Rosanne Regan Hansel

FOREWORD BY MARY JO POLLMAN

Exploring the 3-D World

Developing Spatial and Math Skills in Young Children

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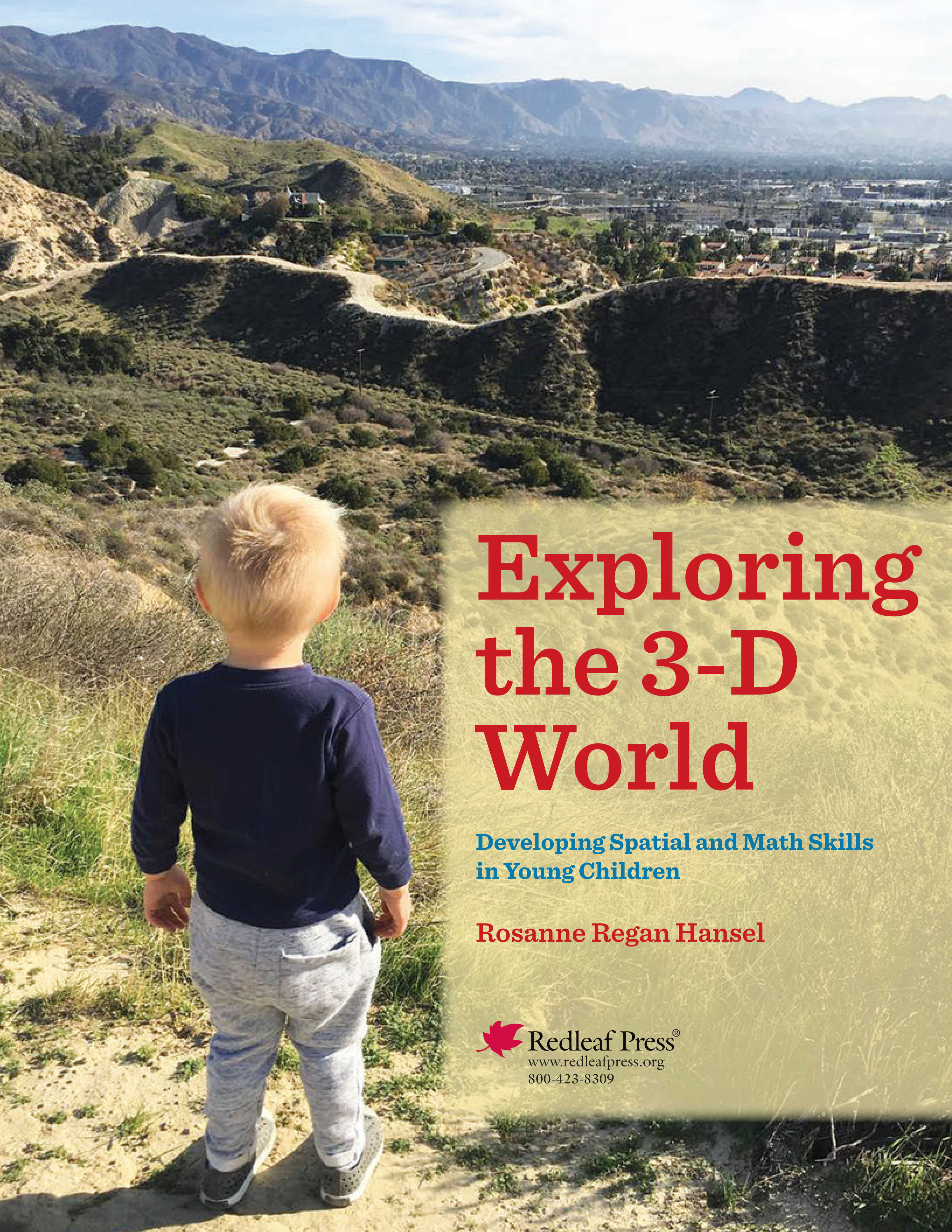

Exploring the 3-D World

Developing Spatial and Math Skills in Young Children

Rosanne Regan Hansel

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This book is dedicated, with love, to Dagan and Aspen.
With you on the West Coast and me on the East Coast, the space between us is too wide!
Using my new dimension-shifting skills, I will take giant steps from here to there
to give you big hugs and kisses!

Contents

Foreword

If you were to ask teachers to talk about the importance of spatial thinking, many of them would not be able to express its significance or give examples of it. Teachers often cannot see spatial development's connections in their daily lives, especially because spatial development has often been overlooked in favor of the emphasis on literacy and number sense in our schools. Nonetheless, it is particularly important for STEM (Science, Technology, Engineering, and Math) as well as the arts.

Rosanne has elevated the often-unobserved skill of spatial development in early childhood to a new prominence that teachers will observe and significantly value in their early childhood programs, and she has greatly extended the possibilities for the important skill of spatial literacy for the reader. She has used research from cognitive researchers and the STEM fields to make the case that spatial learning is crucial for young children. The connections to spatial development need to be made at school, home, libraries, and museums while children are playing, and Rosanne does this at a multifaceted level. She has managed to capture and pass on to her readers examples of a variety of unique spatial skills demonstrated by children in different settings.

Many people think that spatial ability is innate, but it can be learned, and it can be an integral part of a play-based curriculum. Teachers and parents, however, need to support spatial understandings with skillful guidance, and Rosanne has shown through a myriad of examples how to promote these concepts. She offers many open-ended activities as well as guided activities to promote spatial development. She encourages teachers to pay close attention to spatial skills and understand that these skills are an entryway to math skills such as subitizing and recognizing two- and three-dimensional shapes.

This book echoes and extends the work of historical figures who emphasized block building, including Friedrich Fröbel and Patty Smith Hill. However, Rosanne has taken the concepts in spatial development to a higher, more comprehensive level with two- and three-dimensional objects. Rosanne's art and early childhood background have enhanced her many ideas with geometric shapes and patterns and her unique ideas for transforming, composing, and decomposing figures. The inclusive examples bear witness to little architects and engineers becoming creative spatial thinkers. Building is an important part of play, the initial step in a child's education. Play can encompass manipulating objects at a basic level, but in extended play children can tackle complex construction and artistic problems. This helps children grow into adults who are problem solvers.

Exploring the 3-D World will turn spatial development from an overlooked skill to a focused skill for all teachers to promote throughout their classrooms. This book will benefit so many organizations interested in promoting the STEM arts through the interdisciplinary use of spatial development. Expanding on her previous award-winning book, *Creative Block Play*, Rosanne's work will increase the value and significance we place on spatial problem solving in our early childhood programs.

—Mary Jo Pollman, PhD
Professor Emerita, Early Childhood Education
Metropolitan State University, Denver, Colorado
Author of *Blocks and Beyond: Strengthening Early Math and Science Skills through Spatial Learning* and *The Young Artist as Scientist: What Can Leonardo Teach Us?*

Acknowledgments

This book would not have been possible without the contributions of extremely dedicated early childhood educators and administrators from several New Jersey school districts. They went above and beyond sharing inspiring stories and photos of the children you see featured in this book. I extend my deepest appreciation to Kate Rosander, elementary supervisor at Scotch Plains–Fanwood Regional School District, for her expert feedback and for supporting her teachers over the years in documenting their students' progress in spatial learning. My heartfelt thanks go out to the following preschool and kindergarten teachers from Scotch Plains–Fanwood: Jennifer Campanile, Kristen Cecchini, Kim Ciemniecki, Karen Glod, Filma Marchishin, Madison Savulich, Laura Smoot, Kate Szczubelek, Heather Terantino, Suzanne Toriello, and especially Amber Jarrett and Kelly Bhatia, who so graciously invited me into their classrooms. I thank Katie Spadola Whalen for her inspiring guidance to these teachers at Scotch Plains–Fanwood and for photo contributions from her classroom and home setting. Warmest thanks to Dr. Jorie Quinn, STEM specialist, and kindergarten teacher Krista Crumrine from the Union City School District, for their continuing enthusiasm and contributions. Many thanks to former director of early childhood Dr. Renee Whelan (now assistant professor at William Paterson University) and math supervisor Melanie Harding at Long Branch Public Schools, who invited me to speak about spatial development. First-grade teachers Kevin Gilbert, Lisa Pangborn, and Tracey Cummings and kindergarten teachers Sean Kelly and Michelle Fiore deserve a big thanks for their photos. Heartfelt thanks to James DeSimone, curriculum supervisor of early childhood education at the Mount Laurel Schools, and Carolyn Wiley, kindergarten teacher at Parkway Elementary School. I so appreciate the invitation to visit the Mountain Villa School in Allamuchy Township School District and the contributions of kindergarten teachers Catherine Cefaloni, Robin Samiljan, and Paige Schmiedeke and their administrator, Melissa Sobel.

At the 2019 conference of the National Association for the Education of Young Children (NAEYC), I attended the inspiring session "Building Developmentally Appropriate Learning Environments for Spatial Thinking: Understanding Learning Trajectories for Maps and Coordinates," presented by Dr. Kevser Koc, PhD, associate professor in early childhood education at Istanbul Medeniyet University, and Dr. Yusuf Koc, PhD, associate professor of mathematics education at Kocaeli

University (Koc and Koc 2019). Each agreed to share photos and stories from the Çam Koleji school located in the Kartal district of Istanbul, Turkey. My sincerest thanks to the teachers at Çam Koleji, Nergis Sunbul Dogan, Seher Eksi, Yasemin Yildirim, Dr. Kevser Koc, and Dr. Yusuf Koc, for taking the time to contribute examples of what young children can do when given adult guidance. A special note of appreciation to school founder Mr. Nevzat Çam and the school governing board for supporting this research and work.

I was fascinated to hear Dr. Doug Clements present "Children's Mathematical Thinking, B-Grade 3: Using the Learning and Teaching Trajectories Tool to Teach Arithmetic" at the same NAEYC conference. I have included in this book only a tiny fraction of the incredible work that he and Dr. Julie Sarama have contributed to early childhood education. I so appreciate Dr. Clements's answers to my many questions following his presentation and hope you will visit www.learningtrajectories.org for more information.

The Boulder Journey School in Boulder, Colorado, is known for its innovative programs for young children. Alison Maher, executive director; Andrea Sisbarro and Vicki Oleson, school directors; Alex Cruickshank Morgan, community outreach specialist; and Jacie Engel, studio specialist, shared their extraordinary visual documentation of "The Exploring Boulder Game." They were also gracious enough to provide photos from their "Digital Humanities" presentation at the 2019 NAEYC conference, which gives the early childhood field new perspectives on the "T" aspect of STEM. I cannot thank the Boulder Journey School enough for permission to use their outstanding photos and stories.

Inspired at a workshop on block play by kindergarten teacher Kathleen Blass and preschool teacher Carrie Williams, I accepted an invitation from director Laura Sacco to visit the Charlestown Playhouse in Phoenixville, Pennsylvania. It was amazing to see well-loved blocks that were more than eighty years old still at the center of the curriculum. Many thanks to all the teachers who so warmly welcomed me to their classrooms, especially Kathleen Blass, Carrie Williams, Cindy Shillinger, and Rachel Applegate.

Beyond the early childhood classroom, we applaud the parents and grandparents who support spatial development by offering their little ones opportunities to explore the three-dimensional world. I am forever grateful to Pam Bonsell, Cecilia Tubo, Katie Whalen, and Emily and Jeffrey Engel for sharing their photos!

My eternal thanks to all the participants in the hundreds of workshops and seminars I have facilitated over the years. I continue to be inspired by your willingness, despite the overwhelming demands on you, to step out of your comfort zones to try out new ideas and strategies. I've included a few of the creative constructions and amazing drawings from the 2019 workshops.

I extend my profound appreciation to all the researchers, educators, and writers who have blazed new territory in bringing spatial development to the attention of those who care for and teach young children. The 2017 article in *EdWeek* by Jill Berkowicz and Ann Myers was the impetus I needed to set the ball in motion for this book, which was first sparked by the new research on spatial development I had discovered for my book *Creative Block Play.* In addition to Mary Jo Pollman, Douglas Clements, and Julie Sarama, in this book you will see names such as Kelly Fisher, Brian Verdine, Kathy Hirsh-Pasek, Nora Newcombe, Roberta Golinkoff, Susan Golbeck, Elizabeth Gunderson, Susan Levine, Brenna Hassinger-Das, David Lubinski, Sheryl Sorby, David Uttal, Jonathan Wai, and so many others who have inspired my thinking about spatial learning. You will also see many references to Ontario's Ministry of Education and Joan Moss, Catherine Bruce, Bev Caswell, Tara Flynn, Zachary Hawes, and the K–2 educators who have done an incredible job of documenting their work on spatial thinking in Toronto, Canada. Thank you Jo Boaler and Deborah Stipek for reminding us that everyone can learn mathematics, and to Karen Worth, Ingrid Chalufour, and Jeffrey Winokur for guiding me when I was the early childhood specialist for the National Science Foundation–funded Math Science Partnership at Rutgers University and for helping me understand the science of inquiry and the importance of representation.

From my beginnings as an art educator, I have been astounded by the many connections between the arts and STEM. I am thankful to Cathy Weisman Topal for her contributions to both these worlds and for introducing me to the process of line printing. It was also Cathy who urged me to read Mary Jo Pollman's book *Blocks and Beyond: Strengthening Math and Science Skills through Spatial Learning.* Dr. Pollman has written beautifully about these intersections in her books, widening my understanding of both worlds and providing feedback on the first manuscript. I am deeply indebted to her for agreeing to write the foreword to this book.

Many thanks to my agent, MaryAnn Kohl; my editor, Melissa York; art director Renee Hammes; copy editor Christine Florie; Wendy Holdman, layout; Douglas Schmitz, managing editor; marketing and publicity coordinator Meredith Burks; and the entire production staff at Redleaf for working out all the kinks along the way and for transforming a 2-D manuscript into a visually engaging 3-D book on math and spatial development.

My love and gratitude to colleagues and friends Pam Brillante, Karen Nemeth, Barbara Tkach, and Elizabeth Vaughan for their vital contributions to the early

childhood world, for keeping me abreast of important early childhood topics I might otherwise have overlooked, and for their most-appreciated ongoing support and encouragement.

It is easy to get carried away with an idea about how we can do a better job of helping young children develop spatial skills and thus give everyone an equal shot at achieving their highest potential. Reading Ann Pelo and Margie Carter's book *From Teaching to Thinking* and Erika Christakis's book *The Importance of Being Little* while in the process of writing this book reminded me that nothing is as important as the caring relationship between adult and child in the learning process. And while I have always believed in play-based learning, the new research on guided play cited in this book underscores that point and urges us to become even more attentive to mastering the art of teaching. May we never forget this!

My humblest thanks and deepest appreciation go to all the remarkable children who appear in this book and made amazing contributions. Finally, to my family—David, Amber, Andy, Jennifer, Emily, and Jeff—for their continuing love and support. I have dedicated this book to my beloved grandchildren Dagan and Aspen, who fill my life with incredible joy and give me so much hope for the future.

Introduction

We live in a 3-D world, but many of our learning environments offer few opportunities for three-dimensional exploration. A wide variety of hands-on tools are available that are known to improve cognitive development, yet we invest millions of dollars in curriculum materials that are inappropriate for young children. Our world is one of images, but our classrooms are frequently geared toward teaching words and numbers. Ironically, new brain research and child development studies are filling professional journals with mounting evidence that early childhood educators, those who care for and teach children from birth to age eight, need to start paying greater attention to spatial skill development. Exploring the 3-D world is key to building spatial skills in the early years. However, interacting with two- and three-dimensional materials, and learning to use and interpret images along with words and numbers, are also crucial aspects of spatial development.

As an educator who taught the visual arts to elementary-age schoolchildren, I was convinced that the spatial and perceptual experiences they had during art explorations benefited them in ways not typically acknowledged in the education world. For example, during an exploration of architecture, preschool and kindergarten children learn about geometric shapes, both 2-D (rectangle-shaped windows and doors or triangle-shaped roofs) and 3-D (cylinder-shaped towers and cone-shaped steeples) in the built environment. Positioning themselves in front of or beside a building, children observe building exteriors from many different perspectives and then draw what they see. They learn about builders' blueprints and how to create floor plans, imagining themselves with a bird's-eye view of a familiar room or making maps as they plan out a city. Through trial and error children learn about scale when they calculate how many cars fit into a garage made out of magnetic tiles or how big to make an enclosure of blocks so three children can fit inside. These authentic play-based explorations are prime opportunities for learning spatial skills in the early years.

In her presentation "Architecture and the Hundred Languages of Children," Ann Gadzikowski (2019) wondered why the study of architecture isn't more prevalent in early childhood curricula. The children's books Gadzikowski featured in her workshop as a provocation for playful explorations focus on architecture and literature and are a perfect accompaniment to the construction materials found in most early childhood classrooms. They are also an excellent way to introduce and teach spatial skills. I have included a few of her suggestions, in addition to my own, in the chapters that follow.

We know that spatial skills are far more important to achievement than previously realized (McClure et al. 2017). Having good spatial skills strongly predicts a child's future achievement in science, technology, engineering, and math (STEM) subjects (Lubinski 2013; Uttal et al. 2013) and mathematics in particular (Clements 2019). For example, scientists say that there is a relationship between playing with puzzles and blocks, having a strong number sense, and being able to solve computation problems (Moss et al. 2016). Because of this growing body of research, the National Council of Teachers of Mathematics (NCTM) has recommended that a stronger focus be placed on spatial reasoning in pre-K–eighth-grade math education (Schwartz 2017). If we truly want to close the achievement gap, researchers say that we must start in the early years. Children living in poverty, children with disabilities, English-language learners, and any child who learns better with a visual-spatial approach to STEM subjects will benefit from the development of their spatial skills. Chapter 1 will provide a definition of spatial skills and why they are important.

While we know that spatial reasoning skills are critical to STEM subjects and provide equitable access for underrepresented populations, helping children excel in math and be prepared for STEM careers is not our only goal. There is much we can do to help children navigate and understand the world around them, cultivating their curiosity, persistence, and intellectual capacity beyond the narrow definitions of academic achievement. After visiting the extraordinary early childhood centers in Reggio Emilia, Italy, Reggio-inspired schools in the United States, and the preschools of Auckland, New Zealand, where abundant resources are available for creating the highest quality learning environments for young children, it is painfully apparent that we could be doing more for young children, especially those living in poverty, throughout the United States. Pelo and Carter echo this sentiment when they state that "poverty definitely has an impact on the child and family, but so do rich experiences, provocative and engaging environments and quality interactions" (2018, 344). All too often play has been eliminated for these children and replaced with paper and pencil activities in order to meet a long list of learning goals and standards. You are sure to be inspired by the teachers you will meet in this book who have not forgotten the importance of what Pelo and Carter call "intellectually rigorous, full-hearted teaching" (2018, 29) as they playfully integrate the spatial skills needed for STEM success and for all areas of life.

What can we do to infuse spatial skills into the curriculum and everyday life? A wealth of information is now available from research to guide best practices that support spatial learning. Chapter 2 summarizes many of the strategies for teaching math and spatial skills recommended in this literature, starting with the basic fact that it is critically important for teachers to understand what spatial skills are. Here I recommend joining professional learning communities, communities of practice, and other models that encourage practitioners to meet in order to connect theory to practice. One example would be to meet with interested colleagues on a regular basis, using this book as a guide to plan spatial activities and to inspire reflection and discussion as you implement these playful explorations in your classroom.

Many experts find that children benefit from regularly engaging in a variety of tasks across subjects, guided by their interests and responses, rather than through discrete lessons squeezed into an already crowded curriculum. For example, children can learn important spatial skills, such as composing, decomposing, turning, and rotating, while playing with blocks. Having time to engage in play with a variety of materials is critically important to fostering spatial skills, but we know that is not enough. The experts say that children are unlikely to learn the intended concept solely through play (Seo and Ginsburg in Moss et al. 2016; Verdine et al. 2017) but rather require adult guidance to maximize understanding. Chapter 3 introduces the idea of "guided play," where adults offer feedback to scaffold children's learning. During guided play children are provided materials and opportunities for learning that focus on spatial skills while adults guide children to a deeper understanding of those skills and encourage the use of spatial language in context. Chapter 3 goes on to outline the essential components necessary to plan a playful exploration that is focused on spatial skill development.

Based on the research outlined in chapters 1 and 2 and the essential components of a playful exploration in chapter 3, chapters 4 to 9 feature key spatial skills that researchers have identified as important for young children to learn. The skills are accompanied with illustrated examples of activities designed for children ages four to six. These authentic examples come from public preschool and kindergarten classrooms, private preschools and child care centers, and home settings. While the activities in this book are primarily geared for children in preschool and kindergarten, some can be adapted for younger or older children. You will see that each chapter in this book focuses on specific spatial skills, with ideas to support spatial skills in learning centers, a list of important spatial skills and vocabulary, suggested questions and conversation starters to expand learning, ideas for experiential activities to try at home, and recommended children's books that reinforce the spatial skills introduced. In every case the important spatial concepts will be clearly presented so that both children and adults trying out these ideas for the first time can become more skilled at observing, questioning, exploring, and reflecting to deepen understanding of each concept.

In chapter 10 we will take a look at how visual representations, such as documentation of children's experiences and displays of data in graphs and charts, are helpful in opening new pathways to learning across the curriculum. Also covered is how visual representations, such as drawing, can be an important tool in the development of spatial skills.

It is not the intention of this book to prescribe activities to be copied step-by-step. Once you have a better understanding of spatial skills, I hope you will be inspired by the teachers and children featured on these pages to challenge yourself and your students to create your own spatial learning experiences based on newly discovered passions and interests.

Embracing the importance of spatial skills and starting to incorporate more playful explorations into your classroom may seem overwhelming. However, remember that children are phenomenal learners, full of curiosity and joy. When you share in their excitement in learning while guiding the children to deeper understanding, you will be amazed and inspired by what very young children can accomplish!

Part One

What We Know about Teaching Spatial Skills

1

Definition and Rationale for Teaching Spatial Skills in the Early Years

Because you are reading this book, you may already be convinced that you should be teaching spatial skills in your early childhood classroom. I have found, however, that most teachers have little guidance from their curriculum materials on what spatial skills are, why it is so important to support children in developing these critical skills, what type of activities strengthen spatial skills, and what strategies they can use to support spatial learning.

DEFINING SPATIAL THINKING

Spatial skills have been studied for more than a hundred years, but the definition of spatial skills varies depending on the field—be it geography, cognitive psychology, art, science, mathematics, or engineering (Sorby 1999). It can be confusing! In this book we will use the definition provided by the US National Research Council in its publication *Learning to Think Spatially*: "Spatial reasoning, or thinking, involves the location and movement of objects and ourselves, either mentally or physically in space" (National Research Council in Ontario Ministry of Education 2014, 3). We will focus primarily on spatial skills in STEM with an emphasis on mathematics, using the general term “spatial skills.”

A think tank of mathematicians, math educators, and psychologists from Canada, Australia, and the United States has developed a list of actions included in spatial thinking skills, including perspective taking, visualizing, locating, orienting, dimension shifting, pathfinding, sliding, rotating, reflecting, diagramming, modeling, symmetrizing, composing, decomposing, scaling, mapmaking, and designing (Davis, Okamoto, and Whitely in Moss et al. 2016; Ontario Ministry 2014). This list provides the organizing framework for playful explorations promoting spatial skills that you will find in part 2. Note that each of these spatial skills does not fit neatly into a chapter heading, and many of the explorations introduced in one category can actually nurture more than one spatial thinking skill.

Research shows that there are seven basic reasons why we should be helping children develop spatial thinking skills in the early years.

1. Spatial skills are essential for functioning in our day-to-day world

Having good spatial sense helps us pack our luggage, select the appropriate-sized container for storing leftovers, and follow a map so we don’t get lost. In her article on improving spatial skills in children, Dr. Gwen Dewar defines it beautifully when she says, “It’s the mental feat that architects and engineers perform when they design buildings. The capacity that permits a chemist to contemplate the structure of a molecule, or a surgeon to navigate the human body. It’s what Michelangelo used when he visualized a future sculpture trapped inside a lump of stone” (2018). When you really think about it, and as you learn more about spatial orientation in chapter 9, there are many fields beyond STEM that require strong spatial thinking skills, such as architecture, the arts, geography, professional sports (Ontario Ministry 2014), and many others that we haven’t even dreamed of yet.

2. Spatial thinking is important in many subject areas

Knowing that spatial thinking skills are critical in many fields, it only makes sense that spatial thinking is also important in many subject areas in school. For example, spatial knowledge is basic to organizing words on a page from left to right (for the English language) and in understanding how to use horizontal, vertical, and diagonal lines to make the shapes of specific letters (Golbeck 2005). The arts are filled with opportunities that engage spatial skills, whether through manipulating shapes and forms while working with clay or moving the body through dance or dramatic play. The visual arts, in particular, are most often seen as a means for self-expression in the early years, and while that is extremely important for young children, embedding spatial thinking skills in the visual arts should not be overlooked. We will provide explorations in part 2 that you can try in your early childhood classroom or at home.

In *Learning to Think Spatially*, the National Research Council issued a call to educators "to recognize spatial thinking as important not only across mathematical strands but also across subject areas" by infusing spatial thinking into existing curricular objectives (National Research Council in Ontario Ministry 2014, 5). For early childhood educators, integrating spatial learning in all areas of the curriculum is just as important as addressing the physical, social-emotional, and cognitive development of the whole child.

3. Spatial thinking plays a critical role in learning mathematics

Research findings from psychology and neuroscience as well as education are converging to highlight the importance of spatial skills. According to one study (Gunderson et al. 2012), for example, over the course of one school year, children's spatial skills in first and second grade predicted improvements in linear number line knowledge. This may come as a surprise to many early childhood educators and even some math specialists who have focused solely on numeracy in the early years, but research has shown that "children will not learn number and operations, which includes solving problems involving these topics, unless they also learn spatial reasoning" (Clements in Moss et al. 2016). Susan Levine, a leading authority on spatial and mathematical learning, adds that improving children's spatial thinking at a young age not only may help foster skills specific to spatial reasoning, but also improves symbolic numerical representations (Gunderson et al. 2012).

In 1967 Jean Piaget came to the conclusion that young children didn't learn mathematics through verbal instruction alone but rather through hands-on interaction with many kinds of materials (Hirsch 1996). However, we are now just beginning to understand the interplay between spatial reasoning (especially with manipulatives such as blocks and puzzles) and mathematics. We know that by focusing on spatial thinking, we can tap into a child's diverse strengths. New research on spatial thinking underscores the importance of spatial reasoning skills in geometry, measurement, and problem solving in children's early math experiences (Shumway in Ontario Ministry 2014). Because of this growing body of research, the NCTM has recommended that a stronger focus be placed on spatial reasoning in pre-K–eighth-grade math education (Schwartz 2017).

4. Spatial thinking is a predictor of achievement in STEM careers

When children are just learning to speak, write, and count, teachers and parents are probably not thinking about preparing them for career paths, even though we know that good spatial skills strongly predict achievement and attainment in STEM fields (Uttal, Miller, and Newcombe in Berkowicz and Myers 2017). You may ask, why worry about spatial skills while children are so young? One reason to start early is because it is becoming increasingly clear from the research that strengthening executive function skills, such as working memory and attention along with early spatial skills, improves children's math scores (Verdine et al. in Berkowicz and Myers 2017). And when you consider that young children who may not be exceptional in mathematical or verbal abilities might have strong, but overlooked, spatial abilities, we are leaving an untapped pool of talent for STEM careers (Wai, Lubinski, and Benbow 2009).

5. Spatial thinking is an overlooked area of STEM instruction

When the insightful report *STEM Starts Early: Grounding Science, Technology, Engineering, and Math Education in Early Childhood* (McClure et al. 2017) first appeared, it brought attention to the barriers that exist in supporting early STEM learning. Some of those barriers include the need for additional STEM training for teachers so that they can engage young children in developmentally appropriate STEM learning; the need for more connections between school, home, and community learning environments, such as libraries and museums; and the lack of research and policy to support STEM learning in the early years. However, citing important research on spatial development, authors Berkowicz and Myers (2017) argue that spatial skills were overlooked as a key feature of STEM education in the report. Echoing this concern, mathematics educators and researchers in Toronto, Canada (Moss et al. 2016), also noticed a curious neglect of spatial reasoning in their math curriculum and took action to create one, Math 4 Young Children, that included spatial-focused activities.

If we know that improving children's spatial skills has a positive impact on their future success in STEM disciplines, then we need to incorporate spatial skills more explicitly and recognize the critical role they play in children's development. As Berkowicz and Myers state, "We must increase awareness of what spatial skills involve, their relevance to everyday life and STEM success, and how we can support young children's spatial development as part of our improvements in STEM education" (2017, 3).

6. Spatial thinking provides equitable access to math for all children

Despite efforts to close the math achievement gap for children from communities with low socioeconomic status where children of color disproportionately reside, the gap remains throughout elementary, middle, and high school (National Assessment of Educational Progress in Davis and Farran 2019). Improving access to quality math instruction is a matter of social justice. Knowing the connection between spatial thinking and success in math, there is much work to be done to include spatial skills with instruction and intervention (Jordan and Levine in Ontario Ministry 2014, 9).

Identifying children's spatial abilities, which often go unrecognized, and using those strengths to learn math is an important step in reaching underserved populations. In addition to children from underresourced communities, this includes girls and children with learning disabilities, particularly difficulties in learning math. Assessments to measure spatial ability have been around for decades, but since they don't cover the full range of spatial skills and aren't typically designed for young children, this book recommends performance-based assessments as introduced in chapter 2 and outlined in chapter 3 as one way to identify and strengthen spatial skills.

While not specifically focused on spatial thinking skills, the team of STEM experts called together by the US Department of Education (2016) Office of Innovation and Improvement put forth an urgent call for early exposure to and engagement in STEM learning experiences, as well as equitable access, in its report *STEM 2026*.

7. Spatial thinking can be improved

For many years people believed that spatial ability was something you either had or you didn't. In 2013 a team of researchers led by David Uttal summarized two decades of research on spatial training. They concluded that all age groups can improve spatial thinking with practice, through familiar activities such as puzzle play, block building, and art and design tasks (Uttal et al. 2013).

The bottom line is that intentionally designed, play-based spatial explorations with adult guidance can improve math and spatial skills for all children. The next chapter will provide an overview of what the research tells us about successful strategies for teaching these critical math and spatial skills.

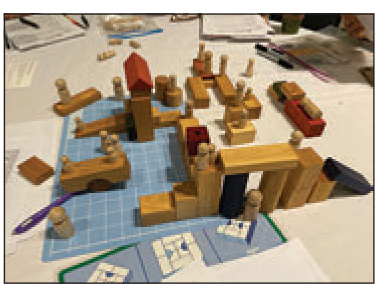
2

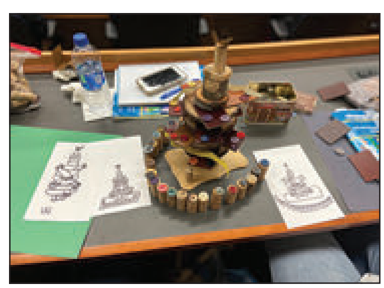
Strategies for Teaching Math and Spatial Skills

As discussed in chapter 1, spatial skills are important and can be improved through early education and experience. In early childhood education, we understand that teaching discrete spatial skills is not as effective as integrating them across all areas of a play-based curriculum. The teaching strategies shared below are from the leading experts in mathematics and spatial skill development.

KNOW WHAT SPATIAL SKILLS ARE AND OVERCOME ANXIETIES ABOUT TEACHING THEM

Knowledge of what spatial skills are and how best to support spatial development in children is evolving. The definition and justification for teaching spatial skills proposed here is just the beginning. Keeping up to date with new research through readings and professional development increases teachers' familiarity and comfort with teaching spatial skills. Participating in workshops where there are opportunities for hands-on exploration with three-dimensional materials, as illustrated in the photos below, helps build new perspectives in introducing these skills in the classroom.





Workshops are a good place to start, but having support during the initial phase of implementation helps teachers gain confidence in teaching spatial skills and strengthens their instruction. In the Scotch Plains–Fanwood Regional School District in New Jersey, elementary education supervisor Kate Rosander created a community of practice for preschool and kindergarten teachers offering professional development on specific spatial reasoning skills and facilitating discussions on best practices in teaching them. You will see examples throughout this book showcasing the successes and challenges teachers experienced as they documented their work with children. Here is Kate's story:

Mrs. Kate Rosander, Elementary Education Supervisor, Scotch Plains–Fanwood Regional School District, New Jersey

"What began as a simple invitation to contribute photographs to this book quickly blossomed into a collaborative journey of inquiry alongside fourteen dedicated preschool and kindergarten teachers. Over the course of several months, we read research, observed children, shared stories, and asked questions to better understand how children develop spatial reasoning and what role we, as educators, played in that development. The photographs of children in action became a springboard for reflection, which started with our noticing what children were doing and led to wonderings of 'why' and 'what if.' Why did boys frequent the block center more often than girls? What would happen if we introduced smaller blocks, added accessories, provided authentic examples, or changed the classroom space so that more children could build simultaneously? Why did children struggle with creating radial patterns when line printing? What would happen if we encouraged them to rotate their papers while working? These questions piqued our curiosities, challenged our thinking, and ultimately opened doors to improving our practice to best meet the needs of our youngest learners."

UNDERSTAND WHAT TYPES OF ACTIVITIES SUPPORT SPATIAL DEVELOPMENT

An experienced early childhood teacher knows that standards and curricula should guide, not dictate, instruction because each child requires us to make adjustments in our approach to meet their needs. This is even truer when guiding children in developing spatial skills. Because spatial skills are rarely addressed in most curricula, it is necessary to target specific spatial skills by supplementing the curriculum (Stipek 2019).

Understanding that teachers are already overwhelmed by the demands of a crowded curriculum, Newcombe (2013) suggests "spatializing" the existing curriculum by infusing spatial skills into the school day. She says you can easily incorporate puzzles, promote guided play with blocks and geometric shapes, read books with spatial words in them, include spatial skills in the visual arts, and encourage spatial learning both inside and outside the classroom. This is a great place to start, but we know that it is not enough. Teachers need support as they plan and implement these activities.

In a university setting in Istanbul, Turkey, Professors Kevser Koc and Yusuf Koc partnered to collaborate with kindergarten teachers to develop activities that foster mathematical and spatial reasoning skills. This is their story:

Dr. Kevser Koc, PhD, Associate Professor in Early Childhood Education, Istanbul Medeniyet University, and Dr. Yusuf Koc, PhD, Associate Professor in Mathematics Education, Kocaeli University, Turkey

"We are working with kindergarten children at a private school, Çam Schools in Kartal, [a district in] Istanbul, Turkey. The school houses a middle school, an elementary school, and a kindergarten. The kindergarten has two rooms with mixed-aged children. In each room, there is a master teacher. There is also an assistant teacher working with both master teachers.

"We have been collaborating with these teachers about a year; working through developing and implementing activities to support mathematical and spatial reasoning skills. These activities are based on Learning Trajectories by Clements and Sarama (2014). We used the trajectories as a guide to plan the activities that are developmentally appropriate and challenging enough to provoke children's thinking toward a higher level. Also, we considered children's individual needs and differentiate our instruction.

"Throughout this project, Dr. Kevser Koc visited the school at least once a week and worked with teachers and students to build a richer environment that facilitates children's understanding of spatial orientation. We began with initial basic ideas such as directional, locational, and relational concepts, including 'in,' 'on,' 'under,' 'up' and 'down.' Then, we developed more complex tasks, each time directing children toward more abstract forms of thinking and introducing different representations of space. Children worked in multiple organizations; individual, small groups, and whole class. After about four months, children did not only love those activities, but they also improved a lot. We believe this is just a beginning!"

ORGANIZE THE LEARNING ENVIRONMENT TO PROVIDE MATERIALS AND OPPORTUNITIES TO INVESTIGATE SPATIAL SKILLS

Providing diagrams, maps, graphs, drawings, photographs, and visual daily schedules is important to creating a rich learning environment (Ontario Ministry 2014). Children require different methods, pathways, and representations for learning math (Boaler 2016) and for applying spatial skills to all other subject areas (more on this in chapter 10).

In early childhood classroom learning centers, children can be offered meaningful opportunities to investigate mathematical and spatial thinking concepts. By using hands-on materials in the block area, in the math center, or embedded in art, games, and dramatic play, children can broaden their math and spatial skills. Although a few recommendations for technology use are included in this book, research does not show that it is more effective than interactions with real objects (Zosh et al. in Berkowicz and Myers 2017).

Blocks are an excellent example of a 3-D material that helps young children move between concrete representations and abstract ideas, building a deeper understanding of math and spatial concepts.

Block Activities That Support Spatial Skills

Block Activity	Spatial Skill
Constructing with blocks	Transforming shapes by rotating, sliding, or flipping them (making as many combinations as possible through manipulation)
Filling containers with blocks; filling enclosures with objects	Learning to judge capacity and volume. How many can fit in the container? Does the object fit in the enclosure?
Fitting blocks together and taking them apart	Decomposing (part-whole integration that involves seeing the shapes embedded in other shapes and seeing them as a whole)
Changing the shape and arrangements of blocks by stacking or enclosing them	Composing (physically or mentally combining shapes to make different shapes)
Observing block constructions from different viewpoints, such as from above, from behind, or in front of a mirror	Perspective taking (considering the perspective of someone who is in a different location and how that view might be different from yours)
Describing positions, directions, and distances, such as outside, inside, over, and under, while building	Using spatial language in context while building

Continued on next page.

Block Activities That Support Spatial Skills (continued)

Block Activity	Spatial Skill
Building on the floor or outdoors	Knowing your body's position and where it is in space (spatial awareness, spatial orientation)
Using blocks to represent other objects	Representing symbolically one object for another
Interpreting spatial relations in drawings, pictures, and photos	Using nonverbal reasoning; seeing connections between 3-D objects and 2-D representations
Drawing 3-D constructions or reproducing real-life structures	Understanding spatial relationships and reinforcing visual-spatial memory
Comparing and measuring the size, shape, thickness, length, and height of blocks	Comparing objects; scaling up or down (imagining objects or amounts as proportionally larger or smaller)
Making a model from a map or blueprint	Visually interpreting maps and blueprints
Building a bridge	Learning to judge the distance between objects; learning to fit blocks together and balance them
Designing with blocks	Creating patterns (radial, linear, symmetrical, tessellations)
Playing hide-and-seek with blocks	Locating and remembering locations of objects
Putting blocks back on the shelves (marked with the shape of the blocks)	Classifying, sorting, and sequencing shapes

MAKE MATH LEARNING EXPERIENCES CHALLENGING, COLLABORATIVE, AND PLAYFUL

A rich learning environment with hands-on materials for exploring is important, but it is not enough if we want children to develop strong spatial skills. Stanford professor Dr. Deborah Stipek, who studies early childhood math and motivation, says that children do not learn solely through play (2017). When thinking specifically about spatial skills, the teachers who contributed to this book found this to be true. Spatial concepts and vocabulary typically did not surface in children's play but had to be intentionally planned with clear learning goals, appropriate materials, and skillful guidance.

Learning math doesn't have to be painful, however. Stipek insists that "young children enjoy learning math and can learn far more than was previously assumed—without a single flashcard or worksheet" (2019, 59). Dr. Jo Boaler, a Stanford mathematics educator and author of *Mathematical Mindsets*, agrees that the traditional methods used in math education don't work. She is convinced that we kill curiosity and creativity when we expect children to work alone on meaningless worksheets instead of allowing them to work collaboratively to solve a problem they care about (Boaler 2016).

Piaget said that learning is the "mindful construction of new knowledge based on hypothesis testing and revising one's own knowledge," but he emphasized that a hallmark of this type of inquiry-based education was learning through play (Zosh et al. 2018, 3). One of the challenges identified by STEM experts who authored the *STEM 2026* report (US Department of Education 2016) was the need to redesign learning activities to be more play-based and less centered on a prescribed set of activities. Chapter 3 will show how it is possible to promote spatial thinking skills in challenging, collaborative, and playful explorations.

EMPHASIZE SPATIAL LANGUAGE, SPATIAL THINKING, AND THE USE OF GESTURES THROUGHOUT THE DAY

Teaching and modeling specific spatial words (such as *left, right, above, below*) throughout the day has been correlated to children's spatial ability. Studies have shown that children who were taught spatial language performed better on spatial tasks than children who were not (Tepylo, Moss, and Hawes in Ontario Ministry 2014). One example of an activity using spatial language to promote children's understanding and use of spatial words is number sudoku. In a traditional sudoku game, players complete a grid so that every row and column and 3 x 3 box contains every digit from 1 to 9 inclusively. In this game adapted for younger children, each child is given a 4 x 4 wooden grid and four sets of square tiles numbered from 1 to 4. The teacher guides children in placing a tile next to another tile, under another tile, or between two tiles, or two tiles under another tile. Players are expected to complete the sudoku, making sure no number is repeated in a row or column. Research also shows that the more children are exposed to spatial language, the more likely they will use that language themselves, especially in the presence of spatial materials such as building blocks (Ferrara et al. in Moss et al. 2016). Throughout the explorations in this book, we encourage parents and educators to emphasize spatial language, including words that describe shapes, positions, movements, comparisons, height, width, length, distance, and properties of a shape or line.

Spatial Language

Location/position words: on, off, on top of, over, under, in, out, into, out of, top, bottom, above, below, in front of, in back of, behind, beside, by, next to, between, in the middle, same/different side, upside down, right, left, north, south, east, west

Movement words: up, down, forward, backward, around, through, to, from, toward, away from, sideways, across, back and forth

Comparison words: larger, smaller, same, more, less, higher, lower

Spatial words that describe height, width, and length: tall, short, wide, narrow, long

Distance words: near, far, close to, far from, shortest/longest path

Transformation words: turn, flip, slide, reflection, rotation, put together, take apart, fold in half

Spatial words that describe properties of a shape or line: curve, point, angle, line, edge, corner, base, face, parallel

Shape vocabulary: see chapter 4

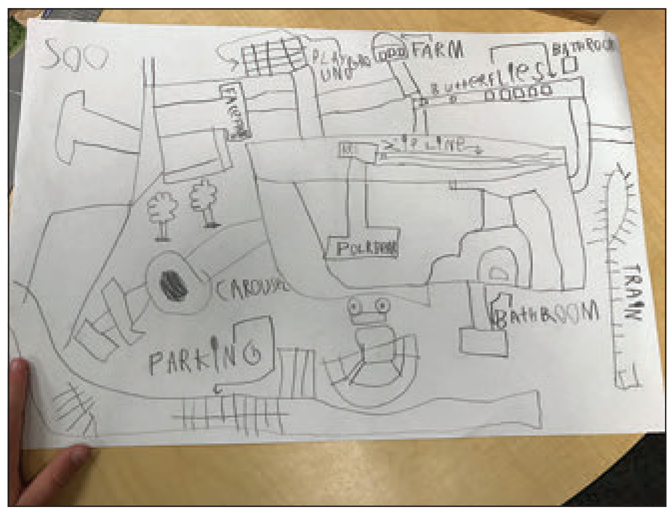
(Moss et al. 2016; Copley 2000)

Young children are not always able to offer verbal explanations for spatial solutions to a problem, especially those who are dual-language learners and those with language delays. Communicating ideas using hand gestures improves spatial thinking (Newcombe 2010). For example, a child might gesture that they want to build a tall structure by standing on their tippy-toes and stretching their hands up high. The child's teachers can help match the word to the child's gestures. "Yes, you want to make your building tall, even higher than your head." Likewise, teachers can help their students understand ordinal numbers as the children line up in first, second, and third place by using body and finger gestures.

ENCOURAGE ACTIVE, PHYSICAL EXPLORATION OF THE REAL WORLD

The *STEM 2026* report features the Smithsonian Early Enrichment Center (SEEC), an early childhood demonstration school in Washington, DC, for children ages two to five that encourages active exploration outside the classroom. Exploring the museum's collections is the foundation of the center's culturally diverse curriculum. Children learn through personal encounters with museum staff as they practice making observations, testing hypotheses, and discussing ideas (US Department of Education 2016). When the children create their own collection of mittens, shoelaces, or other favored objects, they begin to understand the idea of collections as an important mathematical concept.

You can take advantage of opportunities in your own community and offer activities that encourage spatial thinking. In one kindergarten classroom, children visited a local zoo and used a map provided from the zoo as a reference to draw their own zoo maps.



Children recreate the zoo with blocks.

EMPHASIZE THAT SPATIAL SKILLS CAN BE MASTERED WITH SOME TIME AND EFFORT

Many mathematics educators, including Boaler and Stipek, are concerned with the way math is taught. Boaler says we seem to reward those who can come up with the right answer quickly: "Math continues to be presented as a speed race, more than any other subject—timed math tests, flash cards, math apps against the clock. It is no wonder that students who think slowly and deeply are put off by mathematics" (2016, 30). Stipek adds that "strict adherence to pacing guides often results in instruction that is too hard for some children and too easy for others" (2019, 63), taking the focus off the needs of the individual child. The most challenging and important part of teaching is scaffolding, which helps children revisit ideas and learn them deeply.

In chapter 1 we learned that researchers found that spatial skills could be improved with practice. Boaler cites study after study that shows how intelligence can grow, adapt, and change when we have conversations, play games, or build with blocks, to give just a few examples. Yet so many people have been traumatized by math and believe that you are either gifted in math or you aren't. In her work with Carol Dweck, the developer of the idea of growth mindsets, Boaler has found that it is your willingness to persist (growth mindset) that is key to tackling more challenging problems. "If we believe that we can learn, and that mistakes are valuable, our brains grow to a great extent when we make a mistake" (Boaler 2016, 13).

A small percentage of children have disabilities that make math learning difficult, Boaler says, but most (about 95 percent) can learn math. It is important to know that children with poor spatial skills are often slow in making progress at first (Newcombe 2010), so it may take patience on your part to continue reinforcing these critical skills. If spatial activities are age appropriate and playful and adults provide encouragement and support, learning will be less stressful and more enjoyable for children.

Creating a radial pattern, one that starts at a center point with lines or shapes that move outward like the spokes of a wheel, can be challenging for young children. In this story, notice how Daraja is eager and willing to figure it out. As Kate Rosander tells it:

Mrs. Kate Rosander, Elementary Supervisor, Scotch Plains–Fanwood Regional School District, New Jersey

"Moments after being introduced to line printing and radial patterns, Daraja went to task. He worked systematically from the center out, in layers. First, he stamped the circle and put two intersecting lines through it to create the X. *Then he added the lines sticking out from the circle one at a time, proceeding around the circle like spokes on a wheel. Next came the lines perpendicular to each spoke to form a* T.

"Pausing in thought, Daraja examined his work before adding the next feature, which was the line perpendicular to the top of the T. *Again, he worked systematically around the circle, experimenting with the orientation of each line before placing it on the paper. With a quiet excitement and beaming smile, Daraja showcased his finished product."*

DEVELOP EQUITABLE APPROACHES FOR REACHING ALL CHILDREN

We learned from the research outlined in chapter 1 that children from low-income communities, predominantly those of color, enter kindergarten with a math achievement gap that persists into high school. We also learned about the need to address gender inequities and to implement new approaches for helping children with learning disabilities, including those with difficulties learning math.

Unfortunately, young children often receive unintended messages about their abilities based on group membership, such as boys being seen as more adept at engineering than girls or children of Asian ancestry being good at math. These messages can influence children's perceptions of themselves and teacher interactions with them (Erikson Institute 2017). In their chapter on fostering positive experiences in the math center, authors Davis and Farran suggest that early childhood teachers can change that perception "by having positive individual interactions, providing opportunities for exploration, extending children's initial interest, and structuring the environment to continuously attract and engage children in math learning," all of which are particularly beneficial for African American boys (Davis and Farran in Masterson and Bohart 2019, 81).

Sheryl Sorby has studied gender differences in spatial abilities (those that are innate) and spatial skills (those that are learned), and although tests of spatial reasoning show that women score lower than men, she is "not interested in arguing why the gap exists because training and practice can close it" (Kris 2016). Sorby believes that regardless of spatial abilities, engaging with spatially rich activities starting at an early age improves spatial skills and sets the stage for later STEM success. This means that teachers and parents must encourage girls to engage in more block and puzzle play, try out engineering and construction toys, make and read maps, and perform other practical spatial tasks. She is a strong advocate of having children build with blocks and then sketch what they constructed, which helps build mental visualization and rotation skills (Sorby 1999).

Children with learning disabilities and difficulties in learning math are another group that specifically require our attention. While we know a great deal about children with difficulties in language development, we don't know as much about identifying and helping children in math. We do know that some children have the learning disability dyscalculia, which means they have trouble understanding and solving math problems as well as learning basic math facts and concepts, such as sorting items by size, shape, and color or repeating simple patterns (Brillante 2017). Some children struggle with subitizing (the ability to know instantly without counting, for example, that five dots on a die is the quantity five), which puts them at serious risk in their mathematical development (Sarama and Clements in Ontario Ministry 2014). Another learning disability related to spatial cognition, spatial acalculia, makes it difficult to read symbols and arrange and write numbers (Mix and Cheng in Ontario Ministry 2014). So that teachers can respond immediately with appropriate activities, accommodations, and guidance, it is critical to have ongoing performance-based assessments that identify learning difficulties.

While not specific to math learning, Universal Design for Learning (UDL) is a scientifically valid framework that provides all students, not just those with disabilities, with multiple ways of acquiring knowledge and skills. According to CAST, the Center for Applied Special Technology (2018), the principles of UDL include providing multiple means of representation, expression, and engagement. For example, help children who are struggling with subitizing by giving them many opportunities to play dice games so they can practice identifying quantity more quickly as they read the die.

Targeting math strategies specifically, Boaler (2016) also emphasizes the importance of having high expectations for all children. In addition, she believes that we need to change opinions about who mathematic achievers are and give girls and children of color additional encouragement and support in this subject. Boaler believes that we can greatly improve math instruction for underserved populations by designing hands-on experiences, project-based learning opportunities, curricula with real-life applications, and opportunities to work together. Paying closer attention to spatial reasoning can provide unexpected entry points into mathematics for all children and improve their prospects for the future and success in later life.

USE AN ONGOING PERFORMANCE-BASED ASSESSMENT TO TRACK PROGRESS ON DEVELOPING SPATIAL SKILLS

Children enter preschool and kindergarten with a wide range of knowledge and skills. For example, Stipek (2019) cites a study that found some children had already mastered most of the math skills in the kindergarten curriculum. She is concerned that in our efforts to support low-achieving children, we should be careful not to overlook high achievers who require challenging mathematical tasks. To support her point, I have witnessed preschool children who can confidently identify and describe 2-D and 3-D shapes spending an inordinate amount of time in kindergarten going over the identification and description of shapes they have already mastered.

Even if spatial skills were included in the tests found in most math curricula, testing preschool and kindergarten-aged children at one point in time is not likely to provide reliable information about their spatial skills. Young children may not be able to demonstrate what they know and can do, for example, if they are anxious to perform in the presence of an unfamiliar examiner, if the test is not given in their home language, or if they are not developmentally ready. In addition, math education specialists like Boaler (2016) believe that testing and grading children discourages them from the important goal of taking on challenges and learning from mistakes in math. And yet if we are not identifying spatial abilities and skills in young children, David Lubinski, a researcher and psychologist at Vanderbilt University, says that “we could be losing some modern-day Edisons and Fords” (Quenqua 2013, 1). For this reason it is important to know where children are in their development of math and spatial skills so that they receive the proper support and reach their highest potential. In its position statement on Early Childhood Curriculum, Assessment and Program Evaluation (2003), the National Association for the Education of Young Children recommends that assessments for children birth through age eight should emphasize observation over time using a performance-based assessment to determine young children's strengths, progress, and needs.

Several of the teachers featured in this book use the birth through grade three performance-based assessment Teaching Strategies GOLD to assess children's understanding of spatial relationships and shapes. For example, kindergarten teachers will observe a child to see if they can "show that shapes remain the same when they are moved, turned, flipped, or slid" and can "break apart [and] combine shapes to create different shapes and sizes" (Teaching Strategies GOLD 2016, 125).

If you are currently not using a performance-based assessment that includes spatial skills, referring to the developmental progressions for spatial thinking outlined by Clements and Sarama (2014) could provide useful information. This research-based framework, called Learning Trajectories, helps teachers guide children on a path to reach specific goals. Preschoolers begin identifying shapes and describing spatial relationships, while kindergartners and children up to grade three begin describing shapes and space; composing and decomposing geometric shapes; judging capacity, length, and height; and describing and analyzing the properties of two-dimensional shapes. Several of the specific goals Clements and Sarama identify for spatial skill development include subitizing, composing 2-D shapes, composing 3-D shapes, spatial orientation, and spatial visualization. For spatial visualization, for instance, they describe developmental levels such as "simple turner," "beginning slider," and "slider, flipper, turner," and provide video examples on their website for each, giving teachers a clearer picture of what children can do (Clements and Sarama 2019).

Understanding the research on teaching mathematics and spatial skills as outlined in this chapter is a major consideration when planning playful explorations and tracking children's progress in acquiring critical spatial skills. Chapter 3 discusses more about how we define play and outlines the essential components of a playful exploration in an early childhood classroom.

EDUCATION / EARLY CHILDHOOD / STEM

Develop young children's spatial reasoning through play

"What a fantastic book! It joins two of the most important topics in early childhood education today—spatial reasoning and play. *Exploring the real world using spatial reasoning is not only important to STEM learning, it is essential to understanding who we are as humans on this big round Earth."*

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Developing these skills in children will cultivate their curiosity, persistence, and intellectual capacity beyond the narrow definitions of academic achievement. *Exploring the 3-D World* covers

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- **The essential components of playful exploration**
- **Key spatial skills that are important for children to learn**
- **How visual representations such as displays of data, drawing, and documentation open new pathways to learning**
- **Vocabulary and conversation starters to expand learning**
- **Activities for families to try at home with recommended children's books that reinforce the spatial skills introduced**

The skills are accompanied with illustrated examples of activities taken from public preschool and kindergarten classrooms, private preschools and child care centers, and home settings.

Rosanne Regan Hansel, MS Ed, has been both a teacher and administrator for a variety of early childhood programs and is the author of the award-winning book *Creative Block Play*.

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