Cooperation Between Preschool Peers in Relation to Their Math Learning During Dyadic Activities:

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COOPERATION BETWEEN PRESCHOOL PEERS IN RELATION TO THEIR MATH LEARNING DURING DYADIC ACTIVITIES

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Abstract

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For many children, preschool classrooms are a key context for early learning. While early education researchers and policy makers have focused considerable attention on the instructional and structural aspects of preschool classrooms, classic child development theory also points to the important role that peers play in early learning experiences (e.g., Vygotsky, 1978). Although best practices for early childhood education emphasize peer learning opportunities (e.g., Williams, 2001), adults, including early childhood teachers, often underestimate preschool children's abilities to participate in cooperative interactions (Howes & Tonyan, 1999). And, within the empirical literature, many aspects of cooperative learning among very young peers remain poorly understood.

This research aims to help build the knowledge base on peers and learning in early childhood. Seventy-two preschool children (mean age= 4.66 years) participated in a study designed to target counting skills through early math learning games that were adapted from empirically-supported curricula. In dyads (n=36), the children completed six game play sessions across three weeks with all sessions video-recorded and sessions one, three, and five coded for peer cooperative behaviors. The children's general math skills were assessed prior to the first game play session and their counting skills were assessed after completion of the sixth game play session. The average rates of occurrence, and variations therein, of dyads' peer cooperative behaviors during game play were examined. Using multi-level regression modeling to account for the dyadic nesting of these data, associations between cooperative behaviors and post-study counting skills were also explored. Results showed that these very young children demonstrated all of the peer cooperation behaviors of interest, including dyadic regulatory states and discrete peer cooperation behaviors (although the latter occurred less frequently than the former). Evidence that dyads' peer supportive behaviors were significantly associated with their post-test counting scores was also found. Theoretical and practical implications of these findings are discussed.

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CHAPTER 1: INTRODUCTION

Cognitive growth during early childhood builds a critical foundation for later learning, with early learning environments holding substantial power to shape developmental trajectories (Nelson, 2000; Shonkoff & Philips, 2000). Indeed, the potential long-term benefits of high-quality early education and care have received considerable attention among researchers, policy makers, and the public (e.g., Barnett et al., 2017). Empirical and policy attention to the effects of early education has overwhelmingly focused on instructional, curricular, and structural aspects of classrooms, as these components of quality can be targeted by teaching practices and policy decisions. Yet classic child development theory also points to the important role that peers play in early learning experiences (e.g., Vygotsky, 1978).

Peers are thought to serve as natural teachers with learning benefits for both the "teacher" and "student" (Vygotsky, 1978). In fact, leading perspectives on best practices for early childhood education often emphasize the importance of peer learning opportunities in preschool settings (e.g., Williams, 2001; Coolahan, Fantuzzo, Mendez, & McDermott, 2000). Interactive peer play, for instance, has been found to influence young children's attitudes toward learning as well as their academic success (Cohen & Mendez, 2009) and small group work is positively associated with children's motivation and task completion (Master & Walton, 2013). Research has also uncovered associations between young children's social interactions and their school success. For instance, positive social interactions among young peers in preschool classrooms have been associated with literacy skill growth (Montroy, Bowles, Skibbe, & Foster, 2014) and cooperative social learning interactions have been found to predict preschool children's literacy and math growth (although these relations were not significant once controlling for the children's executive function skills; Nesbitt, Farran, & Fuhs, 2015). It has even been suggested that high-quality social exchange within classrooms may be a protective influence for at-risk children, as peer interactions have been found to mediate the relation between low-income preschool children's problem behaviors and their learning (Shearer, Bell, Romero, & Carter, 2010). It is unsurprising, then, that peer learning has been highlighted as an essential component of 21st century pedagogy (Johnson & Johnson, 2014) and education reform (Barr & Tagg, 1995).

A few studies have also considered the social context of learning that arises when a child partners with a more- or less-skilled peer as relevant for learning outcomes (e.g., Chung & Walsh, 2006; Day et al., 2005). However, the number of empirical studies of mixed-ability learning during early childhood pales in comparison to the number of studies on this topic at later ages. And, more generally, the literature on peers and learning during the preschool years is less robust than the same literature for the elementary and middle school years, which now includes meta-analyses on the topic (e.g., Rohrbeck et al., 2003). In particular, few early childhood studies include direct observations of children's cooperative behaviors during cognitive tasks and, in turn, the learning consequences thereof.

The present study is designed to help build the knowledge base on peers and learning in early childhood. Specifically, this dissertation is focused on investigating preschool-aged children's cooperative behaviors during dyadic math learning activities. This focus on early math learning is justified by increasing evidence on the importance of children's math skills for their later achievement. For example, children's knowledge of basic math concepts (e.g., numbers, ordinality) prior to and during kindergarten has been shown to be a strong predictor of both math and literacy outcomes (Duncan et al., 2007; Claessens, Duncan, & Engel, 2009). Sizeable achievement gaps in mathematics between advantaged and disadvantaged groups have also been found to emerge prior to kindergarten, underscoring the importance of examining early math learning environments (Klibanoff et al., 2006).

In the present study, a sample of 72 racially-diverse children were paired for six sessions of game play using early math learning games that were adapted from empirically-validated curricula. Prior to playing the games, the children's general math skills were assessed. After completing the six game play sessions, counting skills were assessed. In addition, three aspects of peer cooperation were coded from videotaped observations of the first, third, and fifth game play sessions: 1) time spent on-task, 2) the general cooperative quality and regulatory states of interactions, and 3) discrete cooperative behaviors that contributed to the peer learning, such as offering support, direction, or explanations.

As the first analytic step of these data, the extent to which the young children displayed peer cooperation behaviors was examined. As part of this initial step, intercorrelations among the cooperative behaviors and behavioral variability, both within and across dyadic play sessions, were studied. Next, initial math skill disparities between the learning peers were examined, with particular attention given to whether the level of within-dyad disparity in math – measured prior to the learning activities – was associated with peer cooperation during the activities. Given the existing evidence for older children that peers with a moderate level of skill disparity display greater cooperation than do peers with particularly low or particularly high skill disparities (e.g., Chung & Walsh, 2006), it was expected that the greatest cooperation among the young peers in the present study would occur in the moderately-disparate dyads. Finally, peer cooperation was investigated as a predictor of children's counting skills at the conclusion of the six activity sessions, controlling for the children's initial math skill levels. It was expected that better peer cooperation during the game play sessions would predict higher counting skills as well as mediate links between dyadic skill disparities and counting skills. In particular, it was hypothesized that a moderate skill level disparity between peers would be associated with greater peer cooperation and, in turn, higher counting skills.

The significance of this study lies in the fact that, despite classic theory on the importance of peers during early childhood, as well as empirical and policy emphasis on the importance of social contexts in early education, there is limited empirical work on peers and learning during this stage of development. Indeed, much of the discussion in the literature on cooperative learning among preschool-aged children indicates skepticism that young children are capable of such learning interactions. Moreover, the significance of building a better understanding of the roles of peers in early math learning is underscored by the importance of early math skills in children's long-term achievement. This dissertation is thus expected to contribute both to the scientific literature on peers and math learning as well as to improving practice in early education settings.

CHAPTER 2: LITERATURE REVIEW

Theoretical foundations for the study of cooperation. Cooperation is a foundational aspect of human culture (Rogoff, 1990). Classic education theory has, for this reason, suggested that the same should be true of learning in school. Philosopher and psychologist John Dewey argued that children need to be educated in cooperative social environments in order to function as adults in democratic societies (Schmuck, 1985; Dewey, 1922). Life in the classroom, according to Dewey, should be representative of the democratic process: students should aim to complete their academic work with one another and, in doing so, learn to empathize with and respect the rights of their peers. In developmental psychology, the learning and cognitive benefits of interacting with peers (cooperative or otherwise) are also central to dominant theoretical perspectives such as Vygotsky's sociocultural theory (Vygotsky, 1978). Indeed, the role of peers in learning begins as early as infancy (Bakeman & Adamson, 1984; Hanna & Meltzoff, 1993; Goldbeck & El-Moslimany, 2013), and during early childhood, the importance of peers increases as children's cognitive and language skills advance and their exposure to social partners expands (Tobin, Wu, & Davidson, 1989; Coolahan et al., 2000).

In his sociocultural theory, Vygotsky emphasized the role of the social and cultural environment in learning and, in particular, the ways in which children benefit from the support of skilled peers and adults (1978). Vygotsky argued that all learning takes place in cultured settings (e.g., classrooms) and *cultural tools* – whether physical (e.g., a pencil) or psychological (e.g., language) – allow learners to master tasks in ways that are most appropriate to their culture (Kozulin, 2001). As such, in an educational environment, skilled peers and adults introduce children to the cultural tools needed for the learning tasks at hand and support children as they utilize these tools to build their knowledge.

Cooperation has also been of considerable interest, more generally, in the field of psychology. For example, Morton Deutsch (1949) became influential in the field of conflict resolution research in the mid-20th century by offering definitional distinctions between cooperation and competition (Johnson & Johnson, 1999). Deutsch believed that, when learning together, the primary force guiding a student's behavior with their peers is their orientation to the task's goal structure. He conceptualized learners as being oriented either competitively or cooperatively with one another, with both orientations involving some degree of interdependence (a lack of interdependence, on the other hand, results in a lack of interaction and, thus, a lack of social learning). Within *competitive* goal orientations, peers are interdependent in that the performance of one's peers serves as the reference point for one's own goals. In contrast, a *cooperative* goal orientation places an individual's success contingently on others: one student's problem-solving can help others reach their own individual goals while one student's mistakes also become the group's errors. According to Deutsch, goal orientations determine how group members interact with one another and the qualities of such interactions, in turn, determine the group members' learning outcomes.

Developmentally, the ability to cooperate with one's peers is thought to emerge in the second year of life and, by age three, cooperation becomes reciprocal as children recognize and are responsive to one another's behaviors and desires (Brownell & Carriger, 1990). In her classic theory of social play, Mildred Parten (1932) argued that learning and play that involves the sharing of materials and the pursuit of a shared goal (*associative play*) emerges between the ages of 3-4 years, and cooperative behaviors become evident by as early as 4-5 years of age. Juxtaposing these various theoretical perspectives, it is clear that peers and cooperation are key to development and early childhood is a time in which the developmental foundations of cooperation are salient and growing. Yet it is arguable that peer cooperation during early childhood has yet received too little empirical attention to effectively guide developmental science or educational practice.

Contemporary practice perspectives and research on cooperative learning. In the field of early childhood education, cooperative learning maintains a high status among educators as a classroom practice that facilitates learning, critical thinking, and social development (National Association for the Education of Young Children, 2009; Cohen, 1994). In the early childhood classroom, it is argued that the social benefits of social learning opportunities are many: reserved children gain a space to safely engage with their peers; dictatorial children learn to take the perspectives of others into consideration; and all children experience the democratic process of negotiation, compromise, and fair resolutions (Watson et al., 1988). At the same time, however, studies have shown that adults, including early childhood teachers, often underestimate preschool-aged children's abilities to participate in cooperative interactions (Howes & Tonyan, 1999). This is perhaps so because cooperative learning among very young children remains under-researched and, thereby, poorly understood (Brownell, Ramani, & Zerwas, 2006). Below, the current state of the cumulative knowledge on this topic is reviewed.

Interactive peer play has been found to influence young children's attitudes toward learning (Cohen & Mendez, 2009) and small group work has been found to be positively related to children's motivation and task completion (Master & Walton, 2013). In a one-year longitudinal study of preschool classrooms, Nesbitt and colleagues (Nesbitt, Farran, & Fuhs, 2015) preliminarily found that children in classrooms with more associative and cooperative learning interactions demonstrated greater gains in both math and literacy at year end than did children in classrooms that had few peer learning opportunities. Cooperative learning interactions have also been found to benefit young children's burgeoning language skills; for example, when pretending to be a "teacher" teaching a "novice," children as young as five-years-old have been found to adjust their language to emphasize the most important features of task rules and expectations (e.g., "only the blue squares go in this sorting box") (Göckeritz, Schmidt, & Tomasello, 2014).

This is not to say that high-quality cooperative learning is an emergent outcome of all social learning interactions or that the ingredients of high-quality cooperation are necessarily intuitive to learners; there are several challenges inherent to cooperative learning that are present for learners of all developmental levels. When intending to scaffold a peer's learning, for example, children of all ages can face difficulty in identifying the peer's current skill level and, in turn, providing them with the appropriate supports (Person & Graesser, 1999). Indeed, according to Pepitone (1980), cooperative learning requires children to accomplish a complex set of task requirements. These include *task activity* requirements, i.e., the demands that stem from the particularities of a task; *task role* requirements, i.e., the interpersonal relationships and roles that are dictated by the task demands; and *group* role requirements, i.e., the unique needs of the group when performing a task. The author argues that the assumption that young children are unable to meet such demands, though perhaps exaggerated, may be due to inattention to the fact that cooperative skills must be learned. In other words, when young children fail to meet the demands of cooperative tasks, this failure may arise, in part, because the needed scaffolding for such cooperation was not provided.

Processes underlying high-quality peer cooperation. Compared with the relatively robust literatures on (and attention from early education practitioners given to) general theoretical and conceptual perspectives on peer cooperation, there is considerably less work investigating the specific processes underlying effective peer cooperation and learning, especially during the preschool years. Empirical work with older children, however, points to the important roles of peer co-regulation (i.e., all group members interacting with one another through conversation or body language) and joint on-task behavior for peer learning outcomes (Rohrbeck et al., 2003).

For instance, Kutnick, Ota, & Berdondini (2008) investigated whether a two-year classroom intervention focused on relational activities (e.g., sharing thoughts and ideas) would improve students' cooperative interactions between the ages of 5 and 7 years. Researchers trained teachers in the underlying principles of relational activities, including bi-directional communication, trust, and respect, observed the teachers' classrooms over two years. During group work, these teachers' students demonstrated a stronger orientation to the learning task at hand and less orientation to non-task-related socializing. The children also displayed more co-regulation, less disengagement, and a higher preference for group work than for independent work. Academic benefits were also found. Specifically, analyses of the children's reading and literacy scores showed that, although attainment increased over time for all students, the experimental (relation activity-trained) classes gained more than control classes and, in turn, these students' reading and literacy scores were significantly higher in Year 2.

Consistent with these results, Rohrbeck, Ginsburg, Marika, Fantuzzo, & Miller (2003) found positive average effects of peer-assisted learning (PAL) interventions in a meta-analysis of 90 studies of elementary school-age children. Although varying in structure (e.g., dyads or small groups) and curricula (e.g., individualized vs. group learning materials), the included PAL interventions all constructed a classroom environment that utilized peers as agents in learning. Across the studies, the authors found that: (1) the impacts of PAL interventions on academic achievement were greater in younger (grades 1-3) rather than older elementary students; (2) the impacts were largest for urban, low-income, and minority-status students; and (3) no significant differences in achievement were found among PAL interventions implemented across content areas (e.g., interventions focused on math vs. reading). These results indicate that younger students, as well those traditionally considered "at-risk," may especially benefit from peer learning opportunities in school.

The structure of the classroom activities within which children are asked to collaborate can also affect their success, as measured by task completion and learning outcomes (Rohrbeck et al., 2003). For example, similar to Deutsch's (1949) concept of a cooperative goal orientation, the presence of interdependent activity goals and rewards are believed to strengthen the quality of peer interactions by establishing a common goal among partners, promoting peer encouragement, reinforcing collaborative efforts, and establishing group norms that emphasize academic achievement (Johnson et al., 1981; Slavin, 1990). Although little empirical work has investigated interdependent learning at the preschool level, Rohrbeck and colleagues' (2003) meta-analysis of elementary school-age children indicates that interdependent activities are associated with significantly larger effects on cooperation and learning than non-interdependent activities.

It is also suggested that peer learning may be most successful if teachers first provide students with targeted instruction on how to identify one another's *zone of proximal development* (King, Staffieri, & Adelgais, 1998; Vygotsky, 1978). In other words, when scaffolding a peer's learning, children need to identify their peer's current skill level as well as the skills their peer would be capable of if given support. Children generally appear well-attuned to one another's confusion and challenges (perhaps even more so than adults) and such targeted instruction not only boosts children's abilities to identify each other's struggles, but also to explain features of a problem in a more understandable way (Webb & Farivar, 1994).

Based upon their work with kindergarten and first-grade students, Chung & Walsh (2006) further highlight four structural considerations for engendering high-quality peer cooperation in the early childhood classroom. First, as discussed in detail below, children who's within-group ability differences are in the small-to-medium range should be encouraged to work together. Second, young children should be paired with a peer with whom they have an established rapport or friendship (as opposed to nonfamiliar or nonfriend pairs), as this initial relationship allows children to focus more on the learning task at hand and less on behavior management. Third, dyads should aim to keep their same learning partner over time and across learning domains. Such consistency allows children to deepen their personal relationships with one another and also provides ongoing opportunities for children to understand the needed flexibilities of social learning. Finally, the authors argue that, especially for young children, the rules of cooperation and cooperative activities must be made explicit. Because young children have less experience with cooperative learning, they initially tend to interpret cooperative work as being independent. Explicit instruction and ongoing opportunities to practice cooperative behaviors are thus needed in order for young children to understand the concept of cooperation.

Group characteristics of peer learning: Does ability mix or gender matter? The ability to adjust oneself to the foci and behaviors of one's peers emerges as early as 20 months (Ross & Lollis, 1989). And, throughout childhood, an essential component of developing social competence is the ability to adjust oneself to varying social contexts and characteristics, including the number of, and the skill levels of, one's classmates (French, Waas, Stright, & Baker, 1986; Allen, 1976). Indeed, research suggests that group size is relevant for social learning outcomes: small groups or pairs of children, rather than large groups, can limit the complexity of cooperation (Watson, 1988). Even in small groups or pairs, however, some researchers speculate that child ability differences within the group or dyad may affect the quality of cooperation and the subsequent learning outcomes (e.g., Carter & Jones, 1994; Chung & Walsh, 2006; Fawcett & Garton, 2005; Day et al., 2005). Yet empirical studies investigating the impacts of mixed-ability peer learning have been inconsistent and largely ignore preschool populations (Kutnick, Ota, & Berdondini, 2008).

According to Brownell (1990), examining mixed-age learning – as a proxy for pairing more- and lesser-skilled children – provides a unique insight into skills that are seldom evident in same-age interactions. When paired with a more-skilled partner, for instance, a lesser-skilled child may strive to perform at a higher level while the more-skilled peer may be motivated to utilize advanced social skills. In a study of five-year-old children who were tasked with constructing a replica Lego model, researchers found that the children who collaborated with a peer on the task constructed more accurate replicas than did the children who worked independently (Azmitia, 1988). The children whose partners were at an "expert" skill level demonstrated the greatest learning gains and, in fact, only the children whose partners were "experts" subsequently transferred their learning to similar problems when working independently. Both the "novice" and "expert" children spent more time observing their partner if their partner was an "expert" rather than a "novice," indicating that even very young children seem to be aware of their level of competence in relation to that of their peers.

Other studies focused on children in the first few years of elementary school have also demonstrated the importance of skill differences in joint learning tasks. Fawcett and Garton (2005), for example, had six-and-seven-year-olds complete a block-sorting task either individually or with a partner. The children who worked with a partner demonstrated significantly higher success on correctly sorting their blocks than did the children who worked independently, and it was the lower-sorting ability children paired with a higher-sorting ability peer that demonstrated the most significant improvement in sorting from pre- to post-test. Further analysis revealed that this effect was found for the children (both low-sorting ability and high-sorting ability at pre-test) who verbally explained the sorting rules to their partner.

With similar-aged children, Chung & Walsh (2006) examined interactions during a dyadic writing task on a computer. The authors found that all of the dyads advanced towards a more integrated learning environment as the writing activity progressed (as demonstrated by more equitable use of the mouse and keyboard). In addition, although the more literate children demonstrated a more dominant role in the activity at first, over time, the lesser-skilled children took on important actions more often (e.g., finding letters and symbols on the keyboard). The higher-skilled children also demonstrated various scaffolding behaviors, such as voluntarily checking their peer's spelling, indicating that even young children are capable of independently accommodating their peers' skill development.

In light of the findings discussed above, mixed-ability pairing may indeed be advantageous for preschoolers during math learning activities. However, the theoretical rationale for mixed-ability grouping also suggests, albeit implicitly, that extreme skill disparities between peers could undermine their cooperative interactions and subsequent learning. If, for example, the value of peer cooperation in learning is that children have opportunities to be "teachers" and "students" during their interactions (e.g., Göckeritz, Schmidt, & Tomasello, 2014), partnering with a peer whose skills are significantly different from one's own could increase the difficulty of these roles. Moreover, while moderate skill disparities may increase motivation (e.g., Brownell, 1990), there is reason to speculate, based upon the motivation literature, that working with a peer who is too highly skilled or too lowly skilled could undermine motivation and increase negative social comparisons. For instance, research has found that low-achieving elementary-aged students working with highly skilled peers can, throughout their learning interactions, develop lower self-efficacy and an increased awareness of their lesser competence (Gabriele & Montecinos, 2001). At the same time, highly skilled peers may gradually rate their own peers as being relatively incompetent. Although such evidence indicates that a moderate skill disparity level between peers may be the best "fit" for peer cooperation and learning in older children, this author is unaware of any studies that have examined whether there is an optimal skill level disparity for preschool children.

Researchers have also found mixed results when investigating the role of dyadic gender structures in children's cooperative learning interactions. For example, Lee (1993) examined gender differences during fifth- and sixth-grade students' interactions with a small-group computer-based problem-solving task. In the female-only groups, girls were found to be more willing to both ask for and provide help to their peers. Although this same trend was not found in the male-only groups, in the mixed-gender groups, boys were found to talk more and to both seek and receive more support from their peers. In a preschool sample, on the other hand, Underwood, Jindal, & Underwood (1994) found mixed-gender dyads to perform worse on a spelling puzzle task than did same-gender dyads. Although the performance of all of the dyads improved when they were explicitly instructed to cooperate on the task, these instructions had the least effect on the cooperative behaviors of the mixed-gender dyads and the strongest effect on the male-only dyads.

Finally, when looking at gender differences in the *language* of peer cooperation, a study of four- and five-year-old children found differences in the verbal exchanges of same-sex versus mixed-sex dyads during a problem-solving task (Holmes-Lonergan, 2003). In this study, mixed-sex dyads were more likely than same-sex dyads to engage in controlling verbal interactions (i.e., giving one's partner direct commands and challenges while ignoring questions and suggestions) and, overall, girls offered suggestions and compromises to their partners more frequently than boys did. While these findings do not together point to clear hypotheses about gender groupings, they do indicate the importance of controlling for group gender structures when examining peer cooperation.

Peer cooperation during math learning activities. Mathematics is notably missing from the limited early childhood literature on peer cooperation and learning. From both a practice and empirical standpoint, this is a significant limitation, as it has become increasingly clear over the last two decades that mathematical knowledge in early childhood is predictive of children's future success in school. For instance, knowledge of basic math concepts (e.g., numbers, ordinality) in kindergarten has been shown to be a stronger predictor of later learning than early literacy or social-emotional skills (Duncan et al., 2007; Claessens, Duncan, & Engel, 2009). In a meta-analysis of six longitudinal data sets, Duncan and colleagues (2007) found that children's math knowledge at school entry predicted their math achievement through at least the fifth grade and Watts, Duncan, Siegler, & Davis-Kean (2014) demonstrated this relation through the high school years. Research also suggests that learning math at a very young age is particularly important for at-risk children (Sarama & Clements, 2009), as sizeable achievement gaps in math skills between advantaged and disadvantaged groups have been found to emerge prior to kindergarten entry (Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006). Moreover, empirically-supported early math curricula such as *Building Blocks* (Sarama & Clements, 2009) are rich with activities that encourage or require peer cooperation. A better understanding of peer cooperation processes during these types of early math learning activities could thus have substantive implications for improving early education interventions and practice.

The Present Study. The purpose of this dissertation is to advance understanding of cooperative learning processes during early childhood, with a particular focus on cooperation during early math learning activities. In this study, preschool-aged children repeatedly engaged in dyadic guided learning with three early math learning games that were adapted from empirically-validated curricula. The study occurred at three sites, each in major urban areas, and participating children were diverse with regard to race and ethnicity. The three games used in the study were designed to target children's early counting, addition, and subtraction skills. Using an approach similar to micro-genetic research (e.g., Goldbeck & El-Moslimany, 2013), repeated observations of the children's dyadic interactions during the game play sessions were conducted twice a week across three weeks. A standardized assessment of children's math skills was collected prior to the first session of game play and a standardized assessment of children's counting skills was collected at study completion. In addition, children's cooperative behaviors during the first, third, and fifth game play sessions were qualitatively coded for analysis.

Using these data, the present study addresses two primary research questions:

Research Question 1. When pursuing a shared math learning goal, what are the average rates of occurrence, as well as variations and intercorrelations therein, of peer cooperation behaviors?

For this first question, three domains of peer cooperation were examined:

a. time spent *on-task*

b. the overall quality of the peer cooperation, with attention to three dyadic interactive and regulatory states:

   i. *co-regulation* (i.e., active, goal-directed participation through verbal and nonverbal actions by both peers during game play),

   ii. *unilateral regulation* (i.e., one child in the dyad dominates the activity, often ignoring their partner), and

   iii. *disengagement* (i.e., the dyad fails to share any aspect of the activity, with each member of the dyad having a different focus).

c. four discrete child behaviors that contributed to, or detracted from, the overall quality of the peer cooperation:

   i. *supportive* peer behaviors (i.e., the children encouraged or assisted one another)

   ii. *engaging* one another in the learning activity (i.e., the children attempted to engage or redirect one another towards the game play)

   iii. peer *explanations* (i.e., the children explained or modeled a mathematical concept, process, or solution to one another)

   iv. *distracting* behaviors (i.e., distracting or disruptive behaviors that the children engaged in)

Given the limited empirical work on cooperative learning during early childhood, specific hypotheses were not offered for average rates of these constructs, or the precise pattern of intercorrelations among the constructs. However, as part of this first question, variations across game play sessions, dyadic characteristics (i.e., skill disparities and gender), and learning environments (i.e., intervention site and game) were also examined. Given prior evidence, both empirical and theoretical, on the consequences of skill disparities for cooperation and learning, specific hypotheses were made for this variable. With regard to the overall quality of peer cooperation, it was expected that co-regulation would be highest – and unilateral regulation and disengagement lowest – among dyads with moderate disparities in initial math skills as compared with dyads having small or large disparities in initial math skills. It was also expected that supportive behaviors, peer engagement, and peer explanations would be most frequent – and distracting behaviors least frequent – among the dyads with moderate disparities.

Research Question 2[1]*. Are (1) the collaborative qualities and regulatory states of dyadic interactions (i.e., the time dyads spent co-regulating, unilaterally-regulating, and disengaged), or (2) the discrete cooperative behaviors that contribute to peer cooperation (i.e., supportive behaviors, peer engagement attempts, peer explanations, and distracting behaviors) during early math activities associated with children's end-of-study counting skills, controlling for initial math skills?*

It was hypothesized that more time spent co-regulating, versus unilaterally-regulating or disengaged, during the math activities would be predictive of better counting skills, controlling for initial math skills. In addition, it was hypothesized that higher rates of supportive, engaging, and explanatory behaviors would be predictive of better counting skills while distracting behaviors would be predictive of worse counting skills, controlling for initial math skills. As part

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[1]Note that this research question, for both main effects and mediator effects, is focused specifically on the *quality* of peer cooperation (the dyadic regulatory states and the discrete cooperative behaviors); time on-task is necessary for cooperative learning but was not considered sufficient in and of itself to capture peer cooperation per se.

of the predictions for the second research question, it was also hypothesized that the quality of peer cooperation (the dyadic regulatory states and the discrete cooperative behaviors) would mediate relations between dyadic math skill disparities and end-of-study counting skills. That is, given the expected relations between moderate initial dyadic skill disparity levels and peer cooperation and, in turn, between peer cooperation and end-of-study counting skills, an indirect association between moderate initial dyadic skill disparity levels and end-of-study counting skills via peer cooperation was expected.

CHAPTER 3: METHODS

Participants. This dissertation uses data collected at preschools in three metropolitan areas (Boston, MA; Minneapolis, MN; and Chicago, IL) between November 2015 and May 2016. These data were collected as part of larger project investigating whether early competencies in both math and executive functions (EF) can be enhanced through engagement in guided dyadic math learning games played in six sessions across three weeks. Participants were recruited from preschool classrooms serving racially- and economically-diverse children. A total of 72 children between the ages of three and five (44% female; 36% white; 26% Black; 16% Asian; 2% American-Indian/Alaska Native; 10% other (e.g., mixed-race); 17% Hispanic; mean age= 4.66 years; see Appendix Table F1) participated. All game play sessions were conducted in English in the children's schools.

Procedure. Prior to the first session of game play (on a separate day), each child's math skills were individually assessed using the *REMA Brief* test (see details below). Although the original study plan for the larger project from which these data were taken aimed to minimize math skill disparities within dyads, the resulting sample of dyads included a wide distribution of disparity levels (see Appendix Table G1). This occurred in part because attempts to match children based on their initial math skill levels was done within classrooms (with the exception of one dyad that consisted of two children from separate classrooms), limiting how closely matched the dyads were. Moreover, when only two children from a given classroom enrolled in the study, they were paired with one another regardless of their math skill levels. With regard to gender, this process resulted in a within-dyad gender breakdown of: 34% male/male; 20% female/female; and 46% male/female.

In the larger project from which these data were taken, several games targeting different math skill domains were examined. Games were assigned across sites with the intention that most would be played at multiple sites, with some exceptions occurring due to the overarching study goal of examining multiple math domains. In the present study, the focus was exclusively on games that targeted numeric and counting skills, for which three study sites were involved and for which three games were studied. At each of the three sites, children were randomly assigned to play one of the three games. More specifically, at the Boston site, children were assigned to play either the *Big Fish Story* or the *Change Game*; at the Chicago site, children were assigned to play either *Magician's Tricks* or a second game that was focused on spatial skills (not included in the present study); and at the Minneapolis site, children were assigned to play either the *Big Fish Story* or *Magician's Tricks*.

Each child played the same game with the same partner across the game play sessions. The six sessions were held twice per week over the course of three weeks. Each session took place in a quiet space outside of the children's classroom and was accompanied by the instructional support of one researcher (thus, two children and one adult were present for each game play session). Game play lasted approximately 15 minutes per session and all sessions were video-recorded. Post-study assessment of the children's math skills occurred upon completion of the sixth game play session (on a separate day) using the *REMA Counting Learning Trajectory* test.

Excluded Dyadic Interactions. Game play sessions one, three, and five were qualitatively coded for the current study. Because of student absences across the duration of the study, occasions arose wherein one child participated in a game play session either independently or with a research assistant as their partner (in lieu of their classroom peer). Game play sessions that were conducted in this format were not coded. If both children in a dyad were absent for one session of game play (e.g., session one) but present for the other two full sessions of game play (e.g., sessions three and five), they remained in the final sample. 90% of the final sample completed – and were qualitatively coded during – three full sessions of game play.

The Math Games. Prior to the initiation of the present study, researchers from several universities participating in the Development and Research in Early Math Education (DREME) research network conducted a systematic review and coding of early math learning activities in curricula for which there is empirical evidence of effectiveness (e.g., *Building Blocks*; *Big Math for Little Kids*). Activities were coded according to their expected level of challenge of children's math and EF skills. From this analytic process, activities from each of the curricula that scored highly in each challenge domain were used to develop the three math activities used in the present study.

During each of the three activities, dyads were encouraged to *Think, Pair, Share (TPS)* with one another; a three-part strategy used to facilitate cooperative discussion among students (Kaddoura, 2013; see Appendix D). In order to *TPS*, children must first consider their own thoughts and ideas ("think"), then pair with a peer ("pair"), and finally share their thoughts and ideas with one another ("share") (Marzano & Pickering, 2005). All children completed a practice *TPS* exercise (e.g., "Let's *think-pair-share* our favorite foods") before the first session of game play began and, throughout the sessions, were prompted to *TPS* their game play strategies and mathematical reasonings with one another.

The *Big Fish Story* game (see Appendix A) was administered to children in Boston and Minneapolis. In this game, each child was provided with their own laminated ocean picture mat placed directly in front of them on the table. A shared bowl of plastic fish pieces was placed between the two children, and a "shark" (a tissue box wrapped in shark-printed paper) was placed outside of the children's view. The shark box had an open center (the "mouth") where children would insert fish when the shark "ate" them.

In the first phase of the *Big Fish Story* game, the researcher prompted the dyad to each take a small quantity of fish (e.g., three fish pieces) from the shared fish bowl and place the fish onto their individual ocean mats. Once each child confirmed that there were three fish "swimming" in their "oceans," the children proceeded to add quantities of fish ranging from one to four fish pieces to their ocean mats. After two iterations of adding fish (e.g., each child added three fish to their ocean mat and subsequently added two more fish), the researcher placed the shark box on the table to "eat" a quantity of fish ranging from one to four fish pieces. Once the shark ate the assigned fishes, the dyad was asked to calculate how many fish remained swimming in each of their oceans. The quantities of fish being added and subtracted ("eaten") were the same for both children. Once the iterations of adding and subtracting fish pieces resulted in zero fish remaining on each child's ocean mat, the game transitioned to Phase II.

In the second phase of the *Big Fish Story* game, a thick sheet of brown paper – "ocean mud" – was laid on top of each child's ocean mat such that the ocean scene was no longer visible. The children continued adding and subtracting fish pieces as in Phase I. However, in Phase II, the children were instructed to "sneak" the fish underneath the ocean mud and onto their ocean mats without looking (addition) as well as sneak the fish out from underneath the ocean mud when feeding the shark (subtraction). After each iteration of addition or subtraction of the fish pieces, the children were asked to calculate from memory how many fish remained swimming in their oceans. For instance, if the child's ocean mat contained three fish pieces hidden underneath the ocean mud and two of those fish were eaten by the shark, the child would need to remember the three fish and calculate ($3 – 2 = 1$) using mental math.

Challenge prompts implemented by the researcher throughout the *Big Fish Story* game included a *How did you know?* prompt. This question was asked after the children identified the number of fish pieces remaining on their ocean mats (correct or not), pushing the children to reflect on and verbalize their calculation and/or memory strategies. The *Big Fish Story* also integrated several learning-supportive materials, including a laminated number line and laminated numerical operations cards (see Appendix D). The numerical operations cards each contained a symbol and a numeral (e.g., “+3”; “-2”) and were employed to increase the challenge level throughout the game: when children were consistently able to correctly identify the quantity of fish pieces remaining on their ocean mats after an additive or subtractive round, the researcher would present the dyad with a numerical operations card and ask the children to perform the operation listed (e.g., if presented with a +3 card, the children would add three fish pieces onto their ocean mats and determine the resulting number of fish).

The primary math domain targeted by the *Big Fish Story* was counting; game play required each child to accurately count quantities of fish out of the fish bowl and onto their oceans mats and to continue accurately counting as fish were added or subtracted. The level of challenge was increased in Phase II as children were required to count and calculate from memory. The secondary math domain targeted by the game was addition and subtraction; game play required each child to add (incorporate new fish pieces onto their ocean mat) and subtract (remove fish pieces when eaten by the shark) various quantities. Phase II of game play increased the level of challenge as the addend numerals (e.g., the three fish underneath the ocean mud and the two new fish being incorporated) required children to calculate from memory. Finally, the challenge prompts and the TPS prompts were expected to engender peer collaboration during the *Big Fish Story* game. If one or both children in the dyad miscounted or miscalculated the number of fish on their ocean mats, the researcher's prompts encouraged the children to work together to identify the mistake, offer suggestions (e.g., "count again"), and model the correct mathematical steps and/or solution (e.g., "You have three fish now, see? One, two, three.").

The *Change Game*. The *Change Game* (see Appendix B) was administered at the Boston site only. In this game, one long game board was placed horizontally on the table in front of the dyad. A small container of plastic game "chips" in either blue or green was given to each child. Illustrated at the starting end of the game board (the dyad's far left) was a bear and at the opposite end of the game board was the bear's cave. Squares numbered 1-10 (game board #1) or 1-20 (game board #2) connected the bear to its cave.

The goal of the *Change Game* was for the bear to traverse the numbered squares and reach its cave. To do this, the dyad took turns rolling a number cube (containing numerals 1-6) and filled the squares between the bear and its cave with the number of chips that were rolled on the number cube. For instance, if one child rolled numeral four on the number cube, one blue chip was placed in squares one through four on the game board. If the second child then rolled numeral five, one green chip was placed in squares one through five. The game board would therefore have both one green chip and one blue chip in squares one through four, and one green chip in square five. Each game board square required both one blue chip and one green chip in order for the bear to traverse all of the game board squares and reach its cave.

In the *Change Game*, each child assumed a role that rotated throughout the game: the "roller" or the "checker." As a reminder of their respective roles, the roller was given a small card with an illustration of a hand while the checker was given a small card containing a green check mark symbol. After rolling the number cube and identifying the rolled numeral, the roller placed a matching quantity of chips onto a small plate. The roller then asked the checker to check their work – "*Am I right?*" – prompting the checker to determine whether the quantity of chips on the plate correctly matched the rolled numeral. If incorrect, the researcher prompted the dyad to correct the quantity of chips on the plate. Once correct, the roller placed their chips onto the game board squares and the dyad switched roles.

Two game boards were utilized throughout the *Change Game* to increase or decrease the level of challenge. One board consisted of 10 squares between the bear and its cave while the alternate board consisted of 20 squares between the bear and its cave. Once dyads demonstrated success with the 10-square board, the 20-square board was introduced. Two number cubes were also utilized in the *Change Game*. One number cube consisted of the written numerals 1-6 while the alternate cube consisted of the quantities 1-6 represented by dots (similar to a traditional die). Once dyads demonstrated success with the numerals cube, the dots cube was introduced. For further challenge, the numerical operations cards as described in *The Big Fish Story* game were also utilized in the *Change Game*; when presented with a numerical operations card, the children were asked to add or remove the appropriate quantity of chips from the game board.

The primary math domain targeted by the *Change Game* was counting; game play required the roller to count out the correct number of chips onto their plate and, when using the dots cube, also required accurate counting of the dots. In turn, the checker was required to count the number of chips on the plate. To monitor progress as each child advanced toward the final game board square, the dyad was prompted to count the number of chips on the game board as well as the number of empty squares. The secondary math domain targeted by the *Change Game* was addition and subtraction. During game play, the numerical operations cards were used to prompt the dyads to calculate an addition or subtraction of chips. For instance, after a child rolled a three on the number cube and correctly counted three chips onto their plate, a +2 card was presented. The child then needed to determine that the addition of two chips would result in five chips on their plate and, in turn, five more chips on the game board.

The peer collaborative focus of the *Change Game* was primarily rooted in the children's assigned roles. That is, in order for game play to proceed, the roller was dependent on the checker's confirmation that the number of chips on their plate was correctly counted. If incorrect, the checker could prompt the roller to re-count until the correct number of chips had been retrieved. The use of both the numerical operations cards and TPS prompts increased the levels of game challenge and discourse demands. For instance, if one child's chips on the game board reached up to the sixth game board space, the dyad was prompted to TPS to determine which numeral operations card would need to be selected in order for the chips to reach the tenth square.

Magician's Tricks. The *Magician's Tricks* game (see Appendix C) was administered in Minneapolis and Chicago. In this game, numeral cards (numerals 1-10 or 1-20) were placed face-down on a table from left to right in front of the dyad. If the 20-card deck was used, numerals 1-10 were arranged in top row with numerals 11-20 in a row directly below. Each child was assigned a role that rotated throughout the game: the "pointer" and the "magician." As a reminder of their respective roles, the pointer was given a small card containing an illustration of a hand with its index finger extended (i.e., pointing) and the magician was given a small card containing an illustration of a top hat and wand. The pointer used their card to "point" to one of the face-down numeral cards on the table and the magician was tasked with determining the numeral on the card by announcing, "*Abracadabra, the number is X*."

In the first phase of the *Magician's Tricks* game, the researcher took on the role of the magician while the dyad shared the pointer role. After a card was selected by the dyad, the magician counted aloud from the first card to the selected card, pointing to each as it was named. After announcing the numeral of the selected card ("*Abracadabra, the number is X"*), the magician turned the card face-up to reveal the numeral. Each card previously revealed by the magician remained upturned for the remainder of the game. In the second phase of *Magician's Tricks*, the dyad took turns assuming the roles of the magician and the pointer while the researcher observed. If the magician incorrectly announced the numeral of a selected card, the researcher prompted the dyad to TPS in order to correctly determine the numeral.

Challenge prompts implemented by the researcher throughout the *Magician's Tricks* game included a "*How did you know?"* question prompt. This question was asked after the magician correctly identified a card numeral, pushing the child to verbalize the counting and/or memory strategies utilized (e.g., if the correctly identified card was next to an upturned six, the child may explain that they knew the selected card was a seven because seven is one more than six). *Magician's Tricks* also integrated learning-supportive materials into game play, including a laminated number line as well as a plastic folder used to hold the numeral cards in place.

The primary math domain targeted by *Magician's Tricks* was counting. Game play required the children to count the face-down numeral cards beginning at the one card as well as utilize a counting-on strategy (e.g., counting-on from the up-turned numeral three card to the selected face-down six card: "three…four, five, six"). In order to identify the numeral of the card selected by the pointer, the magician was required to count either forwards (e.g., from three to six) or backwards (e.g., from an up-turned numeral six card to the selected face-down three card). The secondary math domain targeted was comparing and ordering, as children were required to monitor the order of the numerals to correctly identify the selected cards. For instance, if the pointer selected the face-down seven card, the magician needed to consider whether seven is a larger or smaller number than the up-turned five numeral. In addition, if the magician incorrectly identified a selected numeral, the dyad was prompted to TPS about the natural order of numbers 1-10 and to use this thinking to correctly identify the selected card. Finally, as with the *Change Game*, the peer collaborative focus of the *Magician's Tricks* game was primarily rooted in the children's roles. In order to progress in the game play, the magician was dependent upon the pointer selecting a numeral card.

Measures.

Initial math skills. Prior to the first game play session, the children's mathematical competencies – henceforth referred to as "pre-test math skills" – were assessed using the *Research-based Early Mathematics Assessments (REMA) Brief*. This 20-item assessment of preschool-aged children's math skills includes 13 items assessing numeracy knowledge and 6 items assessing geometric knowledge (Weiland et al., 2012). This measure provides an overall mathematics score that can be used to identify a child's approximate developmental level in relation to same-age peers. Children's performance on the *REMA Brief* was compared with performance on the Woodcock-Johnson III Applied Problems subtest and these two assessments were found to have a correlation of $r = .89$ and an overall item reliability of $r = .94$ (Clements, Sarama, & Liu, 2008).

Math Disparity Groupings. A difference score was created for each dyad to represent the quantitative difference between each child in the dyad's *REMA Brief* score. For example, a dyad with Child 1's *REMA Brief* score a 45 and Child 2's *REMA Brief* score a 51 received a difference score of 6. The range of difference scores across the full sample of dyads was then used to categorize each dyad into one of three difference score groups: low disparity (a difference score of less than 4; *n*= 12), moderate disparity (a difference score between 5 and 8; *n*= 13), or high disparity (a difference score greater than 9; *n*= 11).

Within each difference score group, two additional variables were created to identify the dyads with relatively-high or relatively-low skill levels as compared to the full sample's average *REMA Brief* score (μ= 52.82). In other words, despite Dyad A having a low within-dyad skill disparity level and thus being in Group 1, the dyad could have two children whose *REMA Brief* scores were a 47 and 48 (a difference score value of 1). Dyad B, on the other hand, could have two children whose *REMA Brief* scores were a 56 and 57, also resulting in a difference score of 1 and assignment to Group 1. In such a case, Dyad A's math skills were relatively weak as compared to the full sample whereas Dyad B's math skills were relatively strong. To identify this within-skill disparity group variation, a "Matched-low" and a "Matched-high" variable was created (see Appendix Table G1). In a Matched-low dyad (*n*= 13 dyads across all groups), the *REMA Brief* scores of both children in the dyad were below the sample average whereas, in a Matched-high dyad (*n*= 12 dyads across all groups), the *REMA Brief* scores of both children were above the sample average. Thus, in the above example, Dyad A is a Group 1 *Matched-low* dyad and Dyad B is a Group 1 *Matched-high* dyad.

End-of-study counting skills. Children's counting skills were assessed at the conclusion of the sixth game play session – henceforth referred to as "post-test counting skills" – using the *Research-based Early Mathematics Assessments (REMA) Counting Learning Trajectory (LT)* (Clements, Sarama, & Liu, 2008). This measure is a 35-item assessment of counting skills for preschool through second grade children. Test items assess forward counting, backward counting from 10, object counting, cardinality, and error recognition. Correlations between the REMA and the REMA Counting LT are reported as adequate by the authors (ranging from r = 0.71 to r =

0.74) and, when compared with the Woodcock-Johnson III Applied Problems subtest, a correlation of $r = .74$ was found. The REMA Counting LT measures competence using a Rasch-item response theory (Rasch-IRT) scoring method. This method calculates item difficulty, response errors, and mathematical reasonings into an overall weighted score that locates individual children on a common ability scale ("learning trajectory") that in turn allows for accurate comparisons across ages.

Peer Collaboration. For all dyads, game play sessions 1, 3, and 5 were qualitatively coded using a time-sampling coding procedure – four one-minute intervals – and a peer collaboration coding scheme adapted from Kutnick, Ota, & Berdondini (2008). Each one-minute interval observed a component of game play that was likely to evoke dyadic collaboration. In the *Big Fish Story* game, each interval observed at least one iteration of addition or subtraction of fish pieces (a total of two one-minute observations during Phase I of game play and two one-minute observations during Phase II). In the *Change Game*, each interval observed at least one roll of the number cube (a total of two number cube rolls by Child 1 and two number cube rolls by Child 2). In the *Magician's Tricks* game, each interval observed at least one card selection (a total of two turns being the pointer for each child). In total, of the 36 dyads included in the final sample, 420 one-minute intervals across 105 game play sessions were coded.

Development of Coding Scheme. Peer cooperation was coded in the present study using an adaptation of the coding scheme used by Kutnick, Ota, & Berdondini (2008) to examine peer cooperation in the classrooms of five- to seven-year-old children. Specifically, three components of peer cooperative learning were coded: (1) the amount of time that children spent on-task; (2) the collaborative qualities and regulatory states interactions; and (3) the discrete cooperative behaviors that contributed to, or detracted from, the learning. For time on-task, dyads were coded as being "on-task" or "off-task" according to whether the behavior of each child in the dyad contributed to furthering the progression of the math activity (see Table 1 and Appendix E). The on-task variable was calculated as the proportion of the one-minute observation segments that the dyads spent on-task; for example, if children spent 45 seconds of the one-minute observation on-task, they were coded as being on-task for .75 of the observation. Across the four one-minute segments, these time proportions were averaged.

The overall quality of peer cooperation was coded with attention to three dyadic interactive and regulatory states: co-regulation, unilateral regulation, and disengagement. Dyads were coded as being in a co-regulatory state if each member of the dyad was actively engaging with one another in verbal or non-verbal actions in pursuit of the task goal. If the dyad was found to not be co-regulating, the dyad was classified as being either in a state of unilateral regulation (i.e., one child in the dyad dominates the activity, often ignoring their partner) or disengaged from one another (i.e., the dyad fails to share any aspect of the activity, with each member of the dyad having a different focus).

Because these three measures of cooperation quality focus on dyads' orientations toward *each other* – whereas the on-task variable represents dyads' orientation toward *the task* – dyads could be considered both on-task and co-regulating or on-task and unilaterally-regulating. Dyads that were considered both on-task and co-regulating actively engaged with one another in pursuit of the activity goal. Dyads that were considered on-task and unilaterally-regulating, however, pursued the activity goal (i.e., remained on-task) but largely ignored one another throughout game play (and thus were not co-regulating). As with the on-task variable, the co-regulation, unilateral regulation, and disengagement variables were calculated as the proportion of the one-minute observation that the dyad spent in each state. For instance, if a dyad co-regulated for 30 seconds of the observation, unilaterally regulated for 20 seconds of the observation, and were disengaged for the remaining 10 seconds of the observation, the resulting values for each of these variables were: co-regulation (.50); unilateral regulation (.33); disengaged (.17). Across the four one-minute segments, these values were averaged.

Finally, four discrete cooperative behaviors represent child actions that contributed to, or detracted from, the overall quality of the peer cooperation: peer supportive behaviors, peer engagement attempts, peer explanations, and distracting behaviors (see Appendix E for specific examples of each of these behaviors). Peer supportive behaviors refer to instances of children in the dyad encouraging or assisting one another during game play. For instance, a child may cheer for their partner during the game or help them place a game chip on a section of the game board that was difficult to reach. Peer engagement attempts refer to instances of children in the dyad attempting to re-engage or re-direct one another when distractions or frustrations began to affect the game play. For instance, if a child attempted to leave the play table, their peer may remind them to roll the number cube instead. Peer explanations refer to instances of children explaining or modeling a mathematical concept, process, or solution to their peer during game play. Peer explanations could be verbal (e.g., a child explains to their peer that they skipped over the blue fish piece while counting) or nonverbal (e.g., a child demonstrates for their peer how to put the correct number of game chips on the game board). Distracting behaviors detracted from the quality of the peer cooperation. These behaviors refer to instances of children disrupting the game play or intentionally violating the game rules; for example, a child may toss their number cube across the table. The variables for each of these four behaviors were calculated as frequency counts within the observation (e.g., if one supportive behavior occurred during the observation, the variable value for that observation would be 1.0) and, across the four one-minute segments, these values were averaged.

Note that, initially, the four discrete cooperation behavior variables were coded at the individual child level. In order to represent the occurrence of each behavior at the within-dyad level, a variable representing the average number of times each behavior occurred across both children in the dyad was created for each game play session. Thus, the number of, for example, supportive behaviors a dyad engaged in during a game play session represents the number of supportive behaviors engaged in by both members of the dyad during the game play session. Creating a dyadic average variable for each of the discrete cooperation behaviors ensured that these variables could be analyzed dyadically alongside the on-task variable and the three regulatory-quality variables (co-regulation, unilateral regulation, and disengagement). The full set of variables coded in this study are presented in Table 1 below.

Table 1

Peer cooperation variables

Peer Cooperation		
Cooperation context	On-task	the amount of time the dyad spent on-task
Quality of peer cooperation	Co-regulation	the amount of time the dyad spent in a state of co-regulation
	Unilateral regulation	the amount of time the dyad spent unilaterally-regulated
	Disengaged	the amount of time the children in the dyad spent disengaged from one another and from the activity
	Discrete cooperation behaviors	

	Supportive behaviors *contributed to quality*	the number of times the children in the dyad encouraged or assisted one another
	Engagement attempts *contributed to quality*	the number of times the children in the dyad attempted to engage or redirect one another towards game play
	Peer explanations *contributed to quality*	the number of times the children in the dyad explained or modeled a mathematical concept, process, or solution to one another
	Distracting behaviors *detracted from quality*	the number of distracting or disruptive behaviors that the children in the dyad engaged in

Preliminary analyses determined the spread of the four discrete peer cooperative behavior variables across the three game play sessions. 78% (n = 28) of dyads engaged in at least one peer supportive behavior across the three game play sessions and 8% (n = 3 dyads) displayed at least one supportive behavior during every session. Peer engagement attempts were less frequent, with 44% (n = 16) of dyads never attempting to re-engage or re-direct one another and, of the dyads that did make an engagement attempt, most (42%; n = 15) did so during only one game play session. On the other hand, at least one peer explanation was offered by 60% (n = 22) of the dyads across sessions and 25% (n = 9) of dyads provided mathematical explanations to one another during two out of the three game play sessions. Finally, distracting behaviors were the most frequently observed behavior across all of the dyads; 94% (n = 34) of dyads engaged in at least one distracting behavior across game play sessions and 33% (n = 12 dyads) distracted one another during all three sessions of game play.

Think-Pair-Share. The number of *Think-Pair-Share* prompts provided to the dyad by the researcher was also recorded – as frequency counts – during each observation. As with the peer cooperation variables, the overall *TPS* variable represents the average occurrence of *TPS* prompts across the three game play sessions. As reported in the Results section, analyses were conducted to investigate *TPS* prompts as a possible covariate for analyses (see Table 2 below for *TPS* means across sessions).

Table 2

Frequency of Think-Pair-Share Prompts

	Average across all sessions	Session 1	Session 3	Session 5
Think, Pair, Share prompts	.50 (.76) 0 – 3.7	1.26 (2.10) 0 – 11	.03 (.18) 0 – 1	.10 (.40) 0 – 2

Note. *Standard deviations are presented in parentheses; variable ranges are presented below*

CHAPTER 4: RESULTS

Overview of Analyses. The results of the present study are organized into two sections, following the two primary research questions addressed in the study. For the first research question, most of the analyses were descriptive with a focus on average levels of, variability in, and intercorrelations among the peer cooperation variables. In addition, for this question, variations across game play sessions, dyadic characteristics (i.e., skill disparities and gender), and learning environments (i.e., intervention site and game) were examined using growth curve models and ANOVA. To address the second research question, patterns of association were first examined between children's peer cooperation and their pre-test math scores, which was the primary covariate for examining associations with post-test counting scores. Then, for the primary analyses, correlations and multi-level models that controlled for pre-test math scores were estimated to examine associations between peer cooperation and post-test counting skills. In these multi-level models, child-level data (pre-test and post-test scores) was modeled at level one and dyadic data (peer cooperation) was modeled at level two.

Research Question 1. When pursuing a shared math learning goal, what are the average rates of occurrence, as well as variations and intercorrelations therein, of peer cooperation behaviors?

Descriptive statistics for the eight peer cooperation variables are provided in Table 3 below. Statistics for variables in the top half of Table 3 represent proportions of time and, for variables in the bottom half of the table, frequencies are reported. As shown in Table 3, each of the cooperation variables of interest were observed to occur during the game play interactions, although the four discrete cooperative behavior variables occurred at fairly low frequency levels, on average, and some changes were observed across sessions. More specifically, four important descriptive findings are evident.

Table 3

Duration and frequency of the peer cooperation variables averaged across all game play sessions and per individual game play session

	Average across all sessions	Session 1	Session 3	Session 5
	Proportion of time			
Time on-task	.85 (.13) .50 – 1.0	.91 (.12) .42 – 1.0	.85 (.17) .33 – 1.0	.81 (.19) .16 – 1.0
Co-regulation	.72 (.18) .24 – 1.0	.84 (.15) .42 – 1.0	.70 (.21) .18 – 1.0	.63 (.26) .08 – .98
Unilateral regulation	.10 (.06) 0 – .26	.07 (.09) 0 – .35	.09 (.09) 0 – .28	.12 (.11) 0 – .38
Disengaged	.18 (.15) 0 – .57	.09 (.12) 0 – .45	.21 (.21) 0 – .75	.24 (.21) 0 – .89
	Frequency			
Supportive behaviors	.26 (.31) 0 – 1.7	.33 (.46) 0 – 2	.21 (.43) 0 – 2	.21 (.36) 0 – 1.5
Attempts to engage peer	.09 (.19) 0 – .83	.06 (.24) 0 – 1.5	.16 (.31) 0 –1	.07 (.19) 0 – 1

Explanations or modeling	.37 (.40) 0 – 1.33	.47 (.60) 0 – 2	.33 (.62) 0 – 3	.31 (.52) 0 – 2
Distracting behaviors	1.19 (1.1) 0 – 4.5	.73 (1.05) 0 – 3.5	1.30 (1.60) 0 – 6	1.48 (1.60) 0 – 9.5

Note. *Standard deviations are presented in parentheses; variable ranges are presented below*

First, the children were, on average, on-task and engaged with one another in a co-regulatory state for the majority of time during the game play sessions. In fact, dyads were, on average, on-task for more than 80% of the total session time and the proportion of time spent co-regulating approached or was above 70%, on average, across all three game play sessions. Second, there was substantial variability across dyads as indicated by the standard deviations; despite the high average level, some dyads were on-task for as little as 50% of the game play sessions while other dyads were on-task for 100% of sessions. Dyadic co-regulation also ranged widely, with children co-regulating with their peer for as little as 24% of game play to as high as 100%. For dyads that spent less time on-task and less time in a state of co-regulation, it appeared that disengagement may have been a common cause (as compared with unilateral regulation): dyads were, on average, disengaged 18% of the time while unilaterally-regulated only 10% of the time.

Third, turning to the four discrete cooperation behaviors (frequency counts in the bottom half of Table 3), it was evident that supportive behaviors, peer engagement attempts, and peer explanations were fairly rare, occurring less than once per game play session, on average. Children's attempts to engage or redirect one another were observed especially infrequently, with an average of only .09 instances during game play, indicating that as few as three dyads evidenced this behavior. On the other hand, distracting behaviors occurred somewhat more frequently, with an average of 1.19 distracting behaviors observed per session of game play.

Fourth, there was evidence that the rates and frequencies of the cooperation variables changed across play sessions. Using growth curve models – complete results are displayed in Appendix Table J1 – several statistically significant linear trends were found. First, the amount of time that dyads spent on-task during game play decreased across sessions (b = -.03, p<.01) and, in a similar fashion, the proportion of game play that dyads spent in a state of co-regulation also decreased over time (b = -.05, p<.01). In turn, dyads spent significantly more time unilaterally regulating (b = .01, p = .03) and disengaged from one another (b = .04, p<.01) across sessions. Two discrete behavior variables – supportive behaviors and distracting behaviors – also differed across sessions such that dyads engaged in fewer supportive behaviors (b = -.05, p = .01) and more frequent distracting behaviors (b = .27, p<.01) over time.

Table 4

Duration and frequency of the peer cooperation variables averaged across the full sample and per dyadic disparity group

	Full Sample (*n* = 36 dyads)	Small Disparity (*n* = 12 dyads)	Moderate Disparity (*n* = 13 dyads)	High Disparity (*n* = 11 dyads)
	Proportion of time			
Time on-task	.85 (.13) .50 – 1.0	.82 (.14) .53 – .99	.89 (.11) .50 – 1.0	.85 (.13) .54 – .99
Co-regulation	.72 (.18) .24 – 1.0	.69 (.20) .24 – .94	.76 (.15) .41 – 1.0	.71 (.18) .35 – .93

Unilateral regulation	.10 (.06) 0 – .26	.11 (.08) .02 – .26	.10 (.06) 0 – .19	.08 (.06) .02 – .20
Disengaged	.18 (.15) 0 – .57	.20 (.16) .03 – .57	.15 (.14) 0 – .54	.20 (.15) .04 – .46
		Frequency		
Supportive behaviors	.26 (.31) 0 – 1.7	.33 (.39) 0 – 1.7	.29 (.30) 0 – 1.0	.15 (.16) 0 – .50
Attempts to engage peer	.09 (.19) 0 – .83	.03[a] (.11) 0 – .50	.17[a] (.26) 0 – .83	.07 (.12) 0 – .33
Explanations or modeling	.37 (.40) 0 – 1.33	.44 (.48) 0 – 1.33	.33 (.33) 0 – 1.0	.33 (.29) 0 – .67
Distracting behaviors	1.19 (1.1) 0 – 4.5	1.3 (1.3) 0 – 4.5	1.06 (.88) 0 – 3.0	1.24 (1.13) 0 – 4.0

Note. *Standard deviations are presented in parentheses; variable ranges are presented below*
Note. *Means with the same superscript were significantly different from one another at p<.05*

Variation in peer cooperation by dyadic skill level. Variability in peer cooperation was also examined in one-way ANOVA models according to the characteristics of dyads. The first dyadic characteristic to be examined was variation by initial dyadic skill disparity levels (see Table 4; omnibus ANOVA results displayed in Appendix Table I1). Prior to significance testing, dyads with a moderate math skill disparity level – as compared to a low skill disparity and a high skill disparity – appeared to display higher levels of cooperative behaviors. For example, compared with the other dyads, those in the moderate-disparity group spent the highest proportion of game play sessions on-task (89% vs. 85% and 82%) and in a state of co-regulation (76% versus 69% and 71%), and they appeared to engage one another most frequently (.17 vs. .03 and .07) and distract one another least frequently (1.06 vs. 1.30 and 1.24). The low-disparity group also appeared somewhat higher than the other dyads in two areas: supportive behaviors and peer explanations. However, across the eight peer cooperation variable indicators, only one of these differences was found to significantly differ at the omnibus level in the ANOVA models: dyads' attempts to engage or redirect one another during game play ($F(2,69) = 3.73$, $p = .03$). Specifically, as shown in the post hoc comparisons in Table 5 below, engagement attempts were significantly higher in the moderate-disparity group than in the low-disparity group ($p = .03$).

Table 5

Tukey post-hoc comparisons: peer engagement attempts across skill disparity groups

Condition	Condition	*Mean difference*	*SE*	*p*	*Lower bound*	*Upper bound*
Skill Disparity Group						
Moderate disparity	Low disparity	.14*	.05	.03	.01	.26
High disparity	Low disparity	.04	.05	.77	-.09	.17
High disparity	Moderate disparity	-.10	.05	.16	-.22	.03

Note. $^*p < .05$

Note that all of the ANOVA models examining dyadic skill disparity levels were re-estimated as ANCOVA models, controlling for child pre-test math scores and the proportion of dyads for which both children had pre-test scores above the sample mean (i.e., the proportion of *Matched-high* dyads). These analyses were conducted because skill disparity within dyads was correlated with (1) pre-test math scores and (2) the number of dyads within which both dyad members had pre-test math scores above the sample mean (e.g., the high-disparity group had the highest average pre-test math scores and the moderate-disparity group had the most dyads in which both children had pre-test scores above the mean; see full details in Appendix Table G1).

However, the ANCOVA models did not change the results with regard to statistical significance; the significant result for peer engagement attempts favoring the moderate-disparity group remained after making the adjustment for pre-test math scores within the dyads.

Variations in peer cooperation by gender, study site, and game. Next, variations in peer cooperation were examined across three key demographic and design features by which dyads differed: the dyadic gender structures (i.e., male-male, male-female, and female-female dyads), the study sites (i.e., Boston, Minneapolis, and Chicago), and the game children played (i.e., the *Big Fish Story*, the *Change Game*, and *Magician's Tricks*). Although not directly related to the study hypotheses, these analyses were of interest because these three variables represented potential confounds given the non-experimental research design. Results showed that the amount of time dyads spent in a state of co-regulation ($F(2,67) = 4.53$, $p = .01$) as well as the amount of time dyads spent disengaged during game play ($F(2,67) = 3.37$, $p = .04$) differed across dyadic gender structures (see Appendix Table I2 for full results). Specifically, as shown in Table 6 below, the female-female dyads spent more time co-regulating ($p = .02$) and less time disengaged from one another ($p = .03$) than did the male-male dyads. No significant findings emerged for mixed – i.e., male-female – dyads.

Table 6

Tukey post-hoc comparisons: dyadic gender structure

Condition	Condition	*Mean difference*	*SE*	*p*	*Lower bound*	*Upper bound*
Co-regulation						
Female/female	Male/male	.16*	.06	.02	.03	.30
Male/female	Male/male	.11	.05	.06	-.003	.22
Male/female	Female/female	-.06	.05	.53	-.19	.07

Disengaged						
Female/female	Male/male	-.13*	.05	.03	-.24	-.01
Male/female	Male/male	-.06	.04	.30	-.15	.04
Male/female	Female/female	.07	.05	.29	-.04	.18

Note. **p< .05*

Differences in peer cooperation were also detected across study sites (see Appendix Table I3 for complete results), including for the amount of time dyads spent on-task ($F(2,69) = 5.42$, $p = .01$), the number of distracting behaviors observed ($F(2,69) = 4.73$, $p = .01$), and the number of dyads' peer explanations ($F(2,69) = 6.45$, $p = .01$). Specifically, as shown in Table 7, children at the Minnesota site spent significantly less time on-task than did the Boston dyads ($p = .02$) while the Boston dyads spent significantly less time on-task than did the children at the Chicago site ($p = .01$). The Chicago dyads also engaged in significantly fewer distracting behaviors ($p = .01$) and significantly more peer explanations ($p = .002$) than did the Boston dyads.

In addition, variations in peer cooperation were found across the three early math learning games (see Appendix Table I4, for complete results). As shown in Table 8, dyads' attempts to engage or re-direct one another during game play occurred more frequently during *Magician's Tricks* than during the *Big Fish Story* ($F(2,69) = 3.54$, $p = .03$), and more frequent peer explanations occurred during *Magician's Tricks* than during the *Big Fish Story* or the *Change Game* ($F(2,69) = 5.70$, $p = .01$).

Table 7

Tukey post-hoc comparisons: intervention site

Condition	Condition	*Mean difference*	*SE*	*p*	*Lower bound*	*Upper bound*

On-task						
Minnesota	Boston	-.11*	.04	.02	-.21	-.02
Chicago	Boston	.03	.03	.64	-.05	.11
Chicago	Minnesota	.14**	.05	.006	.03	.25
Distracting behaviors						
Minnesota	Boston	.58	.34	.22	-.25	1.40
Chicago	Boston	-.61	.30	.11	-1.31	.10
Chicago	Minnesota	-1.18*	.39	.01	-2.12	-.25
Peer explanations						
Minnesota	Boston	.19	.11	.22	-.08	.46
Chicago	Boston	.34**	.10	.002	.11	.57
Chicago	Minnesota	.15	.13	.48	-.16	.46

Note. **p<.05 **p< .01*

Table 8

Tukey post-hoc comparisons: game

Condition	Condition	*Mean difference*	*SE*	*p*	*Lower bound*	*Upper bound*
Peer engagement						
Change Game	Big Fish Story	-.07	.06	.40	-.21	.06
Magician's Tricks	Big Fish Story	.14*	.05	.03	-.26	-.01
Magician's Tricks	Change Game	-.07	.05	.40	-.19	.06
Peer explanations						
Change Game	Big Fish Story	-.02	.11	.97	-.28	.23
Magician's Tricks	Big Fish Story	.27	.10	.03	.03	.51
Magician's Tricks	Change Game	.29	.10	.01	.06	.52

Note. **p<.05*

Peer cooperation intercorrelations. As a final step in addressing the first research question, zero-order correlations were estimated among the eight peer cooperation variables

(Table 9 below). Given the interdependence of the co-regulation code with both unilateral regulation and disengagement, the latter two were strongly negatively correlated with the former. In addition, co-regulation was moderately to strongly associated with dyads engaging in more frequent peer explanations, $r = .48$ and engaging in fewer distracting behaviors, $r = -.66$. On the other hand, more time spent disengaged from one another was significantly associated with dyads engaging in more frequent distracting behaviors, $r = .54$, and fewer peer explanations, $r = -.46$. Although the amount of time dyads spent on-task during game play was not entirely interdependent with co-regulation, unilateral regulation, or disengagement, the intercorrelations between time on-task and the seven other peer cooperation variables parallel the results discussed above. In other words, more time spent on-task was significantly associated with dyads co-regulating more, $r = .80$ and spending less time both unilaterally regulating, $r = -.48$ and disengaged, $r = -.76$. Time on-task was also strongly associated with dyads engaging in more frequent peer explanations, $r = .37$ and engaging in fewer distracting behaviors, $r = -.66$.

Table 9

Peer Cooperation Intercorrelations

	On-task	Co-reg	Uni-reg	Disengaged	Supportive behaviors	Engagement attempts	Peer explanations
On-task	--						
Co-reg	.80**	--					
Uni-reg	-.48**	-.61**	--				
Disengaged	-.76**	-.93**	.30*	--			
Supportive behaviors	.14	.09	.06	-.12	--		

Engagement attempts	.14	-.14	.17	.10	.18	--	
Peer explanations	.37**	.48**	-.28*	-.46**	.23	-.14	--
Distracting behaviors	-.66**	-.66**	.61**	.54**	-.09	.09	-.29*

Note. **p<.05 **p< .01*

Research Question 2. Are (1) the collaborative qualities and regulatory states of dyadic interactions (i.e., the time dyads spent co-regulating, unilaterally-regulating, and disengaged), or (2) the discrete cooperative behaviors that contribute to peer cooperation (i.e., supportive behaviors, peer engagement attempts, peer explanations, and distracting behaviors) during early math activities associated with children's post-test counting skills, controlling for pre-test math skills?

Prior to addressing the second research question, correlations between children's pre-test math scores – the primary covariate included in the multi-level regression models reported below – and the peer cooperation variables were examined. As shown in Table 10, no significant associations between pre-test math scores and the peer cooperation variables were found.

Table 10

Correlations between children's pre-test math scores and the peer cooperation variables

	Co-reg	Uni-reg	Disengaged	Supportive behaviors	Engagement attempts	Peer explanations	Distracting behaviors
REMA Brief math scores	.29	-.09	-.28	-.02	.12	.10	-.15

Next, correlations were estimated for associations between the peer cooperation variables and children's post-test counting skills (i.e., scores on the *REMA Counting LT*; Table 11). Four significant associations were found. First, more time spent in a state of dyadic co-regulation during game play was strongly and significantly associated with *higher* post-test scores ($r = .45$, $p < .01$) whereas more time spent disengaged from one another during game play was significantly associated with *lower* post-test scores ($r = -.40$, $p < .05$). Two discrete behavior variables also demonstrated significant associations with post-test counting skills: supportive behaviors and distracting behaviors. Specifically, more frequent supportive behaviors during game play was significantly associated with *higher* post-test scores ($r = .40$, $p < .05$) and more frequent distracting behaviors was strongly and significantly associated with *lower* post-test scores ($r = -.46$, $p < .01$).

Table 11

Correlations between the peer cooperation variables and children's post-study counting skills

	Co-reg	Uni-Reg	Disengaged	Supportive behaviors	Engagement attempts	Peer explanations	Distracting behaviors
REMA Counting LT scores	.45**	-.22	-.40*	.40*	.07	.01	-.46**

Note. *$p< .05$ **$p< .01$

To follow-up on these correlations, multi-level regression models were estimated, controlling for children's pre-test math scores. Given the small sample size of this study, these models were built to be as parsimonious as possible. In addition to pre-test scores, four potential covariates were examined as predictors of post-test counting scores: intervention site (two dummy variables), game (two dummy variables), child gender, and whether the dyad had been prompted by the researcher to *Think-Pair-Share* prior to engaging in a cooperative behavior.

However, only child gender demonstrated a significant relation with any of the peer cooperation variables in these models. Thus, for the models in which gender was a significant predictor of post-test counting skills (at $p = .05$ or smaller), both pre-test math scores and child gender were included in the models as covariates. However, for the models in which gender was *not* a significant predictor of post-test counting scores, only pre-test math scores were included as a covariate.

As shown in Table 12 below, the results of these models demonstrated a significant relation for only one cooperation variable: peer supportive behaviors. Specifically, engaging in more peer supportive behaviors during game play significantly predicted higher post-test counting scores ($b = 1.07$, $p = .03$), controlling for pre-test scores. However, this relation was not robust; when adjusting the model to control for both pre-test math scores and child gender, peer supportive behaviors no longer significantly predicted post-test counting skills ($b = .67$, $p = .17$).

Table 12

Multi-level regression analysis examining the relation between the peer cooperation variables and children's post-test counting skills

REMA post-test counting scores	β	*SE*	*z*	*p*	*Lower bound*	*Upper bound*
REMA pre-test math scores	.09	.01	8.20	.00	.07	.11
Gender	.87	.36	2.44	.02	.17	1.57
Co-regulation[a]	1.63	.99	1.63	.10	-.32	3.58
Unilateral regulation[a]	-3.55	3.14	-1.13	.26	-9.71	2.61
Disengaged	-1.33	1.27	-1.04	.30	-3.82	1.17
Supportive behaviors[a]	1.07	.50	2.15	.03[*]	.10	2.05

Peer engagement	-.002	.90	-.00	.99	-1.76	1.76
Explanations	-.08	.50	-.17	.87	-1.06	.90
Distracting behaviors	-.12	.14	-.88	.38	-.40	.15

Note. *Rows with superscript indicate models that controlled for pre-test math skills only*

Note that multi-level regression modeling was also used to test whether dyadic skill disparity levels predicted children's post-test counting scores, controlling for pre-test math scores (see Appendix Table G1 for mean *REMA Counting LT* scores across the three dyadic disparity groups). These results were null. Thus, because (1) no robust associations between the peer cooperation variables and children's post-test counting scores were found, and (2) no significant differences in post-test counting scores were found for dyadic skill disparities, a mediation model (peer cooperation as a mediating factor for the relation between dyadic skill disparities and children's post-test counting skills) was not examined.

CHAPTER 5: DISCUSSION

Cooperative learning opportunities throughout early childhood support children's development of both academic and social skills (e.g., Nesbitt, Farran, & Fuhs, 2015; Göckeritz, Schmidt, & Tomasello, 2014; National Association for the Education of Young Children, 2009; Cohen, 1994; Watson et al., 1988). Yet despite the importance of peer learning at this early stage and in early childhood classrooms, the literature on this topic is limited, with some scholars doubting the capability of very young children to successfully engage in such learning interactions (Brownell, Ramani, & Zerwas, 2006; Howes & Tonyan, 1999). This dissertation has aimed to address gaps in the literature by analyzing cooperative learning interactions between preschool peers. Specifically, this study investigated the frequency and quality of young children's peer cooperation during dyadic early math-focused activities and the relations between peer cooperation and math learning outcomes.

This dissertation's focus on early math is underscored by myriad evidence that the early childhood years provide a critical opportunity to leverage children's natural curiosities and motivations to learn from math-rich interactions (Ramani & Siegler, 2015; Ginsburg et al., 2006; Gelman, 1980). Given that children's math skills at kindergarten entry have been shown to predict math achievement through high school (Watts, Duncan, Siegler, & Davis-Kean, 2014), the preschool years – and preschool learning environments – are essential conduits through which young children's burgeoning math skills can be targeted (Reardon, 2013). And in fact, this process may be especially important for children from low-income backgrounds, as research identifies differences in socio-economic status as a significant factor driving achievement gaps in mathematics in the U.S. (Garcia & Weiss, 2015). To the author's knowledge, this is the first study to examine cooperative learning processes – specifically during math learning activities – in a preschool sample.

In the current study, 36 dyads (72 children) in three metropolitan areas played early math learning games twice per week over the course of three weeks. Children's general math skills were assessed prior to the first session of game play and their counting skills were assessed at study completion. In addition, game play sessions one, three, and five were qualitatively coded for cooperative behaviors. With these data, two primary research questions were addressed.

Evidence of peer cooperation in early childhood. Descriptive statistics illustrated the extent to which the present sample of preschoolers displayed peer cooperative behaviors during the dyadic activities. These young children did, in fact, demonstrate all of the cooperative behaviors of interest, indicating that even very young children are capable of cooperative math learning interactions. In fact, the proportions of time that this sample spent on-task (ranging from 81% to 91% of game play sessions) and in a state of co-regulation (ranging from 63% to 84% of game play sessions) are comparable to the rates of these behaviors observed in five- to seven-year-old children (72-78% of time spent on-task and 61-66% of time spent in a state of co-regulation; Kutnick, Ota, & Berdondini, 2008). This is an important finding given that, although the extant literature recognizes the importance of peer cooperation in the classrooms of older children (e.g., Rohrbeck, Ginsburg, Marika, Fantuzzo, & Miller, 2003; Kutnick, Ota, & Berdondini, 2008), direct parallels between older children's cooperative learning interactions and those of preschool-aged children have yet to be drawn (Brownell, Ramani, & Zerwas, 2006; Howes & Tonyan, 1999; Azmitia, 1996).

Despite spending a relatively high proportion of time both on-task and co-regulating, however, relatively few supportive behaviors, peer engagement attempts, and peer explanations were observed, and distracting behaviors were relatively frequent. This suggests that, although the majority of these preschool dyads were capable of engaging in the cooperative learning context and able to maintain a co-regulatory state (as evidenced by relatively high proportions of time spent on-task and co-regulating, respectively), few dyads spontaneously engaged in the discrete behaviors that promoted the overall quality of cooperation. These differing patterns of peer cooperation – between dyads remaining generally on-task and co-regulating yet rarely demonstrating promotive peer cooperation behaviors – may reflect the need for young children to be explicitly trained in the latter.

In fact, the literature recognizes a nature versus nurture distinction when examining the development of early cooperation skills. On one hand, Chung & Walsh (2006) and Azmitia (1996) argue that it is essential to explicitly teach peer cooperation skills to young children and to provide ongoing opportunities for children to practice these skills once introduced. These authors argue that, without instruction and practice, young children tend to interpret cooperative activities as being independent tasks. On the other hand, some scholars believe that cooperative skills naturally emerge (alongside social skills) at around age three, and increase in complexity throughout the preschool years (e.g., Ashley & Tomasello, 1998; Brownell, Ramani, & Zerwas, 2006). The findings of the present study perhaps indicate a nexus between these differing scholarly perspectives.

In other words, the developmental stage of the present young sample's social skills, as well as their co-existence with one another within their classrooms, may have provided sufficient training to develop a basic peer cooperation skill set before the study began. Given the likelihood that remaining on-task and co-regulating with peers were expectations made of these children in their classrooms (e.g., during center time activities), their baseline cooperative skill levels may have been adequate for remaining on-task and co-regulating for the majority of this study's game play sessions. Yet these pre-existing cooperative skills may have been *insufficient* for the children to successfully engage in the discrete peer cooperation behaviors of interest. Indeed, explicit instruction around peer cooperation may be necessary for very young children to understand the concepts of – and recognize appropriate opportunities for – (1) being a supportive learning partner, (2) helping a peer to re-engage with a joint learning task, and (3) providing a peer with an explanation.

It is also possible that the low observed frequencies of peer supportive behaviors, peer engagement attempts, and peer explanations can be explained, in part, by the developmental trajectories of young children's helping and language skills. For instance, research has suggested that the ability to recognize someone else's need for help emerges between two and three years of age, but it is not until the age of five that children are able to translate this recognition into effective action steps (Paulus & Moore, 2011). The children in the present study thus may have recognized the occurrences of their peers needing support or re-direction during game play but were unable, in the moment, to address their needs. In addition, because one's ability to communicate goals and intentions is thought to underlie cooperation (Warneken, Chen, & Tomasello, 2006), variations in the children's language skills may have affected their use of explanations. In fact, some researchers argue that the assumption that preschoolers are incapable of cooperative learning often results from a misinterpretation of young children's difficulty with language (e.g., limited verbal negotiation skills and difficulty articulating ideas and opinions; see Azmitia, 1996; Tomasello, Kruger, & Ratner, 1993). It is thus possible that some child behaviors in the present study that were coded as being distracting (e.g., grabbing game chips out of a peer's hand after the peer placed an incorrect number of chips on the game board) are the result of the child's inability to verbalize the needed corrective steps. Explicit introduction to, and practice with, the *language* of peer cooperation (e.g., "what do you think?"; "do you need help?") may be a necessary prerequisite step for high quality peer learning interactions in preschool classrooms.

Finally, it is important to consider what influence the researcher's presence may have had on the peer cooperation observed. On one hand, the adult presence may have decreased the cooperative demands felt by the children; should a situation arise in which one child or both children in the dyad needed help, the researcher was ultimately available to intervene. Perhaps, then, more peer cooperation – and especially more peer explanations and supportive behaviors – would have arisen if the children were truly reliant on one another. On the other hand, however, the adult presence may have artificially inflated cooperation; the preschoolers may have reverted to their known cooperative "script" (Nelson, 1981), i.e., the basic cooperative orientation that young children have come to understand is expected of them at school, with the adult nearby. In fact, Lee (1993) found that, when observing interactions between fifth and sixth grade students during a cooperative computer task, spontaneous cooperative behaviors were relatively infrequent. It was not until the researcher provided explicit prompts for the students to cooperate that their peer cooperative behaviors increased. Although an independent work space observed from afar would have been inappropriate for the very young children in this study, incorporating this study's games into classroom center time activity rotations (i.e., where small groups of children regularly work together with and without the direct presence of an adult) may provide an avenue for a more distant, but perhaps authentic, view of preschoolers' cooperative tendencies.

Variations in peer cooperation. This study also explored the role of math skill disparities between learning peers in relation to their cooperative interactions. The mechanisms through which skill disparities between peers affect their cooperative processes – or learning – are not well understood in the literature. If, as early learning theories (e.g., Vygotsky, 1978) suggest, learning opportunities between peers of different skill levels allow for the adoption of the roles of "teacher" and "student," the degree of the skill level disparity may affect this dynamic. For instance, as proposed by Chung & Walsh (2006), a moderate skill level disparity between learning peers may engender an ideal level of challenge for both children; the "teacher's" skill level is sufficient for scaffolding the learning of their less-advanced partner while the "student's" skill level is such that they are able to benefit from their "teacher's" support. If the disparity between learning peers is too wide, however, the "teacher" may lack the pedagogical skill to provide the needed scaffolding to their partner while the "student" may lack the competency needed to make the "teacher's" instruction meaningful. And, if the skill level disparity between peers is too small, there may be little for the peers to teach, or learn, from one another.

Using correlational estimates, peers with a moderate within-dyad skill disparity level initially appeared to demonstrate cooperative advantages, as was hypothesized: more time spent on-task and co-regulating as well as more frequent attempts to engage or re-direct one another during game play. Dyads with a low within-dyad skill disparity level, on the other hand, were initially found to engage in more frequent peer supportive behaviors and more peer explanations than did the moderate- and high-disparity dyads. Although re-examining these associations using ANOVA modeling found primarily null results, one significant finding remained, specifically for the moderate-disparity dyads: more frequent attempts to engage or re-direct one another during game play than was observed in low-disparity dyads. Although hardly robust, this finding fits within the scope of the theoretical and empirical arguments in the literature (e.g., Chung & Walsh, 2006; Brownell, 1990) that favor a moderate skill level disparity between learning peers.

Variation according to dyadic gender structure was also found in this study, with female-female dyads spending significantly more time co-regulating and significantly less time disengaged than male-male dyads. Although the processes through which girls seem to cooperate with one another in unique ways are unclear, it has been suggested that girls, even at the preschool level, and regardless of the gender of their peer, more often gravitate towards sharing materials and offering compromises (Holmes-Lonergan, 2003). Indeed, a study by Lee (1993) found that female-only dyads were more willing to both ask for and provide help and also more frequently offered suggestions and compromises. Boys, on the other hand, tend to gravitate toward controlling behaviors, such as maintaining possession of shared materials and making direct commands (Holmes-Lonergan, 2003). Given these findings, it is perhaps the case that the female-female dyads in the present study capitalized on the natural cooperative tendencies of girls during game play. In other words, when two female children are paired, and both engage in gender-typical patterns of cooperation (i.e., sharing and compromise), the activity at hand is less likely to be derailed as more time is spent in a coregulatory state.

Finally, a clear pattern of behavioral decline was evident across game play sessions, indicating that the dyads became increasingly uncooperative over time. This pattern emerged across all three games and study sites, leading to the question of whether the games themselves – rather than the game players or game play environments – contributed to the children's disengagement. Of course, these young children may have become disinterested in any learning activity that was repeatedly implemented over a relatively short period of time. On the other hand, however, there is literature to suggest that the rule-based structure of these math games may have negatively affected engagement. Ramani (2012), for example, found that when preschoolers repeatedly engaged in a building task that was either rule-based or play-based, over time, the play-based children built better structures and interacted with one another more than did the rule-based children. In the rule-based condition, the researchers assigned the task's goal (the structure to be built) as well as the building rules (how materials could be used). In the play-based condition, however, the children were given autonomy as to the structure built and the rules therein. The math learning games in the present study were indeed rule-based, as each had a predetermined goal and usage rules for the materials therein. Future research should examine whether within-game opportunities for player autonomy could mitigate the cooperative decline observed in the present study. Although inserting high levels of child autonomy into the current game structures would likely require a design overhaul, small autonomy-supportive changes (e.g., allowing players to select the game boards and number cubes to be used) could be accomplished.

A further design consideration turns to the cooperative nuances across the structures of the three early math games. In contrast to the *Big Fish Story*, the *Change Game* and *Magician's Tricks* both assigned children interdependent game playing roles (e.g., in the *Change Game*, the "roller' and the "checker") that explicitly required cooperation in order for game play to proceed. The *Big Fish Story*, however, could be played independently – alone or without substantial dyadic discourse or interaction – making the game inherently *less* cooperative than its counterparts. Although this design feature may have led to significantly fewer peer engagement attempts and peer explanations during *Big Fish Story* game play (see Table 8), these results also suggest that very young children are indeed sensitive to built-in cooperative elements (or lack thereof) within games. Early childhood learning games that incorporate interdependent playing roles may thus be an effective medium for preschoolers to practice their burgeoning cooperative skills.

Peer cooperation as predicting math learning. The second research question of this study investigated whether any of the seven peer cooperation *quality* variables (i.e., co-regulation, unilateral regulation, disengagement, supportive behaviors, peer engagement attempts, peer explanations, or distracting behaviors) predicted children's post-test counting scores. Evidence that dyadic cooperation was significantly related to post-test scores was found using zero-order correlational estimates, however, when re-examining these relations using multi-level regression models, only peer supportive behaviors was significantly associated with post-test scores. Although this result does provide some evidence that more peer supportive behaviors during math learning games is predictive of higher math learning, it should be interpreted with caution as the statistical significance was not robust to controlling for child gender. Given the largely null findings of these multi-level regression analyses, alongside the finding that within-dyad skill disparity level was not a significant predictor of post-test counting scores, the proposed mediation model (cooperation as mediating the relation between skill disparities and post-test counting skills) was not statistically examined.

It was surprising to find that the relations between peer cooperation and children's post-test counting scores were largely null, especially given the research on older children that suggests peer cooperation is predictive of greater gains in spatial reasoning for fourth-graders (Phelps & Damon, 1989) and better numerical and geometric skills for fifth- and sixth-graders (Mulryan, 1995). Taken together, the findings discussed above thus raise an important theoretical question. Note that peer explanations – the discrete cooperative behavior perhaps most associated with the conception of being a "teacher" and "student" – were rare overall, and not significantly associated with dyadic skill disparities nor post-test counting skills. Is it possible, then, that the "teacher" and "student" dynamic can still be present without the use of peer explanations or modeling? Turning again to literature on early language development may provide some insight. As discussed previously, one rationale for the lack of peer explanations observed in the present study focuses on the limited verbal skills of preschool-aged children. And, in terms of peer cooperative discourse, researchers have suggested that there may be an empirical confound between early language and the "teacher-student" cooperative dynamic (e.g., Azmitia, 1996; Tomasello, Kruger, & Ratner, 1993). In other words, in order to both benefit from cooperative learning interactions, the "teacher" must communicate in such a way that is interpretable by the "student" and the "student" must clearly communicate their needs for support. If it is indeed the case that young children need explicit training to use – and receive – peer cooperative language, the lack of language training in this study may have stifled the "teacher-student" dynamic. Future empirical work on young children's cooperative learning interactions should incorporate a "cooperative language training" into curricular or study designs and specifically measure the impacts of such trainings on children's interactions.

Limitations and future directions. Several limitations of the current study should be noted. First, given that this study was derived from a larger research project (that aimed to pilot several early math learning games), this study's design was not experimental. As such, environmental variations, including the math games played and the study site thereof, likely influenced children's cooperative interactions. The non-experimental design also did not allow for children's within-dyad skill disparity levels to be randomly assigned across the games nor across the study sites, leading to an unbalanced distribution of skill disparity groups. Further, in regards to this study's analytic process, the small sample size (72 children, 36 dyads) may have lacked the statistical power needed to achieve robust significant findings via multi-level modeling. Indeed, because the significant relations that did emerge between the peer cooperation variables and post-test counting scores became insignificant once controlling for pre-test math scores, bias – due to low statistical power – may have been introduced.

It is also possible that a theoretical direction of impact (between peer cooperation and math learning outcomes) other than that pursued in the current study should be considered. Because it is possible that the children who demonstrated high pre-test math skills at the start of the study could also have possessed strong pre-study peer cooperation skills, “dual-skilled” children (in both math and cooperation) may have driven the associations between pre-test math skills and post-test counting scores as well as between peer cooperation and post-test counting scores. Although to this author’s knowledge no validated screening measure of children’s peer cooperation skills currently exists, developing a mechanism through which cooperative skills can be assessed would allow for patterns of impact between peer cooperation and learning outcomes to be examined.

Conclusion. Given the importance of cooperative learning opportunities in early childhood (e.g., Nesbitt, Farran, & Fuhs, 2015; Göckeritz, Schmidt, & Tomasello, 2014; National Association for the Education of Young Children, 2009; Cohen, 1994; Watson et al., 1988), as well as the implications of early math skills for later academic outcomes (e.g., Watts, Duncan, Siegler, & Davis-Kean, 2014; Ramani & Siegler, 2015; Ginsburg et al., 2006), improving young children’s cooperative interactions during early math learning activities could have lasting academic impacts. It is thus critical that educators of young children know how to help young peers maximize their cooperative math learning opportunities. The first step in this journey is to understand the nature of cooperation during early childhood as well as the variations and challenges therein. Although the findings of the current study were mixed, the results provide preliminary evidence that cooperative math learning interactions do indeed occur between very young children and indications that cooperative interactions may bolster math learning were found. To the author's knowledge, this is the first study to examine peer cooperation – specifically during math learning activities – in a preschool-aged sample.

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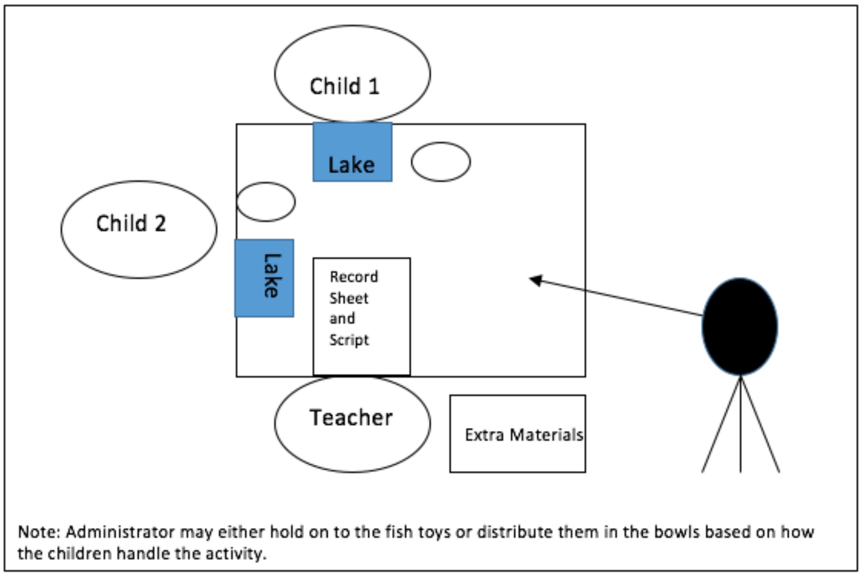
APPENDICES

Appendix A: The Big Fish Story game

A1. Game play set-up



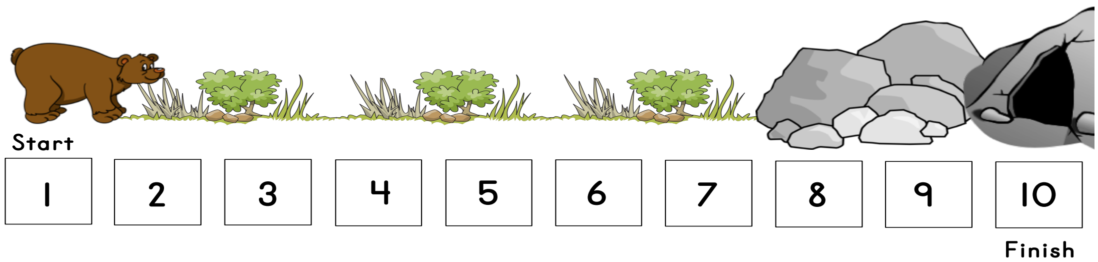
A2. Ocean mat

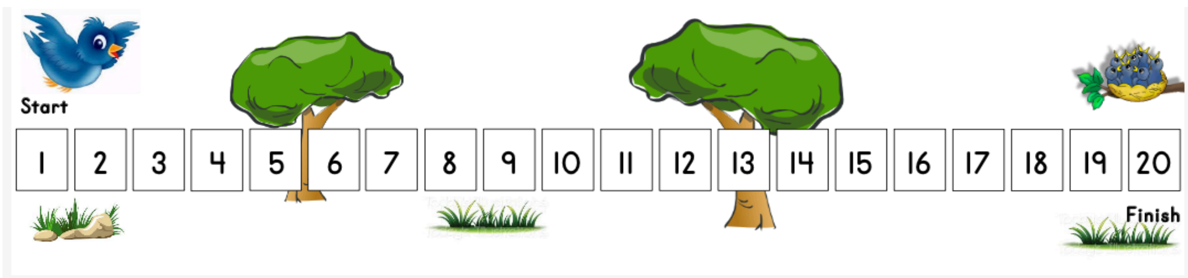
A3. Shark picture

A4. Fish piece

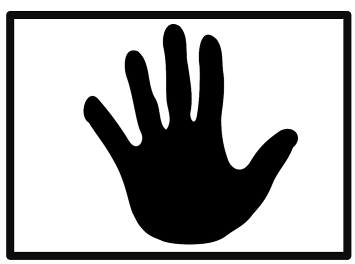
Appendix B: The *Change Game*

B1. Game boards





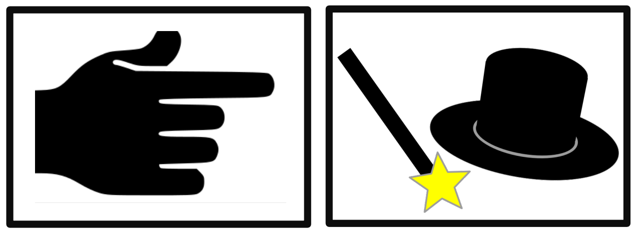
B2. "Roller" card and "checker" card, respectively



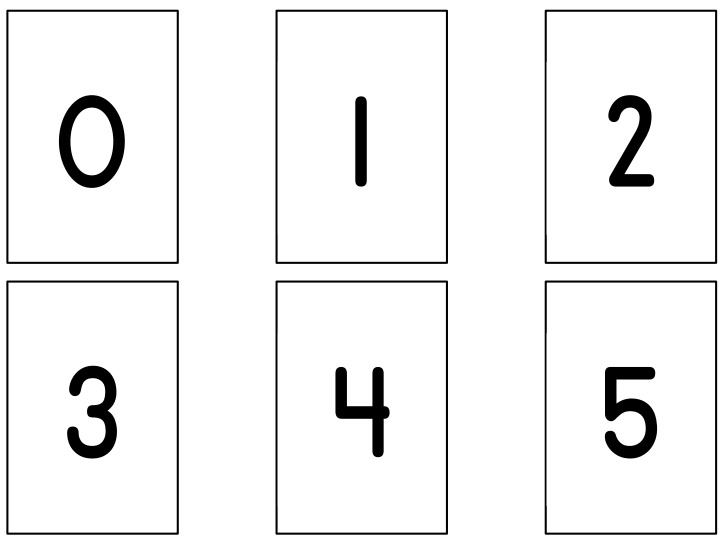
B3. Number cubes

Appendix C: The *Magician's Tricks* game

C1. "Pointer" card and "magician" card, respectively



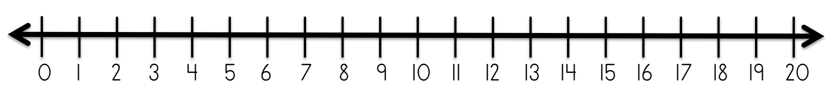
C2. Numeral card deck



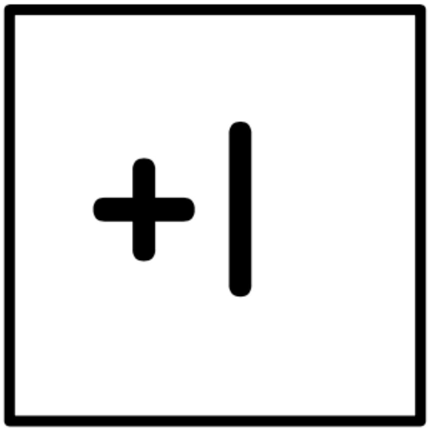
Appendix D: Learning supportive materials

D1. Think, Pair, Share illustration

D2. Number line



D3. Plus/minus card deck



Appendix E: Peer Cooperation Variables

E1. Peer cooperation variables

Variable	Variable description	Example
REMA Brief score	child's REMA Brief (pre-test) score	mean score: 52 range: 29 – 98
Counting LT score	child's REMA Counting LT (post-test) score	mean score: 4.09 range: 0 – 7.29
REMA difference score group	Group 1= dyad has a REMA difference score of 0 - 4 Group 2= dyad has a REMA difference score of 5 - 8 Group 3= dyad has a REMA difference score of 9+	In Dyad A: child 1's REMA Brief score: 52 child 2's REMA Brief score: 61 dyad's REMA difference score: 9 dyads' REMA difference score group: 3
Dyad on-task	Within the game play session, time the dyad collectively spent on-task (proportion of 60s)	both children's behavior furthers the activity; e.g., during the Change Game, child 1 rolls the number cube and counts the dots while child 2 watches
Co-regulation	Within the game play session, time the dyad spent co-regulating (proportion of 60s)	during the Big Fish Story, each child retrieves three plastic fish pieces from the bowl and watches one another add the fish pieces to their "oceans"

Unilateral regulation	Within the game play session, time the dyad spent unilaterally-regulating (proportion of 60s)	when prompted to TPS, Child 1 turns to Child 2 and shares idea while Child 2 ignores Child 1 and shares idea with researcher only
Disengaged	Within the game play session, time the dyad spent disengaged (proportion of 60s)	during the Big Fish Story, Child 1 sits under the table refusing to play while Child 2 makes silly movements with the plastic fish pieces
Supportive behaviors	number of times the child encouraged or assisted their partner during the game play session	when peer correctly identifies the selected numeral in Magician's Tricks, the "pointer" child cheers for their partner
Engagement attempts	number of times the child attempted to engage or redirect their peer during the game play session	child says to distracted peer "*Come on, it's your turn!*"
Peer explanation or modeling	number of peer explanations the child provided during the game play session	when peer incorrectly counts the number of fish remaining on their ocean mat during the Big Fish Story, child says, *"No, you were supposed to count all five"* and models counting the five fish
Distracting behaviors	number of times the child engaged in distracting behaviors during the game play session	child throws the "magician" card into the air during Magician's Tricks
Think, Pair, Share (TPS) prompts	Within the game play session, the number of Think-Pair-Share prompts given to the dyad by the researcher	during the Change Game, while Child 1 is on game board space 7/10, the children are prompted to Think-Pair-Share to determine what number needs to be rolled on the number cube to advance to the tenth space

Appendix F: Child Demographics

F1. Child demographics

	Characteristics of the full study sample (*n = 72*)
Child gender	56% male
Child race	2% Am-Indian/AK native 36% white 16% Asian 26% Black 10% Other (e.g., mixed-race)
Hispanic	17%
Age	4.66 years *Range 3.42 years - 5.70 years*
Dyad gender	34% male/male 20% female/female 46% male/female

Appendix G: Children's Initial Math Skill Levels

G1. Children's Math Skill Levels (overall and by skill level disparity groupings)

	Initial Math Skill Levels			
	All Dyads	Low-disparity Dyads (*n=12 dyads*)	Moderate-disparity Dyads (*n=13 dyads*)	High-disparity Dyads (*n=11 dyads*)
REMA Brief pre-test math scores	μ= 52.82 *Range: 29 – 98* *SD: 9.83*	μ= 50.25 *Range: 43 – 58* *SD: 3.62*	μ= 52.23 *Range: 35 – 69* *SD: 8.67*	μ= 56.32 *Range: 29 – 98* *SD: 14.21*
Dyads with Both Members' REMA Brief Scores Above the Sample Average (i.e., *Matched-high*)		n = 4 μ score = 54.13 *SD: 1.81*	n = 5 μ score = 59.9 *SD: 5.59*	n = 3 μ score = 67.33 *SD: 16.57*
Dyads with Both Members' REMA Brief Scores Below the Sample Average (i.e., *Matched-low*)		n = 8 μ score = 48.21 *SD: 2.55*	n = 3 μ score = 41.67 *SD: 5.13*	n = 2 μ score = 39.0 *SD: 11.67*
Average and Range of Dyadic Disparity on REMA Brief	μ dyad difference score = 8	μ dyad difference score = 2 Range: 0 - 4	μ dyad difference score = 7 Range: 5 - 8	μ dyad difference score = 15 Range: 9 - 29
REMA Counting LT post-test scores	μ = 4.09 *Range: 0-7.29* *SD: 1.65*	μ = 3.82 *Range: 0-6.56* *SD: 1.53*	μ = 3.88 *Range: 0-6.26* *SD: 1.91*	μ = 4.63 *Range: 2.28-7.29* *SD: 1.40*

Appendix H: Archetype Activities

H1. Distribution of participation

	All Dyads	Low-disparity Dyads (*n=12 dyads*)	Moderate-disparity Dyads (*n=13 dyads)*	High-disparity Dyads (*n=11 dyads*)
Site 1 *Boston*	58% of dyads	33%	85%	55%
Site 2 *Minnesota*	17% of dyads	50%	0%	0%
Site 3 *Chicago*	25% of dyads	17%	15%	45%
The *Big Fish Story*	28% of dyads	25%	38%	19%
The *Change Game*	31% of dyads	8%	46%	36%
Magician's Tricks	41% of dyads	67%	16%	45%

Appendix I: Full ANOVA results

I1. Full ANOVA results: Peer cooperative variables across dyadic disparity groups

Source		*df*	*SS*	*MS*	*F*	*p*
Time on-task	Between groups	2	.063	.031	2.01	.142
	Within groups	69	1.086	.015		
	Total	71	1.149	.016		
Co-regulation	Between groups	2	.059	.030	.92	.405
	Within groups	69	2.227	.032		
	Total	71	2.286	.032		
Unilateral regulation	Between groups	2	.005	.003	.64	.531
	Within groups	69	.290	.004		
	Total	71	.296	.004		
Disengaged	Between groups	2	.051	.026	1.14	.326
	Within groups	69	1.546	.022		
	Total	71	1.598	.026		
Supportive behaviors	Between groups	2	.427	.213	2.34	.104
	Within groups	69	6.294	.091		
	Total	71	6.721	.095		
Peer engagement	Between groups	2	.245	.122	3.73	.029*
	Within groups	69	2.260	.033		
	Total	71	2.504	.035		
Explanations	Between groups	2	.198	.099	.72	.491
	Within groups	69	9.481	.137		
	Total	71	9.680	.136		
Distractions	Between groups	2	.807	.404	.33	.723
	Within groups	69	85.373	1.24		
	Total	71	86.181	1.21		

I2. Full ANOVA results: Peer cooperative variables across dyadic gender structures

Source		*df*	*SS*	*MS*	*F*	*p*
Time on-task	Between groups	2	.061	.030	1.92	.154
	Within groups	69	1.089	.016		
	Total	71	1.149	.016		
Co-regulation	Between groups	2	.277	.139	4.76	.012*
	Within groups	69	2.009	.029		
	Total	71	2.286	.032		
Unilateral regulation	Between groups	2	.025	.012	3.12	.050*
	Within groups	69	.271	.004		
	Total	71	.296	.004		
Disengaged	Between groups	2	.146	.073	3.47	.037*
	Within groups	69	1.452	.021		
	Total	71	1.598	.023		
Supportive behaviors	Between groups	2	.333	.167	1.80	.172
	Within groups	69	6.389	.092		
	Total	71	6.721	.095		
Peer engagement	Between groups	2	.023	.012	.32	.724
	Within groups	69	2.481	.036		
	Total	71	2.504	.035		
Explanations	Between groups	2	.446	.223	1.67	.197
	Within groups	69	9.233	.134		
	Total	71	9.679	.136		
Distractions	Between groups	2	6.163	3.082	2.66	.077
	Within groups	69	80.017	1.160		
	Total	71	86.180	1.214		

I3. Full ANOVA results: Peer cooperative variables across study site

Source		*df*	*SS*	*MS*	*F*	*p*
Time on-task	Between groups	2	.156	.078	5.42	.007**
	Within groups	69	.993	.014		
	Total	71	1.150	.016		
Co-regulation	Between groups	2	.175	.088	2.86	.064
	Within groups	69	2.111	.031		
	Total	71	2.287	.032		
Unilateral regulation	Between groups	2	.050	.025	6.94	.002**
	Within groups	69	.247	.004		
	Total	71	.296	.004		
Disengaged	Between groups	2	.054	.027	1.20	.309
	Within groups	69	1.544	.022		
	Total	71	1.598	.023		
Supportive behaviors	Between groups	2	.313	.157	1.69	.193
	Within groups	69	6.408	.093		
	Total	71	6.721	.095		
Peer engagement	Between groups	2	.188	.094	2.79	.068
	Within groups	69	2.317	.034		
	Total	71	2.504	.035		
Explanations	Between groups	2	1.523	.762	6.45	.003**
	Within groups	69	8.156	.118		
	Total	71	9.680	.136		
Distractions	Between groups	2	10.385	5.192	4.73	.012*
	Within groups	69	75.795	1.098		
	Total	71	86.181	1.213		

I4. Full ANOVA results: Peer cooperative variables across games

Source		*df*	*SS*	*MS*	*F*	*p*
Time on-task	Between groups	2	.030	.015	.92	.404
	Within groups	69	1.120	.016		
	Total	71	1.149	.016		
Co-regulation	Between groups	2	.022	.011	.32	.724
	Within groups	69	2.265	.033		
	Total	71	2.286	.032		
Unilateral regulation	Between groups	2	.001	.0007	.16	.849
	Within groups	69	.294	.004		
	Total	71	.296	.004		
Disengaged	Between groups	2	.030	.015	.66	.522
	Within groups	69	1.568	.023		
	Total	71	1.600	.023		
Supportive behaviors	Between groups	2	.011	.005	.06	.946
	Within groups	69	6.711	.098		
	Total	71	6.721	.095		
Peer engagement	Between groups	2	.233	.117	3.54	.034*
	Within groups	69	2.271	.033		
	Total	71	2.504	.035		
Explanations	Between groups	2	1.372	.686	5.70	.005**
	Within groups	69	8.307	.120		
	Total	71	9.680	.136		
Distractions	Between groups	2	1.968	.984	.81	.451
	Within groups	69	84.212	1.220		
	Total	71	86.181	1.214		

Appendix J

J1. Full results: Growth curve models examining changes in the peer cooperation variables across sessions 1, 3, and 5

session	*β*	R^2	*SE*	*z*	*p*	*Lower bound*	*Upper bound*
Time on task	-.025	.073	.007	-3.59	.000**	-.039	-.011
Co-regulation	-.051	.136	.009	-5.63	.000**	-.068	-.033
Unilateral regulation	.013	.049	.006	2.34	.019*	.002	.024
Disengaged	.037	.094	.009	4.01	.000**	.019	.055
Supportive behaviors	-.052	.034	.021	-2.47	.013*	-.093	-.011
Peer engagement	.002	.0007	.014	.14	.886	-.025	.029
Explanations	-.042	.013	.033	-1.27	.206	-.106	.023
Distracting behaviors	.276	.087	.078	3.54	.000**	.123	.429

Appendix K: Think, Pair, Share prompts

K1. Correlations between Think-Pair-Share prompts and the peer cooperation variables

	Co-regulation	Disengaged	Supportive behaviors	Engagement attempts	Peer explanations	Distracting behaviors
Think-Pair-Share prompts	.083	-.057	-.006	-.148	.113	-.085

K2. OLS regression models testing the relation between Think-Pair-Share prompts and the peer cooperation variables

	β	R^2	*SE*	*p*	*Lower bound*	*Upper bound*
Co-regulation	.020	.007	.28	.489	-.036	.076
Disengaged	-.011	.003	.024	.633	-.059	.036
Supportive behaviors	-.002	.000	.049	.962	-.099	.095
Peer engagement	-.037	.022	.029	.214	-.095	.022
Explanations	.055	.013	.058	.346	-.061	.171
Distracting behaviors	-.123	.007	.173	.480	-.469	.223

Appendix L

L1. Full results: Multi-level regression analyses examining the relation between children's dyadic skill disparity levels and the peer cooperation variables

	β	*SE*	*z*	*p*	*Lower bound*	*Upper bound*
Co-regulation	.009	.040	.23	.814	-.069	.087
Disengaged	-.002	.031	-.08	.937	-.063	.058
Supportive behaviors	-.092	.039	-2.36	.018*	-.168	.015
Peer engagement	.020	.018	1.11	.266	-.016	.056
Explanations	-.056	.081	-.70	.484	-.214	.101
Distracting behaviors	-.035	.224	-.16	.875	-.473	.403