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Math and Science in Preschool: Policies and Practice

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Improving mathematics and science learning is of great concern to educators and policymakers. Because early experiences affect later education outcomes, providing young children with research-based mathematics and science learning opportunities is likely to pay off with increased achievement, literacy, and work skills in these critical areas.[1] This report addresses the development of mathematics and science understanding in preschool children, reviews the current knowledge base on educational practices in these domains, identifies areas that require further study, and outlines recommendations for early education policy in mathematics and science.

What We Know:

- Young children have foundational competence in mathematics and science *before* they begin formal schooling.
- Children are motivated to explore mathematical and scientific concepts they encounter in their everyday interactions with the world.
- Comprehensive curricula are strengthening their offerings, and subject-specific programs are emerging. Almost every state has developed mathematics and science learning expectations or standards for preschoolers.
- Despite the existence of learning standards and increased curricular attention to mathematics and science, they tend not to be emphasized by teacher preparation or in-service professional development programs and evidence suggests that preschool educators tend not to support mathematics and science learning.
- In general, little is known about effective teaching of mathematics in preschool and even less is known about science.

Policy Recommendations:

- Mathematics and science should be treated as essential components of a comprehensive, high-quality preschool program, not as extras.
- Policymakers must be certain that curricula, learning standards, and teaching expectations for early mathematics and science are research based and must outline expectations that are attainable and appropriate for preschool learners.
- Early education policies should define mathematics as more than counting and number, and science should be treated as more than learning lists of facts.
- Pre-service and in-service educators need improved preparation to understand math and science content and to provide experiences integrating this content into their teaching practice.
- Appropriate accountability systems that focus on the classroom, the teacher, and the child must be built to support high-quality early mathematics and science education.
- Mathematics and science learning should be integrated with each other and with other content domains.

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1. Foundational Competence in Mathematics and Science

Very young children demonstrate a natural interest in exploring "everyday" mathematical and scientific concepts. They count steps as they walk up stairs, create patterns with different colored materials, build towers with blocks, and comment that one tower is taller than the other.[2] They question where cow babies come from, observe that people have different color eyes, and generate explanations for this difference.[3] These early explorations and engagement in associated thinking processes serve as foundations for learning as children continue toward more formal understandings. Although mature understanding of mathematical and scientific concepts requires further cognitive development, teachers and parents can support learning by encouraging preschoolers to reason mathematically and scientifically, to explore concepts in these domains, and to explain their thinking as they do so.

1a. Early Mathematics Competence. When they consider mathematics in preschool, many people (and many preschool teachers) think of learning to count and identify numbers, but young children also possess considerable competence in numerical operations, geometry and spatial relations, measurement, algebraic thinking, and data analysis.

Most preschoolers count verbally, which serves as an explicit sign to adults of the child's burgeoning number skills. However, research suggests that children have a basic understanding of one-to-one correspondence even before they can enumerate a set of objects verbally. Without counting, they can match up two sets of items or point to items in a collection, labeling each with a number, even if it is not the correct number. Evidence also suggests that they can make a matching collection for one that is not visible but is mentally represented. For example, a toddler who retrieves two dog treats for two pets in another room is saying, in effect, "This [one] is for [the first dog], and this [one] is for [the second dog]."[4] Such intuitive understandings and everyday applications of knowledge may help lay the groundwork for later understandings of numerical equivalence and operations, such as addition and subtraction.

Young children also enjoy exploring spatial positions and relationships and properties of geometric shapes.[5] Understanding how one's body moves in space and learning how to manipulate objects and shapes in space are important cognitive developments. Preschoolers learn about spatial relationships and shapes by moving through their classroom and outdoor spaces and by manipulating toys such as puzzles and two- and three-dimensional shapes. They also demonstrate emerging awareness of measurement, long before they know how to use standard measurement tools, when they begin to notice differences in the height, weight, and length of various objects.

Along with curriculum focal points on number and operations, geometry, and measurement, the National Council of Teachers of Mathematics (NCTM)[6] also identifies algebra and data analysis as important, connected content areas. NCTM[7] defines algebra simply as a way of thinking and reasoning about relationships. This means that children as young as 3 or 4 years old begin to think algebraically by manipulating pattern blocks, making their own patterns, arranging objects according to a rule, or calling attention to patterns they observe in the environment.[8] The object attributes that children attend to, as part of their emerging geometry and measurement skills, are foundational for data analysis as well.[9] Children's propensity to collect and sort items by their attributes is a key component of the ability to represent, analyze, and interpret mathematical data.[10]

1b. Early Science Competence.

Children entering kindergarten already have a great deal of knowledge about the natural world, including understandings of cause and effect; some of the differences between animate and inanimate objects; ways in which people's beliefs, goals, and desires affect behavior; and substances and their properties. These knowledge domains include concepts related to physics, biology, psychology, and chemistry (see Duschl, Schweingruber, & Shouse, 2006, for a review).[11]

Consider, for example, young children's understandings of animals and plants. Preschoolers know quite a bit about the differences between animate and inanimate objects and the kinds of changes and states they take.[12] When shown photographs of novel objects, they accurately predict that animates can move by themselves but inanimates cannot[13] and that the insides of an unfamiliar machine are different from those of an unfamiliar animal.[14] Young children distinguish between living and non-living things on a number of critical features. They seem aware that animals and plants can grow and heal but that artifacts cannot, and they understand some aspects of the life cycle of plants and animals.[15] Preschoolers can also correctly name germs as causes of illness, and know that germs can transmit disease through physical contact, even though germs are invisible.[16] With educational intervention, they can form a beginning notion of genes and inheritance.[17]

The foregoing examples illustrate that preschool children can think abstractly about various scientific concepts. They also possess dispositions and thinking skills that support later, more sophisticated, scientific reasoning. For example, preschoolers are motivated to clarify ambiguous evidence. When they play with a jack-in-the-box-type toy, and the mechanism that causes the doll to spring from the box is clear, children stop playing with the jack-in-the-box as soon as a new toy is presented. When it is unclear exactly how the first toy works, they continue to explore it, even when a new toy is available.[18] Children also persist in asking information-seeking questions of adults until they are given a satisfactory response.[19] In addition to being motivated to understand, young children show specific scientific reasoning skills. Older preschoolers are able to interpret simple data patterns and show some understanding of how different patterns support different conclusions.[20] Often, though, children this age use sophisticated reasoning without being aware that they are doing so and without being able to describe their reasoning.[21] Like all learners, children's use of logical thinking is constrained by their knowledge of, and experience with, the conceptual domain they are reasoning about; whether the problem being posed makes sense to them; and whether they are comfortable in the assessment situation.

2. School Readiness and Achievement

Children have very positive attitudes toward mathematics and science during the preschool years, and opportunities to use mathematics and logical thinking to solve problems help children develop dispositions such as curiosity, imagination, flexibility, inventiveness, and persistence. These positive attitudes toward learning contribute to future success in and out of school and should be preserved by providing appropriate materials and instruction in the preschool years.[22]

Supporting children's early mathematical thinking has implications for school readiness which, in turn, impacts later achievement. A recent analysis of the links between school readiness indicators and school achievement in six large-scale studies revealed a strong correlation between mathematics skills at school entry and later mathematics and reading achievement.[23]

The research base in early mathematics and science can be leveraged to design appropriate learning experiences, build further understandings, and prepare children for the mathematics and science they will encounter in school. However, work remains to describe the course of development in these domains, to understand the ways development can best be supported for diverse learners, and to identify the links between early knowledge and skills and later school achievement. The importance of identifying learning trajectories or pathways in math and science domains has been acknowledged in the current educational literature,[24] and progress is being made, especially in the field of mathematics (e.g., Clements & Sarama, 2004).[25]

3. Connections Among Literacy, Mathematics, and Science

As researchers continue to explore the importance of specific science and math experiences and skills for school readiness and later achievement, we already know that early math and science experiences matter because they can support *language and literacy* development, independent of any effect on later math and science achievement.

Science and math interactions support vocabulary development by exposing children to a variety of new words in meaningful contexts. The practices of math and science are described using verbs such as observe, predict, estimate, sort, experiment, and so on. As children engage in these practices, they learn new nouns to label what they are observing—chrysalis, roots, seed pods, parallelogram—and use adjectives to describe attributes—sticky, dirty, roundish, pointy, more than, and less than. Research suggests that exposure to uncommon vocabulary words predicts vocabulary development, which predicts reading achievement,[26] and that participation in sustained science experiences results in vocabulary gains for preschoolers.[27]

Conversations about objects that are not present or events in the past or future support the development of abstract reasoning and are related to literacy skills.[28] Such conversations often occur in the context of a science activity when children make predictions and plan explorations.[29] Children who are asked, "What should we do to find out?" must use language to describe a plan for the future. When they are asked, "What will happen if…?" or "Why do you think seeds need water to sprout?," they are required to reason and talk about objects, events, and changes that they have not yet experienced.[30] Similarly, explaining results and their causes supports the use of complex grammatical structures such as embedded clauses and prepositional phrases. Children's growing science content knowledge and their developing language skills mutually reinforce each other.[31] Encouraging children to talk about their observations, thoughts, and reasoning as part of mathematical and scientific play helps them develop not just their facility with the language of mathematics, but also more general communication skills and their awareness of their own thinking.[32]

Math and science explorations can be used to support literacy development. The content of fiction and nonfiction books can be scientific or mathematical and can serve as the basis for extended conversations between children and adults around key science and math content and ideas.[33] When teachers create science charts to record children's observations, predictions, and explanations of results, they illustrate the links between spoken and written language and support growing print concepts. Producing simple graphs, recording numerical data on charts, and documenting how math problems were solved encourages children to use numerals or other symbols that represent number. Science journals can also be successfully incorporated into preschool activities as tools for supporting the growth of both science and literacy skills. A rich language interaction occurs as children watch their ideas and words translated into print as a teacher transcribes what children have to say about their entry. Recording in journals also provides opportunities for children to practice their own growing printing and spelling skills.[34]

Children have very positive attitudes toward mathematics and science during the preschool years, and positive attitudes toward learning have been shown to contribute to future success in and out of school.

Critical Issues

Basic research has identified mathematics and science competencies in young children. For mathematics especially, we have evidence that early skills are associated with positive school achievement in both mathematics and literacy. The case for early science is less well developed, in part because the particular thinking skills associated with science can be applied to just about any content, making it less clear which skills and content are uniquely scientific.[35] Nevertheless, science joins mathematics and literacy as a domain that early education experts and policymakers believe is foundational for future learning. Further issues addressed in this brief include: 1) the development of comprehensive early learning standards; 2) the development of appropriate and effective curricula; 3) issues of accountability and assessment; 4) teacher preparation and professional development; and 5) home-school connections.

1. Early Learning Standards

In 2002, the National Association for the Education of Young Children (NAEYC) and NCTM issued a joint statement to "affirm that high-quality, challenging, and accessible mathematics education for 3- to 6-year-old children is a vital foundation for future mathematics learning."[36] The document outlines recommendations for educational professionals who teach young children and describes ways in which institutions, curriculum developers, and policymakers can support quality mathematics in preschool classrooms. Many of these recommendations are incorporated into this brief. At this time, parallel documents have not been developed for early science education.[37] Head Start also includes math and science among the eight developmental domains in their Child Outcomes Framework.[38] Further, the 2007 reauthorization of the Head Start Act[39] adds mathematics, science, and approaches to learning as areas that teachers should include in classroom learning experiences to improve school readiness.

Most U.S. states have developed and published at least one set of early learning standards and/or learning expectations that describe what children should know and be able to do when they enter kindergarten. Used as intended, these standards can support teaching and learning by providing a comprehensive description of the knowledge and skills children should have, guidance to administrators and teachers as they design or choose curricular experiences for young learners, and benchmarks for educators to assess the quality of their offerings. Standards can also support continuity between the skills children attain during preschool and the ones they will need to succeed in school.[40]

Experts in early mathematics

agree that standards should be research based and should focus on "big" ideas, including number and operations, geometry and spatial relations, and algebraic thinking/problem solving.[41] Current standards tend to include number and operations, and geometry and spatial relations, but the specific indicators or goals for these topics vary greatly from state to state. Algebraic thinking and data analysis are less likely to be addressed by standards.[42] To our knowledge no analysis of science standards has been published, but expectations for science are included in most state learning outcomes. At the K–8 level, science educators and policymakers are calling for learning expectations that focus on the big ideas of science;[43] this is also a reasonable goal for preschool expectations. However, until research identifies the key science process skills and content that predict improved school readiness and outcomes, it is likely that the specific performance indicators will continue to be inconsistent from state to state.

2. Curriculum and Classroom Practices: More Than Counting on the Calendar and Describing the Weather

A quality curriculum supports skills that relate to later achievement. For mathematics, it provides experiences that not only encourage thinking and reasoning about numbers but support investigations into size, quantity, properties of objects, patterns, space, and measurement. Preschoolers learn mathematics through concrete experiences with materials and through intentional interactions by their teachers to extend their thinking.[44] In most high-quality preschool programs, mathematical thinking and reasoning are encouraged as children engage in activities such as counting, measuring, constructing with blocks, playing board and card games, and engaging in dramatic play, music, and art.[45] By providing children with an environment that is mathematically rich, teachers lay the foundation for their students' future success at learning school mathematics.[46] Similarly, a quality preschool environment supports children as they learn key content and practices of science by providing opportunities to observe, explore, experiment with, question, and discuss a range of scientific phenomena.[47] Children learn when questions and reasoning are encouraged as they explore the world around them. By providing these opportunities, teachers help children to hone their thinking skills and clarify their informal ideas about science.[48]

Mathematics and science are part of many widely used, comprehensive curricula. A number of curricula are strengthening their offerings in these domains. HighScope has developed *Numbers Plus,* which is aligned with NCTM standards and focuses on number, operations, geometry, measurement, algebra, and data analysis.[49] Key developmental indicators and instructional strategies for science and technology are included in the HighScope comprehensive preschool curriculum.[50] The developers of the Creative Curriculum recently published an extensive mathematics supplement and math kits to support instruction in number, geometry, data, patterns, and measurement,[51] and they also have augmented science (and social studies) offerings with *Study Starters.* These volumes are guides for teachers designed to help them identify children's questions and ideas and to build learning experiences around them.

Curriculum developers should be cognizant of the ways in which math and science (as well as other domains) are mutually supporting. Teachers who design and implement classroom experiences should integrate mathematics and science with each other and with other activities. Learning experiences that cut across curricular areas are important for children's conceptual development but are also practically important as teachers design activities to support multiple learning goals in a very full curriculum.[52]

In addition to integrated curricula, "layover" programs that focus on preschool mathematics and science exist, although many have not been evaluated empirically.[53] A recent special issue of *Early Childhood Research Quarterly*[54] featured a number of these approaches to mathematics and science learning. Although the programs vary in the extent to which they have been studied empirically, each is based on the research literature on young children's learning. Further, most have been used with learners from low-income populations. Identifying learning supports for these children who often arrive at school behind their more affluent peers in mathematics understanding is critical.[55]

Despite the existence of standards and some curricular supports for incorporating math and science into early education, very few math and science experiences are available in classrooms[56] and what little does occur is rarely of high quality.[57] Even when preschool teachers agree that mathematics is important and believe that they are exposing children to mathematical discussions, classroom observations reveal that very little mathematical content is being presented. In 12 hours of observation, Graham and colleagues[58] report just three examples of planned math activities and only 12 examples of spontaneous discussion. Rudd and her collaborators[59] saw *no* examples of planned mathematics activities in 40 hours of observation, and teachers' spontaneous mathematical utterances overwhelmingly involved counting or discussion of spatial concepts (over, under, inside) rather than operations, patterns, or even shape concepts. For science, teachers spend little time engaged in either planned or spontaneous science-relevant[60] activities and the science area is one of the least likely centers to be visited by teachers during children's free choice time.[61]

3. Accountability and Assessment

As the number of children enrolled in preschool programs increases, so will the need for valid and reliable ways to assess programs' effectiveness for enhancing student learning.[62] In the upper grades, group-administered testing is the norm; however, this is not recommended, nor perhaps even possible, with preliterate, preschool children.[63] One move has been to develop performance-based assessment tools that rely on systematic teacher observation and documentation of children's ongoing behavior and samples of children's work using a standard checklist or scale.[64] In addition to performance-based assessment tools, a number of individually administered early childhood mathematics assessments exist or are being developed. These include the Child Math Assessment (CMA),[65] the Early Mathematics Assessment System (EMAS),[66] and the Research-Based Early Maths Assessment (REMA).[67] University of Miami researchers have developed a direct assessment of preschool science that assesses a wide range of content knowledge and process skills in science.[68]

Teachers employ more informal assessment techniques every day to identify children's interests, strengths, and needs. Once identified, the teacher can plan learning experiences that build on and extend strengths and address learners' needs. The recommended approach for doing so in mathematics and science is to gather multiple forms of evidence for particular skills or learning indicators. These include observations of children's interactions with materials, one-on-one discussions with them, documentation of conversations with peers, and examples of their drawings.[69] Of course, accurate and complete learning assessments depend on teachers understanding the range of learning indicators to which they should attend. Without this awareness, there is some danger of falling back on familiar, easily recognized skills as evidence for children's learning. Just as knowing the alphabet is only one small piece of literacy, we must be careful that children's rote memorization of the count list or science facts is not taken as evidence for mathematical or scientific understanding. Certainly counting and facts are critical to knowledge in these domains, but they are only pieces, not the whole picture.

Although there is reasonable concern that assessments can narrow what teachers teach,[70] for math and science, which are often overlooked in the preschool classroom, well designed, comprehensive assessment tools can support and expand the learning activities offered by teachers. Assessments that identify the knowledge and skills preschoolers learn across mathematics and science domains, describe expected learning trajectories and ranges for these, and provide illustrative examples of what children are capable of achieving can lead to more intentional instruction and expanded learning opportunities for children in mathematics and science.

4. Teacher Preparation and Professional Development

Although math and science learning materials on their own may provide learning opportunities for young children, it is important for teachers to have a deep knowledge base regarding the development of children's mathematical and scientific thinking and learning.[71] By understanding children's development, teachers are better prepared to identify moments when math and science learning is taking place, to assess what an individual child knows or needs to know about a particular concept, and to plan for future instruction. Recent studies have also demonstrated a direct link between teacher behavior and children's math learning. Specifically, the amount of math-related talk a teacher engages in is correlated with the growth of students' mathematical knowledge over the school year.[72] Unfortunately, very little time is dedicated to mathematics talk. Even when there is math-related conversation, it rarely lasts longer than a minute and is focused on basic, rudimentary concepts such as names of shapes or numeral identification.[73]

Although little research has addressed the actual math and science competencies of early childhood educators, we know that many consider these subjects to be difficult to teach.[74] This is not surprising because teachers traditionally have not been prepared to teach domain-specific knowledge, aside from literacy, to young children.[75] A recent review of requirements for pre-service, early childhood teachers in New Jersey reveals that their teacher preparation programs require relatively little coursework in math and science and that science was very unlikely to be linked to a practicum experience.[76]

The story for in-service professional development in mathematics and science is similarly discouraging. Among the 50 state-funded preschool programs, 41 require at least 15 hours of in-service training per year.[77] Decisions regarding content tend to be determined locally which means that there is no guarantee that teachers will receive training in mathematics and science. Further, if teachers do attend workshops on math or science, these often do not provide the kind of experience necessary to bring about meaningful changes in content knowledge or teaching practices. Professional development should move beyond one-day workshops and into models that allow teachers to explore deeply the content and pedagogy of science and mathematics.[78]

Programs that focus on children's learning trajectories seem to facilitate teachers' understanding of how children learn math and how their curriculum and teaching approaches can further this development.[79] An innovative program that encouraged both pre- and in-service teachers to study and reflect on their own teaching and children's mathematical and scientific thinking resulted in better attitudes about mathematics and extensions of classroom activities beyond teaching shapes and counting sequences. More important, teacher participation was linked to positive math learning outcomes for children.[80]

5. Home-School Connection

Like many teachers, parents report trying to help their children learn math, but they feel less capable to support early math than they do literacy. Many of the recommendations one would make to improve early math and science teaching apply equally to improving the home environment's learning supports. These include educating parents about the importance of early math, providing concrete examples of the ways preschoolers learn math, and providing ways to leverage and increase children's natural interest in math ideas.[81]

Efforts to increase parental involvement should involve more than providing materials; this kind of approach does not educate parents and is particularly ineffective with families most in need of assistance and support.[82] True support requires personal interactions and special training with families that reinforce their critical role in their child's learning and provide clear strategies for supporting it. A successful parent education program designed by Starkey and Klein[83] met the criteria of sustained learning experiences for parents and addressed a range of mathematical topics with specific activity ideas. Experienced teachers modeled activities and directly supported parents' efforts to engage with their children. Parents were very interested in supporting their children's mathematical learning once provided with strategies for doing so. Most important, children whose families participated showed developmental gains in their emergent mathematics knowledge.

A number of authors suggest that professional development for early math and science should provide teachers with strategies to involve and inform parents, and there is some evidence of success on this front.[84] As noted by Cannon and Ginsburg,[85] preschool teachers often share parents' lack of knowledge about supporting early math learning. For this reason, effective professional development becomes even more important if teachers, in addition to supporting children's math and science learning directly, are also doing so indirectly by educating their parents.

Conclusion

Researchers, educators, and policy-makers agree that improving the mathematical and scientific readiness of young children is a critical educational goal. Some progress has been made in meeting this challenge. A rich research base identifies the wide range of mathematics and science competencies of preschool children. We must go beyond identification to describe the developmental trajectories or learning progressions for particular skills,[86] and this work is well underway in early mathematics.[87]

Recognition of the importance of early math and science is evidenced by the fact that standards for early mathematics and science learning are in place in almost every state. A number of widely used preschool curricula are strengthening their offerings in mathematics and, to a lesser extent, science. True research-based curricula for early math have been developed and continue to be tested for effectiveness. Early science programs also exist and some are being evaluated for effects on learning outcomes. The need to assess young children's learning in authentic and appropriate ways has been acknowledged, and new tools are being developed. Required changes in teacher preparation and professional development have been described, and some effective professional development models for early mathematics and science have been identified. Parental involvement is also essential to early mathematical and scientific development, just as it is for language and literacy.

There is no doubt that improvement of early mathematics and science education will require a great deal of effort, time and funding; however, progress is being made and we are cautiously optimistic that it will continue. We note that just a decade ago, authors of an American Association for the Advancement of Science report[88] on early mathematics, science, and technology education

repeatedly lamented inequities in access to quality preschool education and recommended that this be a top funding priority. Ten years later, access to prekindergarten has never been greater, with more than 2 million 3- and 4-year-olds enrolled in state-funded preschool, special education, or Head Start programs in the 2007-2008 academic year.[89] While acknowledging that deep challenges exist to improve the mathematics and science education of preschool children, the evidence presented in this brief provides some clear directions for change. Lessons learned from the language and literacy domains can also guide efforts in early math and science. A number of promising approaches to curriculum, assessment, teacher training, and parent education exist. These can serve as models for larger scale efforts to improve practice in the preschool classroom, increase teacher knowledge, develop strong home-school connections, and ultimately prepare young learners for future success in mathematics and science.

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