Literature Review Summary

The purpose of this literature review is to provide Zeno's MathWays for Early Learning staff with relevant research to answer the following questions to inform the development of the program:

1. What methods are found useful in teaching early learners foundational math concepts?
2. How is play incorporated in engaging kids in learning foundational math concepts?
3. What role do families play in teaching early learners foundational math concepts?
4. What is the impact on early learners of developing foundational math concepts?
5. What are the risks of too much math in early learning?
6. What programs are addressing math in early learning?

1. What methods are found useful in teaching early learners foundational math concepts?

Guided discovery techniques that include opportunities for children to experience structured, playful exploration of math concepts are most useful.

There was consensus in the literature that the most useful methods for teaching early learners foundational math concepts involved guided discovery techniques that incorporated opportunities for structured, playful exploration of the concepts at hand. Alfieri, Brooks, Aldrich, and Tenenbaum (2007) described these directed and structured, yet still exploratory methods, to include (a) guided tasks that have scaffolding in place to assist learners, (b) tasks requiring learners to explain their own ideas and ensuring that these ideas are accurate by providing timely feed-back, and (c) tasks that provide worked examples of how to succeed in the task" (p 13).

Ginsburg, Lee, and Boyd (2008) approached early childhood math learning similarly, describing the ideal early childhood math-learning environment as one which involved six components:

1. A rich environment containing a variety of materials that could be incorporated into mathematical learning,
2. Opportunities to play,
3. A teacher who carefully observed the children's play and took advantage of spontaneous, teachable moments to promote mathematical learning,
4. Projects in which a teacher guided the children in the exploration of complicated, math-related topics,
5. An effective and thoughtful curriculum that tied these projects together, and
6. Intentional teaching that aimed to introduce mathematical concepts whenever possible.

Linder, Powers-Costello, and Stegelin (2011) also supported using exploratory learning techniques, specifically highlighting "(1) project work, (2) documentation, (3) recycled materials, (4) integration of the arts and mathematics education, and (5) integration of play and mathematics education" (p 31) as particularly beneficial in increasing student understanding of math concepts.

Didactic teaching was also found to be effective in supporting students who were struggling with math to improve learning gains.

In contrast, one study found that didactic teaching approaches were superior to student-centered approaches insofar as computation and test scores were concerned. Morgan, Farkas, and Maczuga (2014) found that those students without mathematical difficulty benefited more from student-centered activities than did students with mathematical difficulty; in contrast, all students made learning gains from teacher-directed activities. Despite the reservations expressed by these authors, the literature generally supported the use of fully scaffolded and guided discovery-based learning techniques.

Small group activities are an underpinning of most teaching and learning approaches in the literature.

Much of the literature supported the use of guided, small-group activities. For instance, the Pre-K Mathematics with Developmental Learning Materials (DLM) Early Childhood Express Math, reviewed by What Works Clearinghouse (2013), directed teachers to guide repeated small-group activities over the course of a school year. In the following discussion, it should be assumed that each curricular recommendation involves small-group activities.

Embedding math learning in the home, at child care, and in the classroom is important for enhancing child engagement with math.

The literature also supported enhancing math engagement by embedding math-learning approaches into real-world or domain-specific situations. Bowman (1998) emphasized the importance of methods that "embedded" math and science concepts in the real world, highlighting multi-media and non-traditional sources of math and science education for early learners (e.g., Sesame Street) in preparing young children for kindergarten. Gerde, Schachter, and Wasik (2013) asserted that science lessons could be engaging loci for learning about or utilizing counting, measurement, pattern recognition, data display, logic, and algebraic (that is, relationship-oriented) reasoning. Similarly, the Science Research Associates (SRA) Real Math Building Blocks supplemental math curriculum, favorably reviewed by the What Works Clearinghouse (2013), seeks to "mathematize" early learners' every day experiences by integrating software, manipulatives, and print materials in the home, at day care, and in the classroom.

Math talk was found to be positively correlated with increased preschooler math-concept knowledge.

Instructor use of math talk was found to have a positive correlation with increased mathematics concept knowledge among preschoolers. Klibanoff, Levine, Huttenlocher, Vasilyeva, and Hedges (2006) found a significant, positive correlation between the frequency of preschool-instructors' "math talk"—broadly defined as any language referring to numbers, organization, pattern, counting, shapes, or other mathematical skills or concepts—and the preschoolers' understanding of key math concepts. This difference persisted even when socio-economic status and other classroom factors were accounted for. An increase in instructor use of math talk was positively correlated with greater student math achievement. In alignment with these findings, Fromboluti, Magarity, and Rinck (1999) encouraged parents to incorporate math concepts into every-day activities (e.g., count everything, read books with repetition, allow the child to help measure while the adult is cooking, create charts of things observed). This was consistent with the intentional teaching approach recommended by Ginsburg et al. (2008).

2. How is play incorporated in engaging kids in learning foundational math concepts?

The most commonly mentioned strategy for effective math teaching and learning was play.

Wenner (2009) described the critical importance of free-play in healthy, normal child development. Wenner described the socializing effects of unstructured, unsupervised, peer to peer play which allowed for the development of normal boundary recognition, enhanced recognition of social norms, stimulated higher brain development, and had positive effects on stress management and anxiety. Most importantly for this project, children's problem-solving and mental flexibility capacities appeared to be enhanced by play, including activities like play fighting. Wenner recommended that parents "let loose" a little more and allowed their children time to play without intervening or inserting educational materials into their play. However, effective mathematical play must be guided in order to have positive impacts on math outcomes.

Effective mathematical play included guided, goal-oriented, discovery-based activities involving patterns or shapes, as described by Brandt (2013), or manipulatives such as playdough (Caswell, 2007) or sticks (Vogel, 2013). Also common were games involving numbered boards or numerical structures, as described by Ramani et al. (2008, 2012, and 2015) and Siegler and Ramani (2008, 2009). The literature made it clear that a teacher/caregiver must guide these activities in order to constitute effective mathematical play.

3. What role do families play in teaching early learners foundational math concepts?

Family involvement in at-home math activities is positively linked to children's math skills.

Sheldon and Epstein (2005) found that mathematics-focused, learning-at-home activities consistently and positively related to improvements in the percentages of students who were proficient on mathematics achievement tests, after accounting for prior levels of mathematics proficiency in the school. Activities that supported mathematics learning included (a) interactive homework that required students and parents to interact and talk about mathematics, and (b) mathematics materials and resources provided for families to use at home (including math games).

According to a literature review on the impact of family involvement in the education of children ages three to eight conducted by Van Voorhis, Maier, Epstein, and Lloyd (2013), the majority of studies demonstrated that family involvement was positively linked to children's literacy and math skills in preschool, kindergarten, and the early elementary grades. The authors pointed out that there were more studies of and a greater emphasis on family involvement in reading and literacy activities at home than in math or other subjects. Despite this, looking specifically at research on family involvement with mathematics, the authors noted that according to the research, parents of diverse backgrounds could engage their children in math-related learning activities at home that would have an impact on student math scores. This literature review broke down the research into four types of family involvement (1) learning activities at home, (2) family involvement at school, (3) school outreach to engage families, and (4) supportive parenting. The following summary focuses on math learning activities at home.

The **U.S. based** research of Van Voorhis et al. (2013) only found three intervention studies to review. Two randomized intervention studies conducted by Starkey and Klein (2000) examined the Family Mathematics Curriculum, an eight session parent intervention conducted over eight weeks by trained teachers with two low, socioeconomic status Head Start populations in two randomized control trials. The curriculum was very structured and covered specific, early-learning math concepts and skills as well as providing a series of specific activities for parents to engage in with their children at home. Both studies had significantly higher student mathematics posttest scores on informal mathematics knowledge in the experimental condition.

The two other randomized intervention studies reviewed by Van Voorhis et al. (2013) did not find significant differences in math scores (Vandermass-Peeler, Boomgarder, Finn, and Pittard, 2012; Vandermass-Peeler, Ferretti, and Loving, 2011). The authors noted that the interventions of these two studies were considerably shorter than the Starkey and Klein (2000) intervention (one day and two weeks vs. eight weeks), as well as having a small sample size (N = 29 and 25, respectively).

Van Voorhis et al. (2013) also highlighted a promising pilot of the Getting Ready for School (GRS) program (Noble, 2012) which was also a longer term, parent intervention that centered on math. The GRS program was a nine unit, fifteen week workshop series led by a trained facilitator. Parents were shown how to use familiar items (e.g., buttons, laundry, cooking) and everyday interactions in the home and community to prompt children's learning which included solving math problems, connecting math with real life, estimating numbers and sizes, and exploring shapes. The intervention group from this pilot showed significantly improved math scores.

Three nonintervention, **international studies** were also reviewed but were reported separately due to possible cultural differences. These studies examined parents' self-reports of their involvement in and support of learning at home and outlined the positive effects on children's math skills across a range of ages and countries, as young as three years of age in Germany (Anders, Rossbach, Weinert, Ebert, Kuger, Lehrl, and von Maruice , 2012), three to five years of age in Canada (LeFevre, Skwarchuk, Smith-Chant, Fast, Kamawar, and Bisanz, 2009) and Greece (LeFevre, Polyzoi, Skwarchuk, Fast, and Sowinski , 2010), and five and seven years of age in the Netherlands (Kleemans, Peeters, Segers, and Verhoeven, 2012).

In summary, Van Voorhis et al. (2013) concluded that the overall pattern of results provided positive support for the importance of family engagement in math related learning activities at home. They pointed out the need for interventions to have clear activities for parents to engage in with their children. The authors went further to point out that workshop or trainings-based interventions conducted over several weeks that provided explicit activities were seen to be more effective than shorter-term interventions that merely provided suggestions for math activities. The authors speculated that this might be required to help parents feel more confident, positive, and more knowledgeable about interacting with their children around math. A weaker intervention might sustain math fears and anxieties and limited math knowledge, thereby restricting parents' interactions with their children about math.

Math games and math talk in the home were related to children's development of numeracy.

The LeFevre et al. (2009) research was particularly relevant to Zeno's MathWays for Early Learning work, because it was one of the first studies that showed a robust relationship between the frequency with which children participated in indirect numeracy activities (i.e., playing board games with dice or measuring while cooking) at home and mathematical proficiency. According to the regression analysis, these indirect activities were predictive of children developing fluency with basic numerical skills such as addition or number-line knowledge. Another more recent study by Berkowitz, Schaeffer, Maloney, Peterson, Gregor, Levine, and Bellock (2015), in a randomized field experiment of 587 first-graders, saw significant math skills improvement in elementary children whose parents utilized a mobile device app to engage in math story time with their child at home. The intervention consisted of short, numerical story problems delivered through an iPad app. Analysis of log data from the iPad revealed that student math-skill improvements were most dramatic in families where caregivers reported having math anxiety.

A dissertation study examining the frequency of mothers' math talk at home and its link to the children's later math skills (Susperreguy-Jorquera, 2013) was also found to be relevant to Zeno's MathWays for Early Learning work, as this research extended the work on math talk in the home and the importance of connecting math to everyday life. Susperreguy-Jorquera (2013) analyzed the transcribed mother-child conversations during breakfast and dinner times, which included eating, preparing meals, cleaning up, and doing other activities. Mothers involved their children in an average of 38 instances of "math talk" during breakfast and dinner times. This study found that children's informal (home) and formal (school) math knowledge, such as number comparisons, calculation, and understanding concepts, led to better math abilities a year later, as measured by the Applied Problems Subtest of the Woodcock-Johnson III Tests of Achievement.

There are important strategies to use in order to optimize games as mediators of child math learning.

Another, more general study by Kliman (2006) investigated the benefits and challenges of involving parents in children's math learning and found:

- Accessibility of games did not guarantee use; families who chose to play the games integrated the games into regular activities and routines (e.g., family game nights and long car rides).
- Families with younger children were more likely to play the games. The study included children ages seven to thirteen.
- Usability mattered, especially to mothers (e.g., portability, brevity, and that the game was enjoyable and engaging for children of different ages).
- Parents readily supported their children's learning.
- Parents recognized and valued the learning with games but did not relate the learning to school.
- Parents jointly constructed the educational agenda with the games, in contrast to parent-child homework interactions, where the agenda was set by the teacher.

Kliman (2006) also made three recommendations for the best place to distribute games to families (1) school, (2) after-school programs, and (3) science and community centers.

4. What is the impact on early learners of developing foundational math concepts?

The skills early learners brought to school are linked to later school success and achievement.

While emphasis on reading proficiency had been prevalent, research showed that the development of early mathematics skills might be an even greater predictor of later school success (Education Commission of the States 2013). Research by Duncan, Dowsett, Claessens, Magnuson, Huston, Klebanov, and Japel (2007) found that the math skills of early learners not only predicted later success in math but also predicted later reading achievement better than early reading skills. According to the Duncan et al. (2007) study which analyzed six longitudinal data sets, early math concepts such as knowledge of numbers and ordinality were the most powerful predictors of later learning, followed by reading skills and attention related measures (controlling for cognitive, attention, and socioemotional skills measured prior to school entry, as well as a host of family background measures). The results showed that rudimentary mathematics skills appeared to matter most in predicting both later math and reading achievement. The authors went on to suggest that play-based, as opposed to "drill and practice," curricula designed with the developmental needs of children in mind could foster development of academic and attention skills in ways that were engaging and fun.

The findings of Jordan, Kaplan, Ramineni, and Locuniak (2009) also demonstrated the importance of kindergarten number competence for setting children's developmental learning trajectories in elementary school mathematics. Research found that students' number competencies (from kindergarten through the middle of the first grade) was predictive of later mathematics achievement (from the end of the first grade through third grade). Jordan et al. (2009) went on to stress that this predictive relationship between kindergarten number competence and later mathematics outcomes had important implications for educational policy, especially in regards to improving numeracy in children from low-income families as well as in younger children (pre-k, kindergarten, and first grade).

5. What are the risks of too much math in early learning?

Opportunities to play are being eliminated in child care centers, preschools, and kindergarten classrooms in order to increase reading and math academic assessment scores, resulting in children with more aggression and less effective impulse control.

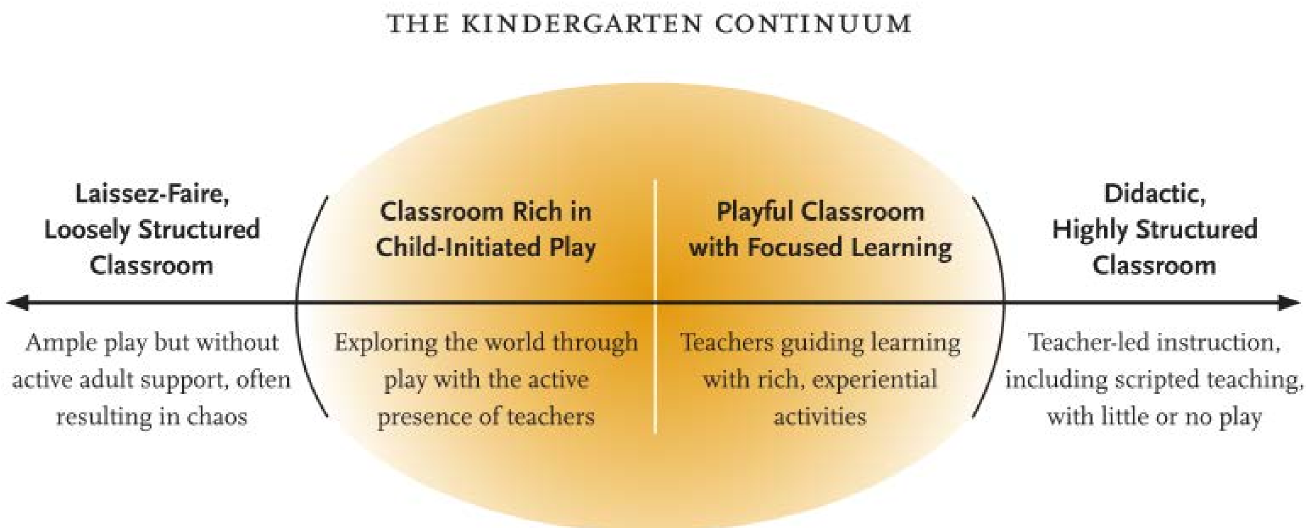
Curwood (2007) and Miller and Almon (2009) argued that the risk of too much math and science in early learning was that it came at the expense of play. Both Curwood (2007) and Miller at al. (2009) pointed to Finland as an example of a country where children began school at the age of seven, spent less time in school overall than American children, and yet still outperformed US children in literacy and math. Miller et al. also highlighted Japan, China, the United Kingdom, and Germany as other countries where children experienced play-based early learning and had much stronger academic outcomes.

According to Curwood (2007) play is crucial to a child's education because: (1) children learn to socialize through play; (2) play teaches numbers, letters, and reasoning; (3) play breeds imagination and innovation; and (4) play helps kids cope with stress. With the decrease in play currently evident in classrooms, the secondary risk Curwood identified was that children might grow to dislike school and become less engaged in academic learning.

In the report by Miller et al. (2009), published by the Alliance for Childhood, the risks and inefficiencies of the current guided-learning heavy kindergarten curriculum in the US were outlined. This report compiled research from peer-reviewed journals and independent education evaluations and posited that there is currently insufficient play in early learning in the US, and that American children are suffering and failing to learn as a result. Current didactic, structured kindergarten conditions were contributing to high levels of frustration, stress, and aggression in kindergartners. Many experts see a probable link between extreme behaviors and the pressures of testing and unreasonable expectations. This report concluded that a lack of play in early learning is a risk to positive child development.

Additionally, Loeb et al. (2007) found that center-based day care raised reading and math scores but had a negative effect on socio-behavioral measures. Center-based programs appeared to offer the most benefits for poor, at-risk, and English-language learners. However, the cumulative amount of time spent in child care was associated with increased problem behaviors including elevated levels of aggression and less effective impulse control. Loeb et al. state that "The duration of center-based care matters: the greatest academic benefit is found for those children who start at ages 2-3 rather than at younger or older ages; negative behavioral effects are greater the younger the start age. These patterns are found across the distributions of family income. The intensity of center-based care also matters: more hours per day lead to greater academic benefits, but increased behavioral consequences. However, these intensity effects depend on family income and race." (p 52). While this study was not directly related to the risks associated with increased math and science in early learning, it did caution that increasing children's time spent in school or academic-oriented programs too early in life might have negative effects on child development.

These findings suggest that playing math games with children three and older could reduce the risk of negative behavioral effects found in center-based day care.



Source: Miller, E., and Almon, J. (2009). *Crisis in the Kindergarten Why Children Need to Play in School. Alliance for Childhood*. Retrieved from www.allianceforchildhood.org.

6. What programs are addressing math in early learning?

We found four programs that were found to have statistically significant, positive effects on children's math-demonstrated knowledge and skill.

Teaching and learning programs that involved scaffolded, guided game-play or exploration were tested on both individuals and small groups. A number of experimental studies showed the positive impact these interventions had on children's mathematical learning. Highlights included:

- What Works Clearinghouse (WWC) (2013) investigated the effectiveness of a pre-k supplemental math curriculum and pre-k Mathematics with DLM Early Childhood Express Math in two randomized control trials performed on 575 students in Head Start and public preschools in California and New York. The curriculum included use of manipulatives in the classroom and use of picture strips at home and directed teachers to guide repeated, small-group activities over the course of a school year. The curriculum was found to have a strong, statistically significant, and positive effect on student math performance. WWC calculated an average curriculum effect size of .50.
- Baroody et al. (2009) performed a multivariate analysis on a game-based curriculum intervention administered individually to at-risk preschoolers that showed that the intervention significantly improved participants' Test of Early Mathematics Ability – Third Edition (TEMA-3) achievement scores from pre- to post and narrowed the achievement gap between these at-risk preschoolers and their non-at-risk peers.
- WWC (2007) also investigated the effectiveness of a pre-k supplemental math curriculum and SRA Real Math Building Blocks in two randomized control trials performed on 250 students in New York. The

curriculum integrated software, manipulatives, and print materials were to be used in the home, at day care, and in the classroom. The activities sought to "mathematize" early learners' every day experiences. Study findings showed that the curriculum had a statistically significant, positive effect on student math performance but categorized the extent of evidence as small given the limited scope of the studies. In the comparison of the building blocks curriculum against a typical curriculum there was a curriculum effect size of 0.49.

- The Ready To Learn pre-kindergarten transmedia mathematics study (Pasnik and Llorente, 2013), a ten week randomized control trial (N = 966), found that economically disadvantaged four and five year old pre-k children who experienced the PBS KIDS Transmedia Math Supplement significantly improved essential, early mathematics skills (including counting; subitizing; recognizing numerals; recognizing, composing, and representing shapes; and patterning). The Ready To Learn program used public media videos and digital educational games played on interactive whiteboards and laptop computers. The study also showed that preschool teachers who enacted the PBS KIDS Transmedia Math Supplement reported significant changes in their confidence and comfort with early mathematics concepts and teaching with technology. The authors also pointed out that professional learning and coaching were an integral part of any effective intervention. The professional learning for the Ready To Learn program consisted of both technical and pedagogical guidance.

Methodology

Data2insight researchers searched the EBSCO Academic Search database (and others as appropriate) for publications from 1990 to June 2015. Researchers retrieved articles related to math and STEM early-learning programs serving children, specifically all-day child care, pre-kindergarten/preschool, and kindergarten, including programs that served children of color, English-language learners, and those struggling with math achievement.

Search terms included "math and early learning," "STEM and early learning," "math and preschool," "STEM and preschool," "math and pre-k," "STEM and pre-k," "math and all day child care," and "STEM and all day child care." No specific key words were required as inclusion criteria.

Researchers retrieved journal articles from diverse fields of study and carefully documented these fields. Researchers also reviewed the reference lists of each article in detail to find additional relevant articles.

Each article was read in full and evaluated for relevance to the literature review questions, and the main findings were recorded in an annotated bibliography. The reviewers slated each article for "inclusion" or "exclusion" based on the article's relevance to the topic. Included articles described theoretical frameworks or problems and solutions associated with math and STEM early-learning programs in response to the questions above. In this literature review, researchers identified and summarized the main framework or problems/solutions identified in each article, grouped by research question.

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