# Building Blocks of Early Childhood Mathematics

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**Z**achary's grandmother was walking him out of preschool. He looked at the tiled walkway and yelled, "Look, Grandma! Hexagons! Hexagons all over the walk. You can put them together with no spaces!"

Zachary and his friends have been working on a curriculum developed by the Building Blocks project (Clements and Sarama 2003a). Building Blocks is funded by the National Science Foundation to develop software-enhanced mathematics curricula for prekindergarten through second grade. The curriculum was designed to comprehensively address NCTM's *Principles and Standards for School Mathematics* for young learners. This article describes the basic features of the Building Blocks program, including the research on which it is based, activities, and field-test results.

## Building Blocks— Based on Research

We designed Building Blocks to enable all young children to build solid content knowledge and develop higher-order thinking. The program is based on theory and research on early childhood learning and teaching (Bowman, Donovan, and Burns 2001; Clements 2001). Its basic approach is to find the mathematics in, and develop mathematics from, children's experiences and interests. The materials are intended to help children extend and mathematize their everyday activities. They include building blocks, art, songs, and stories.

Phases of the Building Blocks design process model (Clements 2002; Clements and Battista 2000; Sarama and Clements, in press) include—

- determining curriculum goals;
- specifying learning trajectories for each goal;
- creating initial activities and software;
- trying out software prototypes and activities with individual students;
- conducting pilot tests in a few classrooms; and
- conducting field tests in numerous classrooms.

During the entire process, feedback from the field results in further refinement of the design of the software and activities, which then results in further testing. In this way, we continually cycle through the earlier phases of the model.

## Program Emphasis

What mathematics should be taught to four-year-olds? Consistent with NCTM's Principles and Standards and an extensive review of the research (Clements, Sarama, and DiBiase, in press), the program emphasizes (a) geometric and spatial ideas and skills and (b) numeric and quantitative ideas and skills. Research shows that young children are endowed with intuitive and informal capabilities in both these areas (Bransford, Brown, and Cocking 1999; Clements 1999). Three mathematical themes are woven through both areas: patterns, sorting and sequencing, and measurement and data. These are children's *mathematical building blocks*, or ways of knowing the world mathematically. The Build-

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ing Blocks name reflects the use of manipulatives such as children's building blocks (on and off the computer) to help children develop mathematical and cognitive building blocks—the foundations for later learning.

## Creating a Building Blocks Activity

To help children see and develop the mathematics in their experiences, the activities in Building Blocks integrate several ways to explore and represent mathematics: with children's bodies, manipulatives (and everyday objects), computers, and print such as books and children's drawings.

Consider the following example to explore the phases of our model for designing an activity (see Clements, Sarama, and DiBiase 2002 for other examples). First, we determine a goal. One important, but often neglected, skill is geometric composition—putting shapes together to form new shapes. This task is significant in developing spatial abilities; geometric ideas and skills, including the notion of building up units into higher-order units; and even foundations for understanding of number (Clements et al. 1997).

The second step of our model is developing a learning trajectory for shape composition (see **fig. 1**). The third step is finding a composition task that young children enjoy and understand, such as completing puzzles. We created mathematically oriented puzzles to move children along the shape-composition learning trajectory. In the "Shape Puzzles" activity, children fill in outline puzzles, using a set of shapes such as pattern blocks and working off and on the computer. They slide, turn, flip, and combine or compose basic geometric shapes. Initially, they solve outline puzzles with physical pattern blocks, without using the computer. Next, they solve similar puzzles at the computer (see **figs. 2a** and **b**).

If puzzles with physical manipulatives are available, why use computers? Research shows that when used wisely, computers can be developmentally appropriate, fun, and beneficial for young children (Clements and Sarama 2002). We used that research to design motivating and educationally effective software and to create a curriculum that uses the computer wisely (Clements, Nastasi, and Swaminathan 1993; Clements and Swaminathan 1995). The computer offers many practical advantages. Children enjoy that the blocks "snap" to each other and stay together accurately. They like saving and returning to, as well as printing, their work. Children learn more by using the computer's tools to perform actions on the shapes. Because they have to figure out how to choose a

motion such as slide, flip, or turn, they become more conscious of these geometric motions. Such choices also encourage children to be more deliberate. They think ahead and talk to one another about which shape and action to choose next. In these ways, the computer slows down their actions and increases their reflection. Using the motion tools helps children become familiar with seeing shapes in different orientations and realize that changing the orientation does not affect the shape's name or classification. Perhaps most important, the Building Blocks software provides puzzles at the appropriate level of the learning trajectory for each student. For example, the puzzle in **figure 2a** would be presented to a child at the level of "Picture Maker" (**figure 2b** shows the resulting picture). The third column of **figure 1,** "Instructional Tasks," illustrates the type of puzzles that the program offers for each level of the learning trajectory.
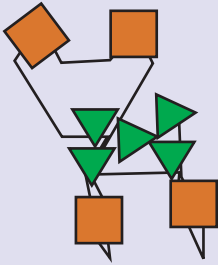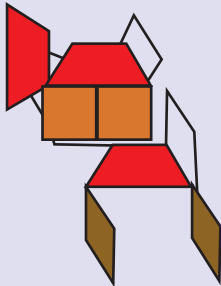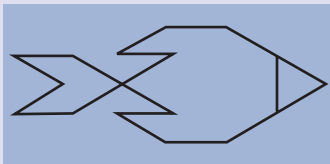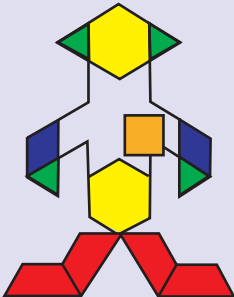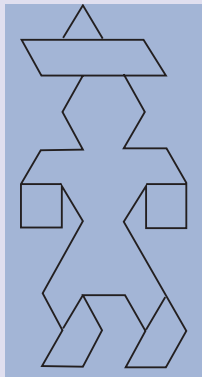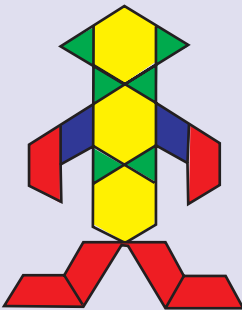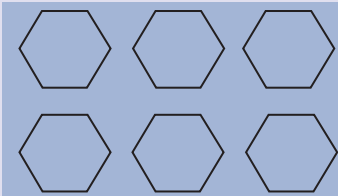
## Testing the Activities in Classrooms

The previous example described only the first three phases of our design model. "Shape Puzzles" and other activities were presented to small groups, and then whole classes, of preschool students. The first pilot test for the geometry materials included only twenty-seven sessions, but we found significant increases from pretest to posttest.

What activities engendered this learning? The children interacted with shapes in many ways. They made pictures with paper cut-outs of shapes, completed pattern-block puzzles, searched for shapes in their environment and recorded what they saw (with adult help, if needed), sorted shapes, built shapes with straws and blocks, and identified shapes in story books. On the computer, they matched shapes, explored pattern-block puzzles and used geometric transformations, and identified shapes in the context of building "Mystery Toys."

For example, when the children sorted rectangles and non-rectangles, the teacher focused their attention on the sides of the shapes. Chandra was able to tell the teacher which pile to put a rectangle in but was unable to articulate her sorting rule. Similarly, her partner, Marnie, said only, "It matches," and pointed to the correct pile. For the next shape, a right trapezoid, Chandra again pointed to the correct pile but gave color as her reason for doing so. Alethea joined the group and disagreed, saying the shape should go in the rectangle pile. Mitchell pointed to the non-perpendicular side and said that the shape was not a rectangle because "someone cut it right here."

Later, the teacher asked Tiffany if she knew the name of the shape. She immediately said "trape-

FIGURE 1

**A learning trajectory for shape composition**

| Level | Assessment Task | Instructional Task |
|---|---|---|
| *Pre-Composer.* Children manipulate shapes as individuals but are unable to combine them to compose a larger shape.<br><br>In assessment-puzzle tasks, shapes do not match simple outlines.<br><br>The instructional task uses outlines in which children can simply match shapes without turn or flip motions. |  |  |
| *Piece Assembler.* Children at this level are similar to Pre-Composers, but they can place shapes touching each other to form pictures.<br><br>Children can fill simple puzzles using trial and error but have limited ability to use turns or flips to do so; they also have difficulty with areas requiring multiple shapes.<br><br>The instructional task first provides substantial spatial support for placements of individual shapes, but not every shape outline is provided. |  |  |
| *Picture Maker.* Children start to combine shapes.<br><br>In puzzle tasks, shapes are chosen using overall shape or matching side lengths. Rotating and flipping are used, usually by trial and error, to try different arrangements (a "picking and discarding" strategy).<br><br>Instructional tasks have considerable "open" areas in which shape selection is ambiguous. |  |  |
| *Shape Composer.* Children combine shapes to make new shapes or fill puzzles.<br><br>Children choose shapes using angles as well as side lengths. Eventually, the child considers several alternative shapes with angles equal to the existing arrangement. Rotation and flipping are used intentionally to select and place shapes.<br><br>Instructional tasks (here, solving similar problems in multiple ways) encourage higher levels in the trajectory and involve substitutions. |  |  |

zoid" and pointed to the computer, indicating that the students had learned that vocabulary term during center time. In the computer activity "Mystery Toys," the computer pronounces each shape name as children match the shapes to build a surprise toy. At another level, the children are asked to click on the correct shape when the computer pronounces its name. This activity is popular with the children and they enjoy imitating the "computer voice" when they name shapes. Throughout the study, discussions encouraged children's descriptions and the development of precise language. Early talk clarified the meanings of terms.
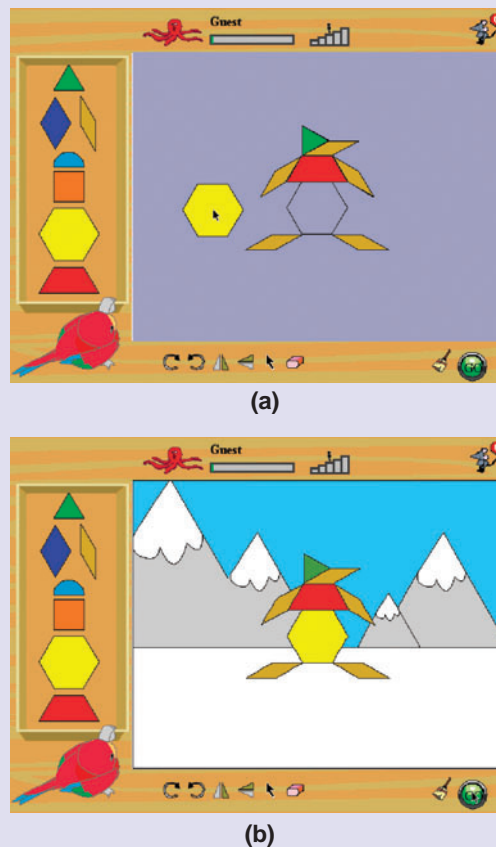
The number activities were piloted in a different classroom. Children made gains on all the posttest items. Several activities facilitated children's learning of the number items. For example, they counted objects continually throughout the study. The teacher read both "non-mathematics" books and books showing numerals to the students during circle time, and books also became part of the centers. In the centers, children were able to interact with the books more extensively. Tanya looked at the book *One Hungry Monster* and wanted to figure out how much food the monster ate on one of the pages. She put cubes near each numeral, counting as she placed them: "One. One, two. One, two, three." She then counted, "One, two, three, four, five, six . . . six!" On the computer, children's counting was supported by the management system, which automatically adjusted the difficulty level of the activity and provided appropriate feedback and help.

In another set of activities, children learn one-to-one correspondence, counting, and equality. For example, children get "just enough" treats or scissors for the children at their table and in other real-world situations throughout the day. A computer activity challenges them to help a character get ready for a party, beginning with setting the table. At a higher level of the same activity, an on-screen character requests that children add a certain number of items to the table. If a dish is missing, a character at the table may say, "I don't have a dish!" This type of natural feedback helps young children learn.

The children had many opportunities to perform simple addition and subtraction. A toy dinosaur shop was set up in the socio-dramatic play area of the classroom. As Geri played with Janelle and Andre, she filled many "dinosaur orders." This involved reading a numeral on a card, counting out the correct quantity for her customers, and collecting the correct number of play dollar bills. Eventually, Janelle wanted to "trick" Geri. She gave Geri two cards, a 2 and a 5. The teacher suggested that Geri give Janelle two of one kind and five of

FIGURE 2

The *DLM Early Childhood Math Software* (Clements and Sarama 2003b) provides puzzles at children's current level of thinking.



(a)



(b)

another. Geri carefully counted out the two piles, put them together, and counted the total. She then asked Janelle for $7.

Ordering towers of connecting cubes became part of pretend play when the children "made stairs" for small characters to climb. On the computer, children progressed through the learning trajectory built into the software: First, they "found the next stair"; then they built an entire staircase; and then they found missing stairs.

Counting out sets of objects was another activity that the children had multiple opportunities to engage in throughout the year. Working in small groups, children placed the requested number of objects in play scenes, made cookies with chips, and filled dinosaur orders. In the beginning of the study, some children could count out only two objects. The children worked on counting out different quantities according to their capabilities. On the computer, the children counted chips on a cookie, silverware, plates for a party, and the correct number of dinosaurs to fill an order. The computer program's management system automatically adjusted the difficulty level, the number of items requested.

## Summary

We believe in the power of young children's mathematical thinking and the power of combined teaching strategies to bring forth such thinking. Using their bodies, manipulatives, paper, and computers, children engage in activities that guide them through fine-tuned, research-based learning trajectories. These activities connect children's informal knowledge to more formal school mathematics. The result is a curriculum that is not only motivating for children but also comprehensive. It includes exploratory environments with specific tasks and guidance, building concepts and well-managed practice in building skills, a full set of essential curriculum components, and a full range of mathematical activities. Results of the initial pilot tests indicate that such an approach can cause significant assessed learning gains consistent with NCTM's Standards.

## References

Bowman, Barbara T., M. Suzanne Donovan, and M. Susan Burns, eds. *Eager to Learn: Educating Our Preschoolers*. Washington, D.C.: National Academy Press, 2001.

Bransford, John D., Ann L. Brown, and Rodney R. Cocking, eds. *How People Learn*. Washington, D.C.: National Academy Press, 1999.

Clements, Douglas H. "Geometric and Spatial Thinking in Young Children." In *Mathematics in the Early Years,* edited by J. V. Copley, pp. 66–79. Reston, Va.: National Council of Teachers of Mathematics, 1999.

———. "Linking Research and Curriculum Development." In *Handbook of International Research in Mathematics Education,* edited by L. D. English, pp. 599–630. Mahwah, N.J.: Lawrence Erlbaum Associates, 2002.

———. "Mathematics in the Preschool." *Teaching Children Mathematics* 7 (January 2001): 270–75.

Clements, Douglas H., and Michael T. Battista. "Designing Effective Software." In *Handbook of Research Design in Mathematics and Science Education,* edited by A. E. Kelly and R. A. Lesh, pp. 761–76. Mahwah, N.J.: Lawrence Erlbaum Associates, 2000.

Clements, Douglas H., Michael T. Battista, Julie Sarama, and Sudha Swaminathan. "Development of Students' Spatial Thinking in a Unit on Geometric Motions and Area." *The Elementary School Journal* 98 (1997): 171–86.

Clements, Douglas H., Bonnie K. Nastasi, and Sudha Swaminathan. "Young Children and Computers: Crossroads and Directions from Research." *Young Children* 48 (1993): 56–64.

Clements, Douglas H., and Julie Sarama. *DLM Early Childhood Express Math Resource Guide*. Columbus, Ohio: SRA/McGraw-Hill, 2003a.

———. *DLM Math Software*. Columbus, Ohio: SRA/McGraw-Hill, 2003b.

———. "The Role of Technology in Early Childhood Learning." *Teaching Children Mathematics* 8 (February 2002*)*: 340–43.

Clements, Douglas H., Julie Sarama, and Ann-Marie DiBiase, eds. *Engaging Young Children in Mathematics: Findings of the 2000 National Conference on Standards for Preschool and Kindergarten Mathematics Education*. Mahwah, N.J.: Lawrence Erlbaum Associates, in press.

———. "Preschool and Kindergarten Mathematics: A National Conference." *Teaching Children Mathematics* 8 (May 2002): 510–14.

Clements, Douglas H., and Sudha Swaminathan. "Technology and School Change: New Lamps for Old?" *Childhood Education* 71 (1995): 275–81.

Fuson, Karen C. "Research-Based Mathematics Curricula: New Educational Goals Require Programs of Four Interacting Levels of Research." *Issues in Education* 3 (1997): 67–79.

Sarama, Julie, and Douglas H. Clements. "Linking Research and Software Development." In *Technology in the Learning and Teaching of Mathematics: Syntheses and Perspectives*, edited by K. Heid and G. Blume. New York: Information Age Publishing, in press.