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## Program Descriptions

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# The Development of Model-Based Reasoning

## Background

The new *Next Generation Science Standards* identifies eight scientific practices that should be central in the teaching and learning of science. Of these, modeling is arguably most central to the epistemology of science. Although forms of inquiry, argument, and evidence vary across and within scientific fields, scientists' work involves building and refining models of the world. Scientific ideas derive their power from the models that instantiate them, and theories change as a result of efforts to invent, revise, and stage competitions among models. Although new technologies are bringing modeling tools into school classrooms, these tools do not resolve the complexities involved in grasping the epistemology of modeling.

Accordingly, the Development of Model-Based Reasoning project team conducted research on the origins and development of modeling in students from kindergarten through middle school. The research goal of the project, which is now completed, was to track the growth of students' capability and propensity to take a modeling stance toward the world as they conducted long-term studies of local ecosystems (a pond, a restored prairie, a school forest) near their school. There was also an associated professional development agenda, namely, to work with approximately 40 participating teachers to craft and sustain forms of instruction that support students' acquisition of both particular scientific models and a modeling epistemology. The purpose of the work was to develop a learning progression extended over the elementary and early middle school years and organized around fundamental concepts in the life sciences that culminate in a strong conceptual understanding of microevolution. Within the project, the team identified four core conceptual themes (variation, growth of organisms, growth of populations, and ecosystems) that collectively formed the basis of the progression and guided the curriculum and research design. Results of teaching studies with classrooms at each grade band were used to refine and revise the accounts of development. Yearly waves of data collection documented change over time in students' understanding within the four conceptual themes, as well as changes in teachers' instructional practices.

## Documented Results

The project generated a number of studies concerning development of children's modeling within the life sciences, from their earliest attempts to represent phenomena with drawings and physical models to subsequent mastery of models based on chance and distribution. The project found that young and inexperienced students find modeling easiest to enter initially by inventing and evaluating representations that preserve resemblance in some way with the phenomena being represented. As their mastery of the "modeling game" and of modeling languages, such as mathematics, grows, students become increasingly capable of inventing and critiquing models that do not resemble their referents in any way, such as functional, statistical, or agent-based models.

Based on this research, the project generated and published a series of construct maps that delineate the kinds of changes observed as children's learning about variation, growth of organisms, growth of populations, and ecosystems progressed from kindergarten through middle school.

Finally, the project also developed a successful approach to working collaboratively with participating teachers who studied science and mathematics at their own level in summer workshops. This included meeting monthly during the academic years of the project to analyze and classify student work, bringing examples of student work to populate the construct maps with typical student thinking, and finally, developing and maintaining a website to share what the teachers were learning collectively about instruction and students.

**Potential Applications**

Teachers who participated in the project developed a website that includes lessons that are illustrated with examples of student work and thinking (indexed to the construct maps). Moreover, the work begun through the project has now expanded into an ongoing set of coordinated ecological projects that are being conducted at multiple school sites throughout the town where the original school is located. Students and teachers are working with the Department of Public Works to evaluate effects of various plantings on the water quality in the town's system of retention ponds.

**For More Information**

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Lehrer, R., & Schauble, L. (2010). What kind of explanation is a model? In M.K. Stein (Ed.), *Instructional explanations in the disciplines* (pp. 9-22). New York: Springer.

Lehrer, R., & Schauble, L. (2012). Seeding evolutionary thinking by engaging children in modeling its foundations. *Science Education*, 96(4), 701-724.

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# Supports for Preschool STEM Learners and the Teachers Who Teach Them

## Background

School-readiness gaps exist in language, literacy, mathematics, and science between at-risk and more-advantaged learners. Risk factors for lack of school readiness include being a non-Asian child of color, coming from a family of low socio-economic status, and speaking a home language other than English. Because the children who arrive in our preschools and elementary schools increasingly fit into one or more of these categories, innovative solutions to enhancing school readiness are critical.

Science has been identified as meaningful content for older English language learning (ELL) students, and high-quality math and science learning opportunities enhance learning in math, science, and language for preschoolers. Therefore, the SciMath-DLL project hypothesized that preschool STEM experiences would improve school readiness and English language and literacy skills for PreK dual language learners (DLLs). Unfortunately, the early education workforce is not well prepared to support STEM learning or DLLs. Teachers report discomfort teaching math and science, and observational studies show that little teaching occurs. Improved teaching practice is required before we can study effects of rich STEM learning opportunities on child outcomes.

*The SciMath-DLL Approach to Professional Development*

The SciMath-DLL project aims to provide inservice teachers with the classroom-based supports they need to improve practice. It involves the design, development, and preliminary testing of an inservice professional development approach that integrates high-quality math and science instructional offerings with supports for DLLs. Our project aims to enhance teacher knowledge and classroom interactions around mathematics and science, improve classroom supports for DLLs, and illustrate that rich math and science learning experiences contribute to improved classroom quality.

Collaborating educators from three urban school districts in New Jersey (Elizabeth, Long Branch, and Union City) worked with researchers to develop the content, procedures, and supporting materials for SciMath-DLL workshops, model lesson plans, teacher workgroups, and individualized practice-based coaching. Coaching follows a reflective cycle of planning, implementing, reflecting on practice, and goal setting for the next implementation cycle. Educator input and feedback has been critical to the success of the project and to creating professional development that is effective and practical to implement.

For example, based on teacher feedback, the content and structure of SciMath-DLL workshops has changed dramatically. PowerPoint slides and lectures have been replaced by multiple in-depth learning experiences that provide teachers with opportunities to participate in a model lesson, reflect on its implementation in the classroom, debate the value of various instructional decisions made when creating the lesson, and determine ways to differentiate the lesson for learners with different needs. Teachers leave workshops with many “things that they can do on Monday” as well as a deeper knowledge of the math and science content and pedagogical content knowledge required to teach these lessons well: *“The workshop helped me dramatically with understanding sink and float. I learned many activities to do in my classroom.”*

**Documented Results**

During the first years of implementation, teachers and master teachers were asked to identify major implementation challenges. They noted the novelty of the coaching cycle, paperwork, and time limitations. Various solutions to these issues were developed for subsequent implementation years.

Educators noted that, even with challenges, the SciMath-DLL approach was valuable because it sanctioned and "forced" reflection on practice, which they value. After engaging in the approach, teachers and coaches noted (1) improved attitudes towards math and science teaching, (2) increased appreciation for reflection, (3) increased awareness that lessons are often "overstuffed," and (4) less directive, didactic teaching. Coaches reported learning STEM content and effective teaching methods, as well as gaining a better understanding of the reflective coaching cycle.

*"It's amazing how much I learn just talking about what just happened, and not focusing on what went wrong, but just what worked, and what could be tweaked for next time. I think that it's so important."*

*"I truly value the way the program has challenged my perspective on teaching science. It's refreshing to have solid examples about the way science is around us. This allows our students to become permanent observers of the world around them."*

*"With [this project], the process has been very clear, and how to truly do the reflective cycle. So, that really enlightened me on how to work with a teacher."*

**Potential Applications**

The SciMath-DLL approach works to change and improve teacher practice in district-based classrooms with master teachers as support. The workshop experiences that we have developed can be offered to educators in other settings, even those that do not have teacher coaches. One of the project's collaborating master teachers has used the reflective coaching cycle with community-based preschool providers to improve their practice for early math and science. The model could also be applied in early elementary school.

**For More Information**

Contact kbrenneman@nieer.org

Brenneman, K. (in press). Promising approaches to early childhood mathematics education (ECME) professional development through in-service training. In H.P. Ginsburg, M. Hyson, & T. Woods (Eds.), *Helping early childhood educators to teach math.* Baltimore, MD: Brookes Publishing.

# Technology and the Future of Preschool: Developmentally Appropriate and Evidence-Based Approaches to Integrating Technology in the Classroom

**Background**

Next Generation Preschool Math (NGPM) is an NSF-funded collaboration between researchers, media developers, and teachers that aims to develop preschool classroom activities and innovative tablet-based games to help preschool children learn sophisticated mathematics concepts crucial to early school success. As part of this effort, the NGPM team is addressing one of the most salient controversies facing preschool educators today: What, if any, are the most appropriate roles for technology in the preschool classroom and how can technology, if used appropriately, provide unique affordances for teaching and early learning?

NGPM is based on research that shows that (1) early mathematics learning is one of the most important predictors of school success broadly across the curriculum in later years; (2) very young children are capable of learning sophisticated mathematics; (3) technology can be used to help young children learn sophisticated mathematics; and (4) most preschool children are only exposed to simplistic mathematics, such as counting and simple shape recognition. Currently, NGPM has developed and pilot tested a 10-week preschool math curriculum supplement, consisting of two modules, that supports young children's learning of key ideas in mathematics: subitizing (key to understanding the notion of quantity and cardinality) and equipartitioning (key to understanding rational number reasoning).

NGPM's evidence-based design begins with the notion of a Curricular Activity System, which considers teachers' professional development needs, children's developmental abilities, available curriculum resources, typical classroom routines and requirements, and learning goals—all as elements in an interrelated system that must be considered in its entirety. Therefore, key features of NGPM include:

- A combination of classroom activities and tablet-based games that complement and support each other to promote children's learning.
    - Classroom activities include a host of common formats/materials that preschool teachers and children are familiar and comfortable with, such as:
        - Children's books and literature, as well as the use of non-digital games, to introduce, reinforce and extend the math and science topics.
        - Whole- and small-group activities that reinforce concepts and use manipulatives and tangible materials.
    - Tablet-based games are designed to both:
        - Allow children to individually explore and practice key ideas and concepts in a fun, "low-stakes" environment that is engaging and provides encouraging feedback.
        - Be inherently collaborative and foster children's social skills by inviting children to engage each other in rich interactions and talk about sophisticated math and science topics.
- Teacher professional development that meets teachers where they are, and demonstrates to teachers via interactive activities and resources (e.g., video) how to infuse their existing classroom routines (circle time, choice time, snack time, playground time) with important math and science.

- A digital Teachers' Guide that provides teachers with supports as they prepare to teach the unit, just-in-time scaffolds as they prepare for a particular activity, and reports on children's progress in the online activities.

**Documented Results**
NGPM was piloted in three classrooms (one each in New York City, the San Francisco Bay area, and the Boston area), all of which primarily serve children from low-income families. The regular preschool teachers implemented the modules. The research team conducted observations of classroom practices throughout implementation and also assessed children's learning before and after implementation. Findings from the child assessment suggest that children improved their understanding of target skills: scores at post-assessment were significantly higher than at pre-assessment ($F(1, 18) = 24.338$, $p < .001$). Analysis of observations and teacher interview data suggests that teachers were comfortable with the use of technology in their classrooms, the use of technology was developmentally and socially appropriate, and the teacher professional development and the Teachers' Guide were helpful. NGPM is currently being evaluated in a larger experimental study, and the results will be available by summer 2014.

**Potential Applications**
NGPM expects its materials to be made widely available in summer 2014, after the current experimental study is completed and revisions are made that can strengthen future implementation. The NGPM design and development model can also inform future development efforts in other areas. For example, the NGPM team is currently working on a similar effort: Next Generation Preschool Science (NGPS), an NSF-funded project to promote young children's learning of science practices and concepts. NGPS is also based on a Curricular Activity System framework. The science curriculum program will include classroom activities (e.g., children's books, hands-on science investigations) and will integrate technology to innovatively support inquiry (e.g., tablets will be used to record and analyze data, and simulations will be developed to reinforce the learning that occurs in the investigations). NGPM believes the Curricular Activity System framework can be of general applicability in designing (or adopting/adapting) effective and appropriate interventions to promote STEM readiness and integrate technology in meaningful ways.

**For More Information**
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Next Generation Preschool Math websites: http://nextgenmath.org/ and http://cct.edc.org/projects/next-generation-preschool-math and http://www.sri.com/work/projects/next-generation-preschool-math

Read: http://www.nytimes.com/2013/09/03/science/field-testing-the-math-apps.html

# The Building Blocks and TRIAD Early Mathematics Projects

**Background**

Early mathematics is surprisingly important. Children's early knowledge of mathematics strongly predicts their later success in mathematics. More surprising is that preschool mathematics knowledge predicts achievement even into high school. And most surprising is that it also predicts later reading achievement, even better than early reading skills. Mathematical thinking is cognitively foundational. Given the importance of mathematics to academic success in all subjects (Sadler & Tai, 2007), all children need a robust knowledge of mathematics in their earliest years.

The good news is that children as young as ages 3–5 have the potential to learn mathematics that is surprisingly complex and sophisticated. Unfortunately, this potential is left unrealized for many children throughout the world—especially for children from low-resource communities. They have the same implicit understanding of mathematics as their higher-income peers but have not had the opportunities to think and talk about mathematics explicitly—that is, to learn the *language* of mathematics.

With funding from the NSF, the Building Blocks project achieved its goal of helping children find the mathematics in, and develop the mathematics from, their everyday activities—from art and stories, to puzzles and games. Comprised of print materials, software, and more, *Building Blocks* is designed to help children learn number concepts, such as counting, basic arithmetic, and spatial and geometric concepts and processes. *Building Blocks* helps all children learn to mathematize their informal experiences by understanding and talking about them. If they do not learn to mathematize, lower-income children lose the connection between their informal knowledge and later school mathematics, and the gap between them and their more advantaged peers widens, year after year. Mathematization emphasizes representing and elaborating mathematically—creating models of everyday situations with mathematical objects, such as numbers and shapes; mathematical actions, such as counting or transforming shapes; and their structural relationships—and using those models to solve problems so derived. Mathematizing often involves representing relationships in the situation so these relationships can be quantified. Mathematics in puzzles, blocks, and songs is great. However, if it's "just play with blocks," too often little mathematics is learned.

**Documented Results**

The project's implementation of the *Building Blocks* curriculum has led to large increases in mathematical knowledge of young children in several small studies. To evaluate *Building Blocks* on a larger scale, a study of 36 classrooms was conducted to understand the impact of these interventions. It was found that *Building Blocks* increased scores on a mathematics achievement test and increased the quantity and quality of the mathematics environment and teaching in all project classrooms, from both low- and middle-income groups.

An example of *Building Blocks* involves using the *Building Blocks* software where children complete puzzles by putting together different 2-D shapes on the computer screen. Children can also make their own puzzles using the shapes. The goal of this activity is to help children see shapes as composed of various parts, a foundational concept of early mathematics. Children can eventually apply this idea to other part-whole relationships, like counting units that make up a set arrangement or (in language arts) combining letters to create words.

The TRIAD project is a model for successfully scaling implementation of an early mathematics curriculum. A particularly challenging educational and theoretical issue is implementing educational programs across the large number of diverse populations and contexts in the early childhood system in the United States. TRIAD is a research-based model designed to meet this challenge in the area of mathematics, with the intent to generalize the model to other subject matter areas and other age groups. The field needs transferable, practical models and empirical evidence of the effectiveness of these models. The TRIAD model was designed to be a collaborative project among administrators, teachers, and families, and provided on-site classroom support; professional development for teachers, coaches, and mentors; and assessments for research collaborators.

Larger-scale studies of implementing the TRIAD model have shown that scale-up is possible and beneficial for preschoolers from low-resource communities. Teachers achieve high levels of fidelity of implementation resulting in consistently higher scores in the intervention classes on the observation instrument, and statistically significant and substantially greater gains in children's mathematics, again with substantial effect sizes in preschool *and* continuing into kindergarten and first grade, significantly more so in the "Follow Through" condition in which kindergarten and first-grade teachers also received professional development.

**Potential Applications**

The scale-up work indicates that scale-up of the *Building Blocks* curriculum is not only possible, but effective. Entire districts or schools can use the TRIAD model to improve early childhood mathematics education for young children.

**For More Information**

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Building Blocks website: http://buildingblocksmath.org.
TRIAD website: http://TRIADScaleUp.org

Clements, D. H., Sarama, J., Spitler, M. E., Lange, A. A., & Wolfe, C. B. (2011). Mathematics learned by young children in an intervention based on learning trajectories: A large-scale cluster randomized trial. *Journal for Research in Mathematics Education, 42*(2), 127–166.

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# The Young Scientist: Teaching and Learning Science in Preschool Classrooms

**Background**

In 2000, Education Development Center, Inc. (EDC), began work on the NSF-funded project The Tool Kit for Early Childhood Science Education. That work—a collaboration between teachers, professional developers, scientists, and science educators—resulted in the *Young Scientist Series*, a comprehensive curriculum designed to improve science teaching and learning for children ages 3–5. Each curriculum unit includes a teacher's guide and multimedia professional development materials. The units include *Discovering Nature with Young Children*, *Building Structures with Young Children*, and *Exploring Water with Young Children*. According to Redleaf Press's website, *The Young Scientist Series* "supports children's early development of important science-inquiry skills, as well as early literacy and math skills. Comprehensive units on nature, structures, and water introduce children to lifelong critical-thinking abilities such as questioning, investigating, discussing, and formulating ideas and theories." A second product of this work is a book for teachers, *Worms, Shadows, and Whirlpools*, which describes the nature and appropriate content of science for this age level along with illustrative classroom vignettes. The development of these materials was guided by several principles about young children's science learning:

- Children ages 3–5 are capable of challenging science inquiry.
- Young children are motivated to make sense of the physical world around them.
- Young children's science inquiry must occur in the service of interesting and meaningful science content.
- Documentation of and reflection on experiences and observations are critical to children's meaning making.
- Teachers play a critical role in supporting and guiding children's science learning,

In addition, the materials take into account the context of early childhood teaching and learning and a research-based understanding of how children learn. They therefore are based in children's work and play, are integrated with daily experiences, draw from the child's world, and emphasize collaboration, use of language, representation, and mathematical thinking.
Despite the fact that it was developed before the *Next Generation Science Standards* (NGSS), *The Young Scientist Series* is aligned with concepts and practices of the NGSS and, thus, continues to be relevant.

**Documented Results**

A small evaluation of the materials, focusing on teacher change and satisfaction, was conducted during the life of the project. Two projects initiated since the end of the original project have contributed to the understanding of the impact of professional development and inquiry-based science in the classroom:

- The development of the Science Teaching Environment Rating Scale (STERS), a tool to help teachers and administrators look for indicators of effective teaching practice and classroom culture that support science learning. This was funded by the United States Department of Education (ED).
- An additional ED-funded project (in progress), *Foundations of Science Literacy* (FSL), was designed to research the effects of professional development on teaching practice. Using the *Young Scientist Series* as a foundation, EDC science educators have developed three more

extensive stand-alone credit-bearing courses, one for each of the original *Young Scientist* topics—*Exploring Water*, *Building Structures,* and *Discovering Nature*. These courses are currently in use, and the research is being conducted with PreK teachers in the Hartford, CT, area in collaboration with the Connecticut Science Center. Preliminary findings from this research indicate that teachers who use these products successfully meet more of the criteria from the STERS than do control teachers.

- A second component of FSL is to conduct research on the effects of professional development on student outcomes. This research is being conducted in classrooms of Hartford-area teachers enrolled in the FSL courses and is in its early stages.

**Potential Applications**

Science has long been neglected by many teachers and programs that serve 3-5 year old children. The emphasis on literacy and numeracy and social and physical development as well as the lack of science and science teaching knowledge of teachers of young children have resulted in a serious lack of challenging science curricula at this level. The *Young Scientist Series* is one of a few curricula in PreK science that also are aligned with the practices and content of the NGSS. *The Young Scientist Series*, as well as *Worms*, *Shadows*, *and Whirlpools*, continue to be used by teachers and programs.

**For More Information**

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*Young Scientist Series* website: http://www.redleafpress.org

Contact choisington@edc.org
*Foundations of Science Literacy* website: http://foundationsofscienceliteracy.org/

# Anywhere STEM Exploration: Supporting STEM Learning in Formal and Informal Settings with *PEEP and the Big Wide World*

## Background

Intended for children ages 3–5, *PEEP* is one of the first media projects to feature a science curriculum targeted to preschoolers, and to promote that curriculum across television, books, the Web, preschool classrooms, and library and museum events. The series is narrated by comedienne Joan Cusack and its theme song is performed by blues legend Taj Mahal. *PEEP* premiered in April 2004 and garnered immediate praise from the media—*TV Guide* lauded the series three times in the first year. E-mails from parents and teachers have been equally enthusiastic: "A home run! There is so much mindless garbage on TV aimed at children… *PEEP* is a rare diamond," and "It's one of the best examples I've seen of education combined with entertainment."

*PEEP* features a chicken, named Peep, a robin (Chirp), and an irascible, endearing duck (Quack), as well as an extended family of friends and (occasional) foes. The show takes place in and around a large urban park—a place of great wonder and mystery, and a place Peep, Quack, and Chirp are forever eager to explore. Airing in both English (on public television) and Spanish (on VMe), each televised half-hour contains two animated stories that highlight specific science or math concepts and two live-action films that show real kids playing and experimenting with those concepts. These segments not only give kids great ideas—like building towers out of shapes or making parachutes for toys—but also show the adults in their lives that play, science, and math are complementary activities that can be done anywhere, anytime…in the kitchen, in the bathtub, on the porch, and in the backyard.

*PEEP*'s animated stories, interactive games, and activities have reached many children, families, and educators. Every month, an estimated 800,000 viewers—including new and returning—tune in to the television broadcast. Last year, the *PEEP* website had more than 3.1 million visits from all over the country. More than half a million Head Start and preschool teachers have been introduced to *PEEP's* science and math investigations via the *PEEP* website and through conference presentations and trainings.

## Documented Results

WGBH developed and preliminarily evaluated the impact of the existing collection of *PEEP* resources. Independent evaluators have found that when presented with materials to manipulate and freely explore, children who were exposed to *PEEP* television episodes interacted with these materials in ways that were more grounded in science process skills than children who were not exposed to them (Goodman Research Group, 2005, 2011). Children who watched *PEEP* episodes were more likely to pose questions (71% vs. 22%), initiate predictions (33% vs. 7%), and use problem-solving strategies (76% vs. 34%). In addition, children who watched *PEEP* episodes made more observations than children who did not (47% vs. 16%). Independent evaluators also found, through surveys, that *PEEP* resources showed promise for supporting preschool teachers' science practices. Teachers reported that, after using the Explorer's Guide (which provides teachers with guidance for implementing the activities that can be accessed via the *PEEP* website), they felt more confident leading science activities and creating an instructional environment supportive of science. Teachers also reported that they found it easier to lead their students in hands-on activities, ask open-ended questions, and encourage children to share their ideas—all key science practices.

**Potential Applications**
Variations of the *PEEP* curriculum and other resources have been used successfully in a variety of formal and informal learning settings with both English- and Spanish-speaking populations of educators and parents.

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*PEEP* website: http://www.peepandthebigwideworld.com/

# Playscapes: Designed Nature Environments to Promote Informal Science Learning

## Background

Early childhood education and informal STEM learning have common key characteristics. Both emphasize meaningful, child-initiated learning strategies that highlight firsthand experiences and active participation, cognitive and affective process development, and an interdisciplinary and holistic approach to problem solving and concept development. The typical venue for learning in early childhood education is a classroom where exemplar teachers thoughtfully craft rich learning environments for experiential learning. In fact, notions of the environment as a third teacher and intentional classroom design are ingrained in early childhood education best practices; however, this is rarely extended to outdoor settings, and many educators underestimate the learning potential of outdoor play.

To address the need for outdoor environments that are intentionally designed to elicit STEM learning while inspiring free play, the University of Cincinnati's Arlitt Child and Family Research and Education Center and Cincinnati Nature Center partnered to create the Cincinnati Nature PlayScape Initiative. The premises and practices embraced by the initiative were derived from existing research and practice in the fields of early education, biological sciences, and environmental psychology. Subsequently, two playscapes designed to kindle free play, environmental awareness, and learning for young children in the Greater Cincinnati area were built to emulate the natural environment using plants and spaces indigenous to the locale. In both the 10,000 square foot urban playscape on the university campus and the 1.6-acre rural playscape at the Cincinnati Nature Center, affordances for exploration were key experiential goals. The Cincinnati Nature PlayScape Initiative is studying where preschool children play within these two respective playscapes, what materials they use, with whom they are playing, if science learning occurs through their play, and teachers' perceptions of their experiences.

## Documented Results

Playscape experiences offer numerous opportunities to observe living things in the environment and explore nature's biodiversity. Play within nature engages children as young naturalists and serves as a venue for drama, exploration, the arts, and the creation of rich play scenarios. Within these scenarios, there are numerous opportunities to engage in mathematics, building and construction, and the use of technology to explore and study the complexity of the environment. Results from the study of how children learn about science in the playscape indicate that young children do this regularly and organically within the context of their play.

To document where children were playing, an iPad behavior-mapping app was created. Results indicate that areas such as the streams and woods have affordances that elicited high levels of play and science learning, thus becoming defined behavior zones that were targeted for further study through video and audio analysis of children's play. Analyses to date suggest that the playscapes offer affordances that prompt children to measure, build, discover, and question natural phenomena using what the initiative team termed as "preschooler's science language."

The premium value of loose parts and play within the playscape were substantiated by data collected through the behavior mapping iPad app and videography. In addition, playscape design elements foster spatial and environmental awareness, evidenced by the manner in which children used maps and commented on the flora and fauna. Results also suggest that playing in these designed settings instills self-determination among children, particularly with regard to choice making, problem solving, self-regulation, and engagement.

Through the initiative, a curriculum-based assessment was created to determine if children were more inclined to engage in inquiry processes and whether or not they gained knowledge about life science. This assessment was administered pre- and post-playscape experiences. Data from the assessments are currently being analyzed.

Lastly, although audio data on teachers' support of children's learning are still being analyzed, teacher participants in the study provided substantiating feedback about the engagement of children in STEM-like exploratory and constructive play that suggests playscapes are excellent venues for informal STEM learning.

**Potential Applications**

Children who are given opportunities to become immersed in nature may become STEM literate at very young ages, creating an understanding on which concepts and content can be built as they mature. Through the use of behavior mapping, our initiative discovered the most compelling spaces within a playscape that attract preschool children's play, inquiry, and construction. What the children did with minimal adult guidance and what teachers did to increase focused attention on STEM learning was also studied. Preliminary results indicate that playscapes for young children inspire play, nurture biophilia, and promote STEM learning.

**For More Information**

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# Ramps and Pathways: Integrating Physical Science and Engineering in Early Childhood

## Background

The *Next Generation Science Standards* makes clear that science and engineering are complementary. Nowhere is this more evident than in the early childhood years. Young children are budding physical scientists; they are curious about the world and possess an intrinsic desire to figure out how the world works. They also have a strong need to be physically active, and inquiry into physical science provides them opportunities to actively explore and control physical phenomena. For example, building ramp structures and rolling marbles down them allows children to investigate how to control force and motion to achieve a goal (maximize speed, make a turn, create interesting effects, etc.). In the process, they begin to construct simple causal relationships. For example, when the angle of incline on a ramp is reduced, the marble travels more slowly. Or, a heavier marble is better at knocking down a block at the end of a ramp than a light marble is. In addition to building content knowledge, such classroom activities also engage children in actively exploring their environments, making sense of them, and using what they learn to design things—the beginnings of both scientific inquiry and engineering.

The Ramps and Pathways project reflects an approach to engaging young children with physical science and engineering that is both developmentally appropriate and intellectually rigorous. It capitalizes on young children's intrinsic desire to *make something interesting happen*; specifically, it engages children in designing, building, and using increasingly more complex ramp structures on which to move spheres and other objects. In doing so, it engages children in the design process: ask a question or identify a problem, plan, create, test, improve, and evaluate. Most engineering curricula for older children include linear models of the design process that consist of variations of these steps. However, such linear models fail to capture the realities of young children's exploratory play and investigation of physical phenomena. The Ramps and Pathways project subscribes to a model of the design process in PreK-2$^{nd}$ grade classrooms that does not reveal itself as steps, but rather as non-sequential components that are often enacted simultaneously (sometimes within a few seconds). The Ramps and Pathways' process emphasizes the iterative nature of the design process which is sometimes quite messy.

The Ramps and Pathways project, funded by the NSF, addresses two overarching goals: (1) to develop an age-appropriate physical science and engineering curriculum based on the movement of objects along ramps and pathways, and (2) to design and implement professional development materials for early childhood educators to best support young children's learning about physical science, scientific inquiry, and engineering within the context of ramps. The Ramps and Pathways project was tested with 42 teachers (PreK–2$^{nd}$ grade, including special education) in four states.

Three recommendations that were specifically highlighted in *Monitoring Progress toward Successful K–12 STEM Education: A Nation Advancing?* (NRC, 2013) stand out as particularly relevant to Ramps and Pathways: Time allocated to teach science in K–5$^{th}$ grade; adoption of instructional materials that embody the *Common Core State Standards* (CCSS) and the *Framework for K–12 Science Education*; and classroom coverage of content and practices in the CCSS and the *Framework*.

Professional development in Ramps and Pathways focuses on both science and engineering content and early childhood pedagogy. Teachers learn about concepts of force and motion as applied to moving objects down inclined planes, causal relationships among variables, and scientific and engineering practices. They engage in the design process themselves, and learn how to support it with young children. They learn how to create learning environments that respect young children's development, how to intervene and ask questions that promote reasoning and concept development, how to document children's learning, and how to integrate across curriculum areas, particularly mathematics and literacy.

**Potential Applications**

The *Ramps and Pathways* curriculum can be implemented in any early childhood classroom serving children ages 3 years through 2nd grade—including Head Start, public schools, and center-based and home-based childcare. It can also be easily adapted for older children or utilized as an after-school enrichment or summer activity. Various levels of professional development are available, ranging from a three-hour introductory workshop to a one-week in-depth course.

**For More Information**

Contact betty.zan@uni.edu

Van Meeteren, B. & Zan, B. (2010, November). Revealing the work of young engineers in early childhood education. *Early Childhood Research and Practice.* Retrieved from http://ecrp.uiuc.edu/beyond/seed/index.html.

Zan, B. & Geiken, R. (2010). Ramps and pathways: Developmentally appropriate, intellectually rigorous, and fun physical science. *Young Children*, *65*(1), 12–17.

# Scaffolding Young Math Learners to Be Effective Spatial Problem Solvers

## Background

This program of research, funded by the NSF, has shown that individual differences in early spatial skills are important factors, both in students' early acquisition of arithmetic and their later math reasoning skills. Spatial skills consist of the ability to use mental pictures for solutions to problems—such as interpreting graphs, charts, and maps, and understanding geometry and measurement problems. It is particularly important to study the relation between spatial skills and math performance in girls, because on average, males tend to do better than females on key types of spatial tasks even in children as young as ages 3 and 4. In older students, higher spatial skills have also been shown to predict math achievement and choice of STEM majors and careers, particularly in fields where women are underrepresented. Research has clearly shown that spatial skills can be improved through training. This research has focused on understanding individual differences in early acquisition of spatial skills and the supportive strategies and methods that can be employed to scaffold these skills by teachers and parents.

Through another NSF grant, the researchers developed instructional materials for children in PreK–2$^{nd}$ grade, with a focus on teaching spatially based math content—covering measurement, geometry, spatial and numerical patterning, block building, and data analysis and graphing. The resulting materials consist of a six-book early childhood storytelling/math series entitled *Round the Rug Math: Adventures in Problem Solving*, for PreK–2$^{nd}$ grade, published by McGraw-Hill in 2002. The books were designed to develop math problem-solving skills through the medium of storytelling. The project included a series of research studies showing the effectiveness of using a storytelling approach to scaffold young children's learning of mathematics, and developed assessment tools for evaluating changes in children's block building and puzzle skills.

For the next step in this NSF-funded research on early learners, the researchers focused on young girls. The goal was to understand first-grade girls' individual differences in early spatial and arithmetic skills within the context of their home environments. The researchers examined multiple factors simultaneously, starting with (1) socio-economic factors (such as income level, mothers' education, and financial stress), moving to (2) the general environmental conditions within the home (such as parental investment of time and material resources), and finally examining (3) the types of specific math and spatial activities experienced by these young girls. Then, the researchers more closely examined factors within the home environment by studying videotaped mother-child interactions when solving a joint origami problem-solving task to determine what types of maternal scaffolding were related to effective spatial and arithmetic skills. Finally, in the most recent NSF grant, they have followed the first-grade girls into fifth grade to determine the relative importance of early spatial, arithmetic, and verbal skills in predicting fifth-grade math reasoning skills.

## Documented Results

Below is a summarization of some of the research findings relating to learners' early acquisition of spatial and arithmetic skills.

- The research evaluation of the storytelling/math books showed that for both geometry and block building, kindergartners improved more when taught within a storytelling context than in a non-story context.

- The first-grade girls with good spatial skills were able to use more-advanced mental arithmetic strategies (rather than using their fingers or counters) when solving both the addition and subtraction problems.
- Mothers who were effective at supporting their daughters' spatial problem solving on the origami task had daughters who performed better on other spatial tasks.
- These girls' spatial skills in turn predicted their arithmetic performance.
- First-grade girls' spatial skills were a stronger predictor of their fifth-grade math reasoning skills than either their first-grade arithmetic or verbal skills.

**Potential Applications**

What is striking about all of our research findings is the strong predictive power of spatial skills on students' math skills. The present results support the hypothesis that spatial skills are an important underpinning of students' math abilities. However, the problem is that within the educational system at all levels, from preschool to college, the teaching of spatial skills is not a major focus. Instead, those with good spatial skills simply rise to the top in math and science. Yet, for boys as well as girls, spatial skills have been found to be important for success in STEM. This program of research documents the critical role of spatial skills for mathematics learning in students as young as kindergartners and first graders. It is encouraging, therefore, that both boys and girls can be effectively taught how to think and solve problems spatially. Based on this research, the goal is to help educators better understand developmental changes in spatial skills and how these skills relate to early mathematics. Most important, a key goal is to help educators understand how to intervene to enable young learners to be more effective spatial problem solvers.

**For More Information**

Casey, B. (2009). Applying developmental approaches to math. In O. A. Barbarin, & B. Wasik, *The handbook of child development and early education: Research to practice.* New York: Guilford Press.

# The Missing T & E in Early Childhood STEM: Young Children as Programmers and Engineers

## Background

The Developmental Technology (DevTech) Research Group examines the role of computational technologies that are developmentally appropriate for young children and that help them learn about new things in new ways. DevTech is exploring the notion of what is "developmentally appropriate" in the light of the opportunities for inquiry and active construction of knowledge offered by new technologies that engage children in programming activities. Through NSF funding, the DevTech Research Group has created a low-cost developmentally appropriate robotics construction kit for children in grades PreK–2 called KIWI (Kids Invent With Imagination). To accompany KIWI, DevTech developed the CHERP programming language, which allows users to create both physical and graphical computer programs to control the robot, as well as several curriculum units. The DevTech Research Group is also collaborating with the MIT Media Lab to develop *Scratch Jr.*, a software designed to engage children in grades K–2 in programming and storytelling. *Scratch Jr.* will be released as a free app in early 2014.

The DevTech Research Group developed the Early Childhood Robotics Network, a virtual community for early childhood educators interested in using robotics and computer programming in their own classrooms. This network features curriculum resources as well as project videos and pictures from educators across the country.

DevTech has developed several curriculum units for use with a variety of robotics kits (LEGO® Wedo™, LEGO® Mindstorms™, and KIWI). These curricula provide a hands-on introduction to a selection of computer programming and robotics concepts, as well as powerful ideas that are integrated with math, science, social studies, and language arts core curriculum frameworks. DevTech regularly offers child-only programs, such as Summer Enrichment Programs, that engage young children with new technologies. Additionally, DevTech offers parent-child programs focused on robotics, such as Project Interactions and professional development programs for early childhood educators with robotics and *Scratch Jr*.

## Documented Results

The DevTech group has been doing research with more than 2,000 children and teachers in grades PreK–2 to document young children's abilities and learning trajectories when engaging in programming. The DevTech group has focused on design features of the technology that make it developmentally appropriate. With *Scratch Jr.,* the DevTech group has also been exploring what elements of the software need to be in place to support executive function.

Findings from DevTech work with the KIWI robots have shown a statistically significant impact on sequencing skills after exposure to KIWI programs, including an increase in collaboration and gender neutrality. Results from these studies can be read in publications found here: http://ase.tufts.edu/DevTech/publications/

The DevTech Research Group has gathered a combination of qualitative and quantitative data from all early childhood teachers participating in studies, and the teachers' changing (or unchanging) technological content knowledge, self-efficacy, and pedagogical views related to technology. Additionally, both qualitative and quantitative assessments on children's knowledge of various robotics and computer programming topics have been collected.

**Potential Applications**

DevTech's work has been implemented in both public and private early childhood settings, rural and urban schools, with a diverse population of both students and children. In early 2014, the free *Scratch Jr.* app for iPads will be ready to launch. Collaborations have been initiated to commercialize the KIWI robot and make it widely available to all early childhood settings.

**For More Information**

Marina Bers website: http://www.tufts.edu/~mbers01/
DevTech website: http://ase.tufts.edu/DevTech/
KIWI website: http://ase.tufts.edu/DevTech/ReadyForRobotics/readyforrobotics.asp#technology
*Scratch Jr.* website: http://ase.tufts.edu/DevTech/ScratchJr/ScratchJrHome.asp
Early Childhood Robotics Network: http://tkroboticsnetwork.ning.com

# Young Children Explore the World: Seriously Amazing Experiences at the Smithsonian

**Background**

The mission of the Smithsonian Early Enrichment Center (SEEC) is two-fold: to provide a high-quality educational program for young children and to advance educational opportunities for all children by sharing SEEC's expertise on a national level, thereby furthering the education mandate of the Smithsonian Institution (SI).

SEEC opened in 1988 with one center located in the National Museum of American History. In 1991, SEEC added programming for infants and, in 1998, a licensed kindergarten was added. Today, SEEC has two sites serving 135 children with 52 staff and a budget of over $2.5 million. In addition, SEEC now gives out over $150,000 in scholarship funds every year.

SEEC is a model lab school with a museum-based curriculum; it addresses the SI mandate for sharing knowledge. At SEEC, children are encouraged to be extraordinary, to wonder, and to explore the world around them. Children are given the time and space to see the results of their curiosity and to think richly and deeply about things. Through a combination of hands-on exploration, learning through collections and exhibits, and play, children are able to experience the world in ways that are developmentally appropriate and engaging. Supporting the latest neuroscience research on brain development and learning in young children, SEEC invites children to share and explore their own ideas.

SEEC believes that children learn by having multiple experiences that allow them to build upon past knowledge and experience. At SEEC, teachers help young children make meaningful connections between objects that are familiar and those that are unknown. The children at SEEC learn about their world in an educational setting that is unparalleled. They are introduced to new ideas through personal conversations with scientists, artists, and cultural historians who share their passion for learning in concrete, engaging ways. SEEC children learn about the era of dinosaurs through personal encounters with paleontologists, where they are able to see the tools used to examine the past. Kindergartners become scientists in a visit to the Smithsonian Environmental Research Center, where they explore nature intimately, make observations, test hypotheses, and discuss ideas with an entomologist. Throughout the year, SEEC children become familiar with people and cultures from around the world through the wondrous collections in nearby museums.

As an organization, SEEC is a leader in the field of museum-based education and influences practice within museums and schools. SEEC educators apply best practices recognized in the early childhood field and enrich the children's learning through an object-based approach to teaching, sharing the rich stories associated with these objects in ways that make the curriculum deeper and richer. Museum educators within the program build on the practice established by the classroom educators within the SEEC model, serving as content experts on the museums and blending theory and practice as a basis for outside consulting and professional development.

**Potential Applications**

The Center for Excellence in Early Learning is the outreach arm of SEEC. Professional development for early childhood and museum educators on a wide variety of teaching and learning ideas that form the basis for work at SEEC is provided through SEEC. In addition, custom consulting is provided to these audiences to assist them in ways that are designed specifically for their organizations or communities. SEEC also has several publications and teaching kits available for purchase. Finally, a completely revised version of an in-depth resource manual that can be used to design and operate early learning programs in schools or museums will be available in 2014.

**For More Information**

SEEC website: http://www.si.edu/SEEC (SEEC outreach work at http://www.si.edu/seec/educators)

Follow us on Facebook at Smithsonian Early Enrichment Center (SEEC) or on Twitter at @SISEEC.