restriction placed on the students.

As mentioned previously, the students may not have been able to fully express their spatial abilities and thus, this coding scheme may be limited in a timed setting. This inference can be made as students in the Year 2 collaborating condition not only showed performance advantages in the quantitative analysis but also showed a higher percentages of constructions in the two highest levels of the coding scheme relative to other groups (see Table 4 in Chapter 3). This suggests that when students were able to work more efficiently (that is, working collaboratively within the same tight time-frame), they were also able to express their spatial reasoning ability better.

5.3. Processing vs. Performance Costs and Benefits

The use of nominal groups in this research allowed for the capture of the possible cognitive benefits afforded to collaborating group. However, the same pattern emerges in this research when testing the collaborating condition against individual condition's performance without creating nominal groups (Leman, 2015), suggesting that the advantages collaborators gain are not purely the result of comparison against nominal groups. The consistency between these two testing methods ensures that the better performers are not penalised by averaging their scores with their nominal peer's and thus strengthening our findings of collaborative advantages further.

Collaborators may also have had the benefit of multiple constructors. The benefit of having multiple people working on the same project may have resulted in an advantage with respect to construction outcomes. It is entirely plausible that students who collaborated simply got further because they had more hands. While this could be considered a limitation, it may also afford greater learning opportunities for children in a classroom. As mentioned previously in the case of the Year 2 students performances, the students who collaborated in the bridge task may have had opportunities to explore their thinking more because they had another person, meaning construction was less laborious and the peer could provide feedback on ideas to make construction more efficient. There was therefore more time for corrections and furthering construction than those working individually who may have needed to do it using trial-and-error methods.

Overall, the findings show a performance benefit in accordance both with the theoretical approach used, but also with studies of spatial reasoning and in mathematics education research. By combining the approaches and paradigms frequently used by mathematics education and cognitive science research, this study was able to bridge a gap in these two fields by providing results that can be compared and contrasted across these disciplines.

5.4. Limitations

Despite the balance between rigorous testing and ecological validity in the current study, there were nonetheless limitations in the methodology. These include limitations of the sample, in participant grouping, and in the tasks themselves.

One of the more prominent limitations include the demographics of the sample. The sample were recruited from one school, and most of the students would most likely have been drawn from a high socioeconomic background. While the number of participants was sufficient to detect moderate and large effect sizes, and for the measure of spatial reasoning structural level (for which there was missing data), pooling a sample from a larger and more diverse population, and including several different school contexts is important for demonstrating potential generalisability.

There were also limitations in participant grouping. The first relates to the way students were paired up. Raven's scores (Raven, 2000) were used to pair students of equal ability. Although this pairing allowed for control of ability and ensured an equal spread of spatial ability across the classes, it may have limited the improvements a student could make if they were paired with a more advanced peer (as in Vygotsky's original sociocultural theory). Thus, the current study may have underestimated the benefits of collaboration.

Finally, the timing restriction of the construction task may have affected performance. While it is not inherently unusual in a classroom setting to complete tasks within a time limit, it may have limited the student's performance compared to their performance in an untimed task. Consistent with this possibility, the students in the Year 2 collaborating condition built constructions that were quite short in height for their tower task although some of them showed a high quality of spatial structure in their method of construction. This was evident in other classes as well, suggesting that the time pressure may have hindered students from building constructions demonstrating their full potential.

5.5. Implications for Theory and Practice

Findings in this study were supported by both sociocultural theory and extended mind theory. The notion that the results presented in this research fit within both an educational and cognitive theoretical explanation suggests that both theories, and the interrelationships emerging from these theories, could be considered in future research. Developing an integrated theory may help to bridge gaps between cognitive science and educational research (and in particular mathematics education research) where research problems and questions are able to be connected and studied together. The theoretical implications of the findings presented therefore support a more integrated and interdisciplinary approach spanning both spatial reasoning and cognitive science research.

The development of an integrated theory can strengthen the findings which may arise from such cross-disciplinary research. It may allow for a more coherent interpretation of findings and for inferences to be drawn and explained across the fields.

There are also important practical benefits from this research. Collaboration is a common feature of learning and communicating in educational contexts today, and it is featured as a learning approach in the Australian curriculum for Foundation/Kindergarten to Year 2 (ACARA, 2019). As such, it is critical that claims that collaboration may be harmful for student learning are urgently assessed using the most reliable empirical evidence available. Not only is collaboration effective for intrinsic motivation, as shown in previous research, but it also supports performance. Fortunately, the findings of this study support the continued implementation of collaborative problem- solving tasks in mathematics education, and in particular for the development of spatial reasoning. This research also supports further studies designed to evaluate the explicit benefits that collaboration can have for learning and pedagogical practice.

5.6. Implications for Future Research

This study was unique in the way it combined mathematics education (including spatial reasoning) and cognitive science research paradigms to address a problem not currently well researched. Future research could address the limitations of this study, and use these findings as a foundation to explore in more depth and scope, the problem researched here.

First, we highlighted the unexpected finding that Year 2 students in the collaborative condition performed poorly on the initial tower-building task. Recall that this task was completed individually to provide a baseline measure of performance: thus, it is unclear why these particular students performed more poorly on this task but not the other students. These students may have been more experienced in construction tasks. As the students were from a high socioeconomic background, it is plausible that they may have had ample opportunities and parental support to build with blocks, or other construction material to a greater extent than students who come from lower socioeconomic backgrounds. Further on this point, most students attended kindergarten at the same school where they were recruited for this study. It can therefore be assumed that they had ample opportunity to use a range of construction equipment as a regular part of their learning, which was evident in the school resources and teaching plans. Further, researching with other socioeconomic statuses, or different forms of schooling (e.g., public school) where there may be demographical differences could help identify what part of this research can be generalised as well as provide insights in to populations where support may be needed.

Other potential lines of enquiry would enable research to examine how different group structures may work to increase or decrease the benefits of collaboration. In the current study, students were matched on their general ability spatial reasoning skill (Raven's Progressive Matrices; Raven, 2000). Thus, while they were still able to cross-cue one another, to our knowledge neither member of the pairs was more expert than the other. Students were also familiar to one another, working in the same classes, and all classroom teachers highlighted the priority they place on collaborative tasks in their classrooms. They were not always as close to one another as friends or siblings may be, however. To tease apart these important questions of closeness/familiarity, communication, and expertise, future research should also consider sibling collaboration, or peer collaboration in which peers have mismatched ability (instead of matched as here), and collaboration in which friendship is manipulated.

One other possible explanation for the findings in this study is the use of a quasi-experimental design. In the current study, students were allocated to condition within their classes. All data collection was collected during class, over two sessions, and this design was preferred by the classroom teachers. It is possible that one class constructed poorly as a result of the classroom environment and the cohesion in the class. Although this same group subsequently performed much more strongly during genuine collaboration on the bridge task, it is important in future research to determine whether there were other whole-class differences that we did not measure. Future research should therefore consider aspects which may be present in such environments which may allow collaboration to succeed or fail.

Further, the coding scheme developed may have been able to capture some developmental differences between Year 1 and Year 2 students. Although small, the difference in distribution on the levels of the coding scheme (see Tables 3 and 4) suggested a small advantage for Year 2 (and in particular the collaborating condition) students as indicated by a larger percentage in the higher categories relative to Year 1. More research is needed to determine whether the coding scheme is effective at detecting such differences, but the results in this study can still contribute to the existing research on the malleability of spatial reasoning skills.

5.7. Conclusions

This study aimed to investigate the differences in performance for collaborating dyads versus individual students on a spatial reasoning tasks. Despite adopting a cognitive science research paradigm, this research discovered collaborative facilitation. The findings reported here aligned with research on peer collaboration in the mathematics education research. As most prior cognitive science research with children of school age demonstrates net negative effects for peer collaborators versus their individual counterparts, these findings were interesting.

Upon further inspection, it was found that the differences were located in the Year 2 students, with collaborating Year 2 students showing advantages in performance compared to the individuals for the bridge task, and there were no discernible difference between the conditions in the Year 1 cohort. Despite the difference in direction, previous research in cognitive science has similarly found no difference in younger children, (age 7) of age but a negative effect for slightly older children (age 9) Gummerum et al., 2013). The differences reported from this study showed that the Year 2 children experienced collaborative advantages compared to the individuals, contrary to previous cognitive science research.

While applying a strict research paradigm adopted from cognitive science with adaptations of mathematics education research, the focus of the study contributed to better understanding of students' on spatial reasoning and its previously established relationship to mathematics learning in the research, particularly for practical tasks which may include mental rotation and problem solving skills.

This exploratory study was limited in scope and depth with participants engaged in spatial problem-solving on just two testing occasions. As part of a more extensive investigation undertaken as a PhD and postdoctoral program of research, an intervention study with multiple follow-up testing points could be designed to both evaluate the long-term effects of collaboration on task performance and to examine how spatial structuring and reasoning skills may develop explicitly through collaboration. In addition, individual differences in the forms of collaborative communication, both verbal and non-verbal, should also be investigated and analysed.

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Appendices

Appendix A – Ethics Approval

Human Sciences Subcommittee
Macquarie University, North Ryde
NSW 2109, Australia

MACQUARIE University

26/10/2018

Dear Dr Van Bergen,

Reference No: 5201832664870
Project ID: 3266
Title: Does peer collaboration help children's spatial reasoning in maths?

Thank you for submitting the above application for ethical review. The Human Sciences Subcommittee has considered your application.

I am pleased to advise that ethical approval has been granted for this project to be conducted by Dr Penelope Van Bergen, and other personnel: Miss Signe Duff, Dr Gabrielle Oslington, Professor Joanne Mulligan.

This research meets the requirements set out in the National Statement on Ethical Conduct in Human Research 2007, (updated July 2018).

Standard Conditions of Approval:

1. Continuing compliance with the requirements of the National Statement, available from the following website: https://nhmrc.gov.au/about-us/publications/national-statement-ethical-conduct-human-research-2007-updated-2018.

2. This approval is valid for five (5) years, subject to the submission of annual reports. Please submit your reports on the anniversary of the approval for this protocol. You will be sent an automatic reminder email one week from the due date to remind you of your reporting responsibilities.

3. All adverse events, including unforeseen events, which might affect the continued ethical acceptability of the project, must be reported to the subcommittee within 72 hours.

4. All proposed changes to the project and associated documents must be submitted to the subcommittee for review and approval before implementation. Changes can be made via the Human Research Ethics Management System.

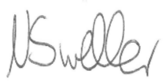
The HREC Terms of Reference and Standard Operating Procedures are available from the Research Services website: https://www.mq.edu.au/research/ethics-integrity-and-policies/ethics/human-ethics.

It is the responsibility of the Chief Investigator to retain a copy of all documentation related to this project and to forward a copy of this approval letter to all personnel listed on the project.

Should you have any queries regarding your project, please contact the Faculty Ethics Officer.

The Human Sciences Subcommittee wishes you every success in your research.

Yours sincerely,



Dr Naomi Sweller

Chair, Human Sciences Subcommittee

The Faculty Ethics Subcommittees at Macquarie University operate in accordance with the National Statement on Ethical Conduct in Human Research 2007, (updated July 2018), [Section 5.2.22].

Appendix B – Approval email from Arden Anglican School

From: Joanne Mulligan <joanne.mulligan@mq.edu.au>
Sent: Monday, September 24, 2018 8:02:30 PM
To: David Watkins
Subject: Macquarie University Research Project

Dear Mr Watkins

Gabrielle Oslington is currently assisting with an Australian Research Council Project through Macquarie University on mathematics and spatial reasoning at Arden, alongside her PhD data collection which is nearing completion. We would like to conduct one more short segment of the research project in Grades 1 and 2 during the first weeks of Term 4. Gabrielle would work alongside the researcher, a postgraduate student and qualified teacher, Ms Signe Duff. The request is for the Year 1 and 2 students to complete a design construction task (a tower and a bridge) either working individually or in pairs. The tasks will take no more than a half hour and will be conducted as a whole class. The segment will be digitally recorded for the purpose of analysis. As with all research Macquarie University ethics clearance will be provided , and consent will be sought from parents/caregivers.

The classroom teachers will also be asked to complete a short survey about the students' collaboration.

We would be happy to provide you with the results of the task completion and share our findings with your staff and/or parent community.

Your cooperation is much appreciated. I look forward to your response and further collaboration with Arden.

Regards

Joanne

From: David Watkins <d.watkins@arden.nsw.edu.au>
Date: Wednesday, 26 September 2018 at 7:01 am
To: Joanne Mulligan <joanne.mulligan@mq.edu.au>
Subject: Re: Macquarie University Research Project

Dear Joanne,

I have spoken to Gabrielle as well as Joshua Harnwell, our Director of Teaching and Learning K -12, and they are both very happy for this project to proceed at Arden, as am I.

I look forward to hearing more about the project and seeing the research results.

Kind regards,, David Watkins

Get Outlook for iOS

David Watkins
HEAD OF JUNIOR SCHOOL

ARDEN

PRE-SCHOOL & PRIMARY SCHOOL
39-43 Wongala Cres
Beecroft, NSW 2119
+612 9484 1146

SECONDARY SCHOOL
50 Oxford St
Epping, NSW 2121
+612 9869 2644

Appendix C –Information and Consent Forms

Parent/Carer

DEPARTMENT OF EDUCATIONAL STUDIES
Faculty of Human Sciences
MACQUARIE UNIVERSITY NSW 2109

Email: signe.duff@hdr.mq.edu.au

DATE TO BE INSERTED

Participant Information and Consent Form – Parent/Carer

Project Title: Does peer collaboration help children's spatial reasoning in maths?

Your child is invited to participate in a study about how collaboration may benefit children's spatial reasoning skills. Understanding this aspect of spatial reasoning is important because spatial reasoning is essential to many aspects of schooling (e.g. STEM subjects) and later life, and collaboration similarly features in schools and life outside the classroom (e.g. workplaces). This study is part of the larger Australian Research Council Discovery Project (DP170101588) conducted by Professor Joanne Mulligan, Dr Geoffrey Woolcott, Dr Michael Mitchelmore, and Professor Brent Davies.

Who is running the study?

My name is Signe Duff and I am a Masters student at Macquarie University. I am completing a Master of Research under the supervision of Dr Penny Van Bergen (penny.vanbergen@mq.edu.au) and Professor Joanne Mulligan (joanne.mulligan@mq.edu.au) from the Department of Educational Studies at Macquarie University. This study is being conducted as part of the requirements for my degree.

What will my child do?

Over two lessons, your child's class will receive a visit from a researcher (me). Working either alone or in pairs, children will be asked to build two complex shapes. We will record the spatial language your child uses when completing the task, and the building itself.

After each building exercise, students will be asked to recall as much as they can about the experience. There will be a small incentive for the students to complete the task (e.g. a sticker).

All children will take part in these activities as part of their regular maths lessons. Participation in data collection is entirely voluntary, however, and we will only collect data from your child if both you and your child agree to this. To collect data, we will use a GoPro camera focused on each desk. The camera will capture both video and audio, but only the audio will be analysed as we are predominately interested in the use of language. Video images may be used in publications or conferences. Please see Recording Rights on the next page for more information.

Are there any other tasks?

Students who participate will also sit a short pre-test called Raven's Progressive Matrices on a third, separate occasion. This is a non-verbal task which assesses spatial reasoning skills, and will allow us to put students in pairs.

Where and how long will the data be kept?

The information collected during this experiment, including the audio and video recordings, will be stored securely on servers at Macquarie University, and on a secure hard drive for analysis. The data will be kept and stored anonymously/de-identified for 5 years after which it will be destroyed. Only researchers and research assistants will have access to the data.

MACQUARIE University SYDNEY·AUSTRALIA

Can I get individual results for your child?

Unfortunately, we cannot provide individual feedback for each child, but general feedback about group performance will be distributed to your school when it becomes available. My full thesis will also be available in the Macquarie University Library late 2019.

Who do you contact for questions regarding this project?

For any questions regarding this project, please contact me on signe.duff@hdr.mq.edu.au.

If you are happy for your child to participate

That's great! Please discuss this with your child and if you are both agreeable, sign and return one of the enclosed consent forms to your child's classroom teacher.

Recording rights

Because we use GoPros to observe children's construction, images of your child may be captured. Some images may be shown at conferences or publications for demonstrative purposes, to demonstrate the kinds of constructions that children are capable of. If you want your child to participate but not be shown in images, we will happily crop or blur your child so they are not visible. Please let us know your preference on the return consent form.

If you don't want your child to participate in the study

Participation is entirely voluntary and if you do not want your child to take part in the study, it will not affect his or her progress or results at school. As this is a classroom-based experiment, your child will still take part in the classroom activities with the rest of the class. However, we will only collect data from children who have parental permission to take part. We will ensure that your child is sitting out of camera view should you choose to not have your child participate.

What to do if you want your child withdrawn from the study after it has begun.

You can withdraw your permission at any time simply by contacting me on my email. Once you have requested to be withdrawn from the study, all of your child's data will be destroyed.

Parent Information and Consent Form – Parent/Carer

Participant's Copy

Project Title: Does peer collaboration help children's spatial reasoning in maths?

On behalf of my child ________________________ (*student name*), I have read and understand the information above and any questions I have asked have been answered to my satisfaction. I agree to let my child participate in this research, knowing I can withdraw them from further participation at any time without any consequences. I have been given a copy of this form to keep.

Video recording

Please note that your child's class may be captured on video. Our focus is on the objects that children are constructing, and not on children themselves. Nonetheless, your child may be in the background of various images. Please indicate below whether or not you give us permission to use these images at conferences and in peer-reviewed publications. Your child may still participate in the project, even if you would rather we did not use any images of your child.

	Yes, you can use my child's image in presentations for professionals and researchers (e.g. conferences, media or peer-reviewed publications). I understand that the audience will be other teachers and researchers.
	No, I want my child's image cropped or blurred in publications and in all presentations
	No, I do not want my child's image to be used at all in publications or presentations

☐ I agree for my child ________________________ (*student's name*) to participate in this research.

☐ I do not want my child ________________________ (*student's name*) to participate in this research or be recorded in the classroom.

Parent/Guardian's Name:
(Block Letters)
Parent/Guardian's Signature: _________________________________ Date:

Investigator's Name: SIGNE DUFF
Investigator's Signature: _____________________________________ Date:

The Macquarie University Human Research and Ethics Committees have approved the ethical aspects of this study. If you have any complaints or reservations about any ethical aspect of your child's participation in this research, you may contact the Committee through the Director, Research Ethics & Integrity (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaints you make will be treated in confidence and investigated, and you will be informed of the outcome.

Parent Information and Consent Form – Parent/Carer

Investigator's Copy

Project Title: Does peer collaboration help children's spatial reasoning in maths?

On behalf of my child ______________________ (*student name*), I have read and understand the information above and any questions I have asked have been answered to my satisfaction. I agree to let my child participate in this research, knowing I can withdraw them from further participation at any time without any consequences. I have been given a copy of this form to keep.

Video recording

Please note that your child's class may be captured on video. Our focus is on the objects that children are constructing, and not on children themselves. Nonetheless, your child may be in the background of various images. Please indicate below whether or not you give us permission to use these images at conferences and in peer-reviewed publications. Your child may still participate in the project, even if you would rather we did not use any images of your child.

	Yes, you can use my child's image in presentations for professionals and researchers (e.g. conferences, media or peer-reviewed publications). I understand that the audience will be other teachers and researchers.
	No, I want my child's image cropped or blurred in publications and in all presentations
	No, I do not want my child's image to be used at all in publications and presentations

☐ I agree for my child ______________________ (*student's name*) to participate in this research.

☐ I do not want my child ______________________ (*student's name*) to participate in this research or be recorded in the classroom.

Parent/Guardian's Name:
(Block Letters)
Parent/Guardian's Signature: ______________________________ Date:

Investigator's Name: SIGNE DUFF
Investigator's Signature: ________________________________ Date:

The Macquarie University Human Research and Ethics Committees have approved the ethical aspects of this study. If you have any complaints or reservations about any ethical aspect of your child's participation in this research, you may contact the Committee through the Director, Research Ethics & Integrity (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaints you make will be treated in confidence and investigated, and you will be informed of the outcome.

Teacher

DEPARTMENT OF EDUCATIONAL STUDIES
Faculty of Human Sciences
MACQUARIE UNIVERSITY NSW 2109

Email: signe.duff@hdr.mq.edu.au

DATE TO BE INSERTED

Participant Information and Consent Form – Teacher

Project Title: Does peer collaboration help children's spatial reasoning in maths?

You are invited to participate in a study about how collaboration may benefit children's spatial reasoning skills. Understanding this aspect of spatial reasoning is important because spatial reasoning is essential to many aspects of schooling (e.g. STEM subjects) and later life, and collaboration similarly features in schools and life outside the classroom (e.g. workplaces). This study is part of the larger Australian Research Council Discovery Project (DP170101588) conducted by Professor Joanne Mulligan, Dr Geoffrey Woolcott, Dr Michael Mitchelmore, and Professor Brent Davies.

Who are we?

My name is Signe Duff and I am currently a Masters student at Macquarie University. I am completing a Master of Research under the supervision of Dr Penny Van Bergen (penny.vanbergen@mq.edu.au) and Professor Joanne Mulligan (joanne.mulligan@mq.edu.au), both from the Department of Educational Studies at Macquarie University. This study is being conducted as part of the requirements for my degree.

What are we doing?

We would like to invite your class to participate in a research project where we will look at how collaboration affects children's spatial reasoning skills in mathematics. Working alone or in pairs, the students will be asked to build a structure (e.g. a house) using paddle-pop sticks and plasticine. We will record the spatial language the students use as well as take some measures of the construction itself.

If you agree to participate, we would like to work with your class in their classroom on 3 occasions (preferably once a week for 3 consecutive weeks) for about 30-45 minutes on each occasion.

We are asking permission from parents to allow their child to participate in this research and they will be required to return a consent form which we will come and collect. Parents are informed that their child will be outfitted with a GoPro and that we will only use the audio captured for analysis. The videos and audio will be kept de-identified/anonymous and parents are able to decide if we may use their child's images at conferences or publications (for demonstrative purposes).

What will your students be required to do?

The students who participate will sit a pre-test consisting of Raven's Progressive Matrices (a non-verbal group test) to assess their existing spatial reasoning skills. A week after that, the class will receive a visit from the researcher (me) and the students will be asked to complete a construction task. A week later, the researcher will be back again and the students will be asked to complete another construction task. After each of these visits, the students will be asked to complete a form recalling their experience, and we will ask them a few additional questions if they were paired up with a peer. There will be a small incentive for the students to complete the task (e.g. a sticker). The students will also be fitted with a GoPro to capture the process of completing the task.

What if a student is not participating in the study?

Participation is voluntary and if parents have decided to not let their child participate, it will not affect the student in any way. As this is a classroom based experiment, the student may partake in the activities with the rest of the class but no data will be collected.

When will the students participate in the task?

We would like the students to do this task during their normal mathematics class. If a student is not participating in the study, they will still be able to partake in the task itself, but no data will be collected.

Where and how long will we keep the data for?

The information collected during this experiment, including the audio and video recordings, will be stored securely on servers at Macquarie University, and on a secure hard drive for analysis. The data will be kept and stored anonymously/de-identified for 5 years after which it will be destroyed. Only researchers and research assistants will have access to the data.

Will we provide individual results for each child?

Unfortunately we cannot provide individual feedback for each child, but general feedback can be distributed upon request when it becomes available. The full thesis will be available in the Macquarie University Library late 2019. The results may also be conveyed at a conference or in publications in Academic journals

Who do you contact for questions regarding this project?

For any questions regarding this project, please contact me on signe.duff@hdr.mq.edu.au. I am more than happy to meet with you to discuss the project further.

Participant Information and Consent Form – Teacher

Participant's Copy

Project Title: Does peer collaboration help children's spatial reasoning in maths?

I (*participant's name)* ______________________________ have read and understand the information above and any questions I have asked have been answered to my satisfaction. I agree to participate in this research, knowing I can withdraw from further participation at any time without any consequences. I have been given a copy of this form to keep.

Video recording

Please note that while the primary aim is to capture the conversations and speech around the construction, video will be captured due to the nature of the GoPro. While it is unlikely, it may be the case that you are inadvertently captured. Images may be used for demonstrative purposes at conferences and peer-reviewed publications. Please indicate below whether or not you give us permission to use these images

	Yes, you can use images of me in presentations for professionals and researchers (e.g. conferences, media or peer-reviewed publications). I understand that the audience will be other teachers and researchers.
	No, I want images of me cropped or blurred in publications and in all presentations
	No, I do not want images of me to be used at all in publications or presentations

Participant's Name:
(Block Letters)

Participant's Signature: _________________________________ Date:

Investigator's Name: SIGNE DUFF

Investigator's Signature: _____________________________________ Date:

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Participant's Name:
(Block Letters)

Participant's Signature: ________________________________ Date:

Investigator's Name: SIGNE DUFF

Investigator's Signature: ____________________________________ Date:

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Principal

DEPARTMENT OF EDUCATIONAL STUDIES
Faculty of Human Sciences
MACQUARIE UNIVERSITY NSW 2109

Email: signe.duff@hdr.mq.edu.au

DATE TO BE INSERTED

Participant Information and Consent Form – School Principal

Project Title: Does peer collaboration help children's spatial reasoning in maths?

You are invited to participate in a study about how collaboration may benefit children's spatial reasoning skills. Understanding this aspect of spatial reasoning is important because spatial reasoning is essential to many aspects of schooling (e.g. STEM subjects) and later life, and collaboration similarly features in schools and life outside the classroom (e.g. workplaces). This study is part of the larger Australian Research Council Discovery Project (DP170101588) conducted by Professor Joanne Mulligan, Dr Geoffrey Woolcott, Dr Michael Mitchelmore, and Professor Brent Davies.

Who are we?

My name is Signe Duff and I am currently a Masters student at Macquarie University. I am completing a Master of Research under the supervision of Dr Penny Van Bergen (penny.vanbergen@mq.edu.au) and Professor Joanne Mulligan (joanne.mulligan@mq.edu.au), both from the Department of Educational Studies at Macquarie University. This study is being conducted as part of the requirements for my degree.

What are we doing?

We would like to invite Year 1 and Year 2 to participate in a research project where we will look at how collaboration affects children's spatial reasoning skills in mathematics. Working alone or in pairs, the students will be asked to build a structure (e.g. a house) using paddle-pop sticks and plasticine. We will record the spatial language the students use as well as take some measures of the construction itself.

If you agree to participate, you will be asked to allow us to work with the students in their classroom on 3 occasions (preferably once a week for 3 consecutive weeks) for about 30-45 minutes on each occasion to conduct the study.

We are asking permission from parents to allow their child to participate in this research and they will be required to return a consent form which we will come and collect. Parents are informed that their child will be outfitted with a GoPro and that we will only use the audio captured for analysis. The videos and audio will be kept de-identified/anonymous and parents are able to decide if we may use their child's images at conferences or publications (for demonstrative purposes).

What will your students be required to do?

The students who participate will sit a pre-test consisting of Raven's Progressive Matrices (a non-verbal group test) to assess their existing spatial reasoning skills. A week after that, the class will receive a visit from the researcher (me) and the students will be asked to complete a construction task. A week later, the researcher will be back again and the students will be asked to complete another construction task. After each of these visits, the students will be asked to complete a form recalling their experience, and we will ask them a few additional questions if they were paired up with a peer. There will be a small incentive for the students to complete the task. The students will also be fitted with a GoPro to capture the process of completing the task.

MACQUARIE University SYDNEY·AUSTRALIA

What if a student is not participating in the study?

Participation is voluntary and if parents have decided to not let their child participate, it will not affect the student in any way. As this is a classroom based experiment, the student may partake in the activities with the rest of the class but no data will be collected.

When will the students participate in the task?

We would like the students to do this task during their normal mathematics class. If a student is not participating in the study, they will still be able to partake in the task itself, but no data will be collected.

Where and how long will we keep the data for?

The information collected during this experiment, including the audio and video recordings, will be stored securely on servers at Macquarie University, and on a secure hard drive for analysis. The data will be kept and stored anonymously/de-identified for 5 years after which it will be destroyed. Only researchers and research assistants will have access to the data.

Will we provide individual results for each child?

Unfortunately we cannot provide individual feedback for each child, but general feedback can be distributed upon request when it becomes available. The full thesis will be available in the Macquarie University Library late 2019. The results may also be conveyed at a conference or in publications in Academic journals

Who do you contact for questions regarding this project?

For any questions regarding this project, please contact me on signe.duff@hdr.mq.edu.au. I am more than happy to meet with you to discuss the project further.

Participant Information and Consent Form – School Principal

Participant's Copy

Project Title: Does peer collaboration help children's spatial reasoning in maths?

I (*participant's name*) ______________________________ have read and understand the information above and any questions I have asked have been answered to my satisfaction. I agree to participate in this research, knowing I can withdraw from further participation at any time without any consequences. I have been given a copy of this form to keep.

Participant's Name:
(Block Letters)

Participant's Signature: __________________________________ Date:

Investigator's Name: SIGNE DUFF

Investigator's Signature: ______________________________________ Date:

The Macquarie University Human Research and Ethics Committees have approved the ethical aspects of this study. If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics & Integrity (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaints you make will be treated in confidence and investigated, and you will be informed of the outcome.

Participant Information and Consent Form – School Principal

Investigator's Copy

Project Title: Does peer collaboration help children's spatial reasoning in maths?

I (*participant's name*) ______________________________ have read and understand the information above and any questions I have asked have been answered to my satisfaction. I agree to participate in this research, knowing I can withdraw from further participation at any time without any consequences. I have been given a copy of this form to keep.

Participant's Name:
(Block Letters)

Participant's Signature: _________________________________ Date:

Investigator's Name: SIGNE DUFF

Investigator's Signature: _____________________________________ Date:

The Macquarie University Human Research and Ethics Committees have approved the ethical aspects of this study. If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics & Integrity (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaints you make will be treated in confidence and investigated, and you will be informed of the outcome.

Appendix D - Alex's Instruction-Letters

Test Time 1 – Both

Hi Kids!

My name is Alex and I am an adventurer. I travel far and wide across the world and I get to experience many fascinating things, but on my last adventure I had a problem.

I was travelling through a forest with many trees standing really close to each other, and I got lost. I came upon a clearing but didn't know where to go. I tried climbing the trees, but I couldn't get high enough to see where I needed to go.

So I have come to ask you for your help, as I have heard you are very clever children. I would like you to construct something for me that I can use in the clearing. I need you to make it as tall as you can so I can see above the tree tops. I have brought sticks and clay for you to build with.

Thank you

Alex

Test Time 2 – Individual

Hi Kids!

It's me, Alex. I need your help again. I made it through the forest thanks to the constructions you built last time, but I had another problem.

When I came out of the forest, I adventured on for a bit but then I came upon a really wide road with many lanes. I could not cross it because there was constant traffic and there was no pedestrian crossing in sight. I am also a bit frightened of cars.

Because you helped me so much last time, I was hoping I could ask for your help again. Can you please help me build something I can use to cross the road? The construction needs to be as long as possible so I can cross all the lanes, and it needs to be high enough from the ground so that this car can fit under it. I brought some more sticks and clay for you to build with.

Thank you

Alex

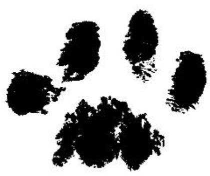
Test Time 2 – Dyad

Hi Kids!

It's me, Alex. I need your help again. I made it through the forest thanks to the constructions you built last time, but I had another problem.

When I came out of the forest, I adventured on for a bit but then I came upon a really wide road with many lanes. I could not cross it because there was constant traffic and there was no pedestrian crossing in sight. I am also a bit frightened of cars.

Because you helped me so much last time, I was hoping I could ask for your help again. Can you please help me build something I can use to cross the road? I would like you to work in pairs. The construction needs to be as long as possible so I can cross all the lanes, and it needs to be high enough from the ground so that this car can fit under it. I brought some more sticks and clay for you to build with.



Thank you

Alex

Appendix E – Template for Explaining Construction to Alex

Name:

Please tell Alex what you did so it can be replicated during the adventure.

- ____

  ____

  ____

- ____

  ____

  ____

- ____

  ____

  ____

Thank you!

Appendix F – Teacher's Survey

Name of children in pair ______________________________

Thinking of the class as a whole, how often do the children work in group or pairs? [You only have to answer this question once]

Never			Weekly		Several times/day	
1	2	3	4	5	6	7

How often do these **two students in particular** work together (pairs or group-work)?

Never (not often)						Very often
1	2	3	4	5	6	7

In your day-to-day teaching, have you observed signs that that these two children like each other? (e.g. Do they get along well? Do they play at recess? Etc.)

No - appear to dislike one another (e.g. negative interactions)			They don't appear to like or dislike each other/I've never noticed			Yes, they appear to really like one another (e.g positive interactions)
1	2	3	4	5	6	7

How often do these two children play together at recess?

Never						All the time
1	2	3	4	5	6	7

Appendix G – Friendship Survey

Your Name: ______________________ Your peer's name: ________________________

How good friends are you with the person whom you worked with today?

☹						☺
1	2	3	4	5	6	7

Appendix H – Individual Student Certificate of Appreciation

Appendix I – Class Certificate of Appreciation

THANK YOU

this certificate is awarded to:

[CLASS]

For all the help provided to Alex the Adventurer

Signature

[DATE]

Date

Human Sciences Subcommittee
Macquarie University, North Ryde
NSW 2109, Australia

26/10/2018

Dear Dr Van Bergen,

Reference No: 5201832664870
Project ID: 3266
Title: Does peer collaboration help children's spatial reasoning in maths?

Thank you for submitting the above application for ethical review. The Human Sciences Subcommittee has considered your application.

I am pleased to advise that ethical approval has been granted for this project to be conducted by Dr Penelope Van Bergen, and other personnel: Miss Signe Duff, Dr Gabrielle Oslington, Professor Joanne Mulligan.

This research meets the requirements set out in the National Statement on Ethical Conduct in Human Research 2007, (updated July 2018).

Standard Conditions of Approval:

1. Continuing compliance with the requirements of the National Statement, available from the following website: https://nhmrc.gov.au/about-us/publications/national-statement-ethical-conduct-human-research-2007-updated-2018.

2. This approval is valid for five (5) years, subject to the submission of annual reports. Please submit your reports on the anniversary of the approval for this protocol. You will be sent an automatic reminder email one week from the due date to remind you of your reporting responsibilities.

3. All adverse events, including unforeseen events, which might affect the continued ethical acceptability of the project, must be reported to the subcommittee within 72 hours.

4. All proposed changes to the project and associated documents must be submitted to the subcommittee for review and approval before implementation. Changes can be made via the Human Research Ethics Management System.

The HREC Terms of Reference and Standard Operating Procedures are available from the Research Services website: https://www.mq.edu.au/research/ethics-integrity-and-policies/ethics/human-ethics.

It is the responsibility of the Chief Investigator to retain a copy of all documentation related to this project and to forward a copy of this approval letter to all personnel listed on the project.

Should you have any queries regarding your project, please contact the Faculty Ethics Officer.

The Human Sciences Subcommittee wishes you every success in your research.

Yours sincerely,

NSweller

Dr Naomi Sweller

Chair, Human Sciences Subcommittee

The Faculty Ethics Subcommittees at Macquarie University operate in accordance with the National Statement on Ethical Conduct in Human Research 2007, (updated July 2018), [Section 5.2.22].