Increasing Logico-Mathematical Thinking in Low SES Preschoolers

Lynn D. Kirkland\textsuperscript{a}, Maryann Manning\textsuperscript{a}, Kyoko Osaki\textsuperscript{a} \& Delyne Hicks\textsuperscript{b}

\textsuperscript{a} University of Alabama at Birmingham, Birmingham, Alabama
\textsuperscript{b} YWCA, Birmingham, Alabama

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Increasing Logico-Mathematical Thinking in Low SES Preschoolers

Lynn D. Kirkland, Maryann Manning, and Kyoko Osaki

University of Alabama at Birmingham, Birmingham, Alabama

Delyne Hicks

YWCA, Birmingham, Alabama

Traditionally, children in low socioeconomic status (SES) inner-city areas in the United States lack experiences that prepare them for academic success, especially in math and science. The purpose of this research was to determine the extent to which a constructivist curriculum emphasizing logical thinking produces higher level thinking in low-SES preschool children. Fifty preschool children participated in the study and were pre- and posttested using Piagetian tasks. Results indicated that 84% of the students in the experimental group progressed at least one level, but only 36% of the control group progressed at least one level. Implications of the study are that implementing higher order thinking activities could result in improved logico-mathematical thinking in low-SES preschoolers.

Keywords: cognitive learning theory, mathematics education, preschool, constructivism

A study by the National Center for Educational Statistics (NCES; 2009) assessed the cognitive skills of children at approximately age 9 months and then again at 2 and 4 years. The study found that though there was little difference among children of different socioeconomic levels and racial/ethnic groups at age 9 months, poverty and racial/ethnic group identification were factors for the 2- and 4-year-olds. Black, Hispanic, and American Indian children performed significantly lower on tests of cognitive skills than their White, Asian, and mixed-race counterparts. Although it is not clear why math disparities appear among ethnic and class groups, it may be the interaction of problematic schooling practices and marginalized communities that contribute to this gap.

Educators acknowledge the need for high-quality preschool education, particularly for low socioeconomic students. Early experiences could possibly prepare them for academic success, because they tend to lag behind their more advantaged counterparts. However, it should be noted that studies as early as the 1980s found little difference in the development of numeracy in children from low SES and middle-class homes (Ginsburg & Russell, 1981; Seo & Ginsburg, 2004).
Over the past several decades, a variety of initiatives have been tried to narrow the achievement gap. Recent results from the 2011 National Assessment of Educational Progress show that though a higher percentage of low SES students performed at basic or proficient achievement levels in mathematics, science, and reading than in 2009, significant gaps still exist by racial/ethnic group and socioeconomic status (NCES, 2009).

In 2007, The National Center for Children in Poverty convened a meeting of distinguished researchers, educators, and policymakers to discuss research regarding best practices for low SES children. The policy briefs that grew out of this meeting support early intervention and intentional preschool curricula as the most likely approach to narrow the achievement gap between low SES children and their more advantaged peers. Intentional curriculum is defined as curriculum that is (1) content driven, (2) research based, (3) developmentally appropriate, (4) directive without drill-and-kill strategies, and (5) supportive of positive peer and teacher interaction (Klein & Knitzer, 2007). The authors of the policy brief developed from the meeting point out that “children make academic gains when they have teachers who encourage communication and reasoning, are sensitive to their interactions with children, and construct an atmosphere of respect, encouragement, and enthusiasm for learning” (pp. 2–3).

Based on international testing results in math and science, the United States trails behind South Korea, Japan, Singapore, and other developed countries of the world (Organisation for Economic Cooperation and Development, 2011; NCES, 2011). Children from low-SES backgrounds lag even further behind their American peers in math, science, and reading.

The quality of educational curriculum varies by country. For example, in Japan, constructivist preschool educators often implement high-quality curriculum that increases children’s readiness for math and science in later years (Kamii & Kato, 2008). The researchers for this investigation have observed and collaborated with a group of Japanese university professors, administrators, and teachers to examine the advantages of implementing such a curriculum.

The researchers hypothesized that a constructivist curriculum would be effective with low-SES preschool children in Birmingham, Alabama. The curriculum, based on the theory of Jean Piaget, a Swiss psychologist, encourages the construction of thinking as children interact while playing math games. Japanese preschool curricula focusing on thinking have been shown to increase children’s readiness for mathematics and science in later years (Kamii & Kato, 2008). DeVries and Kohlberg (1987) explained:

It is the structural aspect of the mind that constitutes the reasoning potential or power to operate mentally on the content of experience—the power to “read” objects and events and thereby furnish the mind with content. From this perspective, the development of knowledge as content proceeds hand in hand with the development of knowledge as intelligence or structure of reasoning. (p. 22)

Previous Attempts to Use Piaget’s Theory in Curriculum Development

DeVries and Kohlberg (1987) analyzed the different ways that Piaget’s theory was translated into educational settings. They classified the different programs and projects into three categories. The types of interpretations include global, literal, and free translations. Global translation was vague generalities made about curriculum practices that are based on inconsistent theory and unspecified learning activities. Literal translation is derived when partial application of Piaget’s theory to cognitive and sociomoral development is based primarily on a strict adherence to Piaget’s stages.
Lastly, free translation is an elaboration process that is driven by implications of Piaget’s theory, rather than application of the cognitive activities of children that leads to constructivist activity.

In the 1960s and 1970s, early childhood educators developed the Perry Preschool Project (Schweinhart, 2002), known as the High Scope Curriculum. This curriculum was based, in principle, on Piaget’s theory. The authors of High Scope Curriculum tried to use a free translation approach of Piaget’s theory for curriculum but were only moderately successful (DeVries & Kohlberg, 1987).

In the 1980s, Kamii and DeVries (1980) applied the tenets of constructivism in their curriculum, based specifically on Piaget’s three types of knowledge: physical, social conventional, and logico-mathematical. The curriculum comprised physical knowledge activities, group games (including card and board games), pretend play, daily living activities, art, literacy, and music. Additionally, children’s interests, actions, and social interactions with peers were emphasized in the curriculum.

Although there was considerable interest in Piaget’s ideas around the world, many of the interpretations were primarily focused on Piaget’s stages (literal translation). Application of these principles to the field of education was a significant problem (DeVries & Kohlberg, 1987). In Jean Piaget’s book (1948/1973), To Understand Is to Invent, he was aware of the problem and stated:

Inspired by the psychological work of the Geneva School, sometimes well interpreted (like the educational achievement of Allmy, Kamii, H. Furth, and so on in the United States) but sometimes, rather naively and unsatisfactorily, these applications may be made in a number of ways. (p. 6)

As there are many different interpretations of Piaget’s theory, we used a curriculum developed by Kamii and Japanese educators and approved by Piaget himself.

**Current Free Translation Attempts to Elaborate Piaget’s Theories in Math Education**

One researcher who implemented Piaget’s ideas in Japan was Professor Yasuhiko Kato, who attended Japanese and American early childhood conferences and met Constance Kamii. Although Japanese by birth, Kamii’s education was in the United States post–World War II. After completing a PhD in psychology at the University of Michigan, Kamii worked at the Perry Preschool Project. Due to her interest in education reform, she developed a professional relationship with Piaget in Geneva. The network of interactions between Kamii and Piaget and then Kamii and Kato laid the foundation for educational leadership and scholarship in the area of curriculum improvement in Japanese constructivist preschools. Kamii has continued to work with Kato to support teachers’ professional development for more than 20 years, which has resulted in extensive classroom research (Kamii & Kato, 2005, 2006, 2008). The work of these two individuals, specifically curricula for preschoolers, continues to be shaped by the tenets of constructivism.

In addition to studying with Kamii, the authors of this article have had numerous interactions with Kato. The principal investigators, Kirkland and Manning, have lectured in Japan since the early 1990s and noticed how Japanese preschool teachers implemented a curriculum that encourages children’s thinking. Each visit convinced the authors that many of the math games and science activities that have been widely used in Japanese constructivist preschools should also be incorporated into preschool curriculum in the United States.
In addition, research on early childhood curricula based on Piaget’s constructs of math and science was conducted at the University of Northern Iowa (UNI) by Rheta DeVries and colleagues (DeVries & Sales, 2011; DeVries, Zan, Hildebrandt, Edmiaston, & Sales, 2002). Although developed separately, the UNI mathematics and science curriculum for young children was remarkably similar to the curriculum developed in Japan. Independent visits to the UNI campus confirmed that the curriculum based on Piagetian theory produced positive outcomes with low-SES children in Iowa (Van Meeteren & Zan, 2010).

How Piaget’s Theory Shows the Importance of Logico-Mathematical Thinking

The researchers used Piaget’s framework for understanding thinking. Piaget (1945/1951, 1967/1971) described three forms of knowledge according to their ultimate sources: social conventional, physical, and logico-mathematical. As cited by Kamii (2003), these forms of knowledge are shown in Figure 1.

Physical knowledge is the understanding of objects and their attributes. Through hands-on experiences with objects, children learn about their color, weight, texture, and other properties. For example, when a child rolls a marble down a ramp made of curved molding, he or she begins to understand that marbles roll down an incline but not when the molding is flat on the floor.

Social-conventional knowledge is knowledge of conventions and societal rules that result from cultural interactions. An example of social-conventional knowledge is language, written and spoken, and the rule that it is polite to say “please” and “thank you” in certain social situations.

Logico-mathematical knowledge is constructed through the building of mental relationships between objects, people, events, and so on. Logico-mathematical knowledge is rooted in an individual’s mind rather than the environment. There are five dimensions of logico-mathematical knowledge: (1) classification, (2) seriation, (3) number, (4) spatial relationships, and (5) temporal relationships.

<table>
<thead>
<tr>
<th>Physical knowledge</th>
<th>Social-conventional knowledge</th>
<th>Logico-mathematical Knowledge</th>
<th>Spatio-temporal relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Ramps &amp; Pathways</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

FIGURE 1 Piaget’s framework.
relationships (see Figure 1). An example of logico-mathematical knowledge can be found in the game of Concentration. If two cards are the same, a player can keep the cards. If the cards are different, the player must put the cards back. “Same” and “different” are examples of classification. It is widely assumed that “sameness” and “difference” can be observable, but these relationships do not exist in the observable external world (Kamii, 2000). In the example of Concentration, players make numerical relationships by determining who has more cards than anybody else. An example of seriation is if there are three players, the individuals order the cards from greatest to smallest. Spatial relationships can be seen when an identical card is turned over in a particular place, and temporal relationships indicate moments in time, such as when a card is turned over either before or after the player’s turn.

In addition to card games, physical-knowledge activities also can be used to help children think. In one physical-knowledge activity using ramps and pathways, children build ramps from curved molding so that marbles will roll down an incline. Observing how different objects roll down the ramp is one example of classification. For instance, round objects roll but square objects do not roll. Seriation can be seen when marbles roll down the ramp faster or farther based on the incline of the ramp. Based on the construction of the incline, children can make spatial relationships to see how objects either promote or deter speed on a specific ramp. Finally, a temporal relationship can be made when the child compares the results of how the marble rolled the first time and subsequent times. From a Piagetian perspective, playing can promote a child’s development of logico-mathematical thinking, a foundational component for academic learning.

**Purpose of the Study**

The purpose of this research was to determine the extent to which a math curriculum emphasizing logico-mathematical thinking produces higher level of cognitive development in low-SES preschool children. The following null hypothesis guided this investigation: A logico-mathematical curriculum does not increase the development of logic in preschool children of low SES.

**METHOD**

**Participants**

Participating schools were selected for this study based on recommendations from local preschool directors in the urban area. The classrooms included in the experimental group had teachers who were willing to participate in professional development and implement the constructivist activities. All of the selected preschools in this study met the following criteria: located in an urban area in a large city in the southeastern United States, nonprofit or church supported, accredited by the state Department of Human Resources, and funded by the United Way. Additionally, children in the preschools were from low-SES families, and participating teachers held a minimum credential of an associate’s degree in early childhood education.

A total of 66 children were recruited from three urban preschools for this study. Because 34 children in the experimental group returned permission slips, it was necessary to identify two preschools to recruit a sufficient number of children for the control group. The total number of
children who were pretested in the control group was 32. Due to program attrition, 25 children from the experimental group and 25 children from the control group were given pre- and posttests. In the experimental group, there were four 3-year-olds, eighteen 4-year-olds, and three 5-year-olds. In the control group, there were six 3-year-olds, thirteen 4-year-olds, and six 5-year-olds. There were three teachers in the experimental group (one for 3-year-olds, one for 4-year-olds, and one for 5-year-olds). There were six teachers in the control group because two preschools were recruited to provide a sufficient number of children as the experimental group.

Permission to participate was requested from the directors of the various preschools and the teachers then sent consent forms to parents and caregivers in the three sites. Consent forms were returned by 66 parents and/or caregivers.

Activities in the Classroom

Children in the control group and the experimental group used a math curriculum based on the state Office of School Readiness (OSR; 2009-2010) Pre-K standards and National Association for the Education of Young Children (NAEYC; 2010) math standards. Although the same amount of time was spent on mathematics instruction for both groups, a portion of the existing curriculum used with the experimental group included 30 minutes per day of constructivist activities.

Before implementing classroom activities, teachers in the experimental group were provided theoretical and practical explanations of what to do. These explanations were presented by a kindergarten teacher who had used the games and activities and a Japanese doctoral student at the University of Alabama at Birmingham (UAB) who had taught in constructivist preschools. The kindergarten teacher and the doctoral student had taken classes on constructivism and, therefore, were students of Piaget’s theory and its implications for the classroom. After the two 4-hour professional development sessions conducted by the kindergarten teacher were completed, the doctoral student served as a mentor/coach for the teachers in the experimental group. She introduced the games and monitored the playing of the games each month.

The teachers played the games with one another to better understand the rules and methods of the games. Teachers engaged in a discussion about how to introduce the game to the children and when/how to intervene or not intervene. At the end of each month, games were introduced that would be played the following month, and children played the games for 30 minutes each day over the course of 5 months. The specific games and physical knowledge activities that were used are listed in Table 1.

Evaluation Technique

The researchers concur with Seehorn (2012) concerning the findings of multiple organizations regarding the inappropriateness of using standardized tests to assess young children—a stance taken by the Association for Childhood Education International (ACEI), NAEYC, and National Association of Early Childhood Specialists (NAECS). We used a classification task to compare the development of the experimental group to the control group. This evaluation consisted of two classification parts: a free sorting and a dichotomy. This is because children’s logical thinking can be seen based on the number of dichotomies demonstrated by each child.
Kamii (2009) stated that “children’s development in classification illustrates some important facts about the nature of their development in logico-mathematical knowledge” (p. 9). Therefore, the classification task used in this study consisted of two parts: free sorting and dichotomy. Free sorting and dichotomy tasks reveal a child’s development as primary aspects of logic (Inhelder & Piaget, 1959/1964). As children construct mental relationships among object attributes, they are simultaneously describing these object aspects and thinking about how attributes are similar and different.

In this study, the two parts were administered to each child in the control group and the experimental group: one free sorting and dichotomy. Both were administered continuously on the same day during pre- and postassessment periods for each group.

Participant interviews were conducted in a quiet place, such as a library or empty classroom, in all of the preschools. Interviews lasted between 10 and 20 minutes, and all interviews were videotaped. The tasks were conducted based on the Piagetian clinical method of using concrete objects to assess children’s thinking. Because of the age of the children, most verbal responses were limited; therefore, the researchers used the child’s performance on the classification tasks as evidence of his or her level of logic.

Data Collection

Materials

For this task, red paper cutouts of the following sizes, shapes, and textures were used:

- 3 small circles (1-inch diameter) with a smooth surface
- 2 big circles (2-inch diameter) with a smooth surface
- 2 big circles with a rough surface
- 3 small circles with a rough surface
- 3 big squares with a rough surface

<table>
<thead>
<tr>
<th>Month</th>
<th>3-Year-Olds</th>
<th>4-Year-Olds</th>
<th>5-Year-Olds</th>
</tr>
</thead>
<tbody>
<tr>
<td>February</td>
<td>Concentration (5 pairs)</td>
<td>Picture Domino II</td>
<td>Go Fish Animal</td>
</tr>
<tr>
<td>Tic-Tac-Toe</td>
<td>Tic-Tac-Toe</td>
<td>Animal Rummy I</td>
<td>Rummy II</td>
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<td>Ramps &amp; Pathway</td>
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<td></td>
</tr>
<tr>
<td>March</td>
<td>Concentration (8 pairs)</td>
<td>Blink I</td>
<td>Line-Up-5s I</td>
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<tr>
<td>Picture Domino I</td>
<td>Picture Domino I</td>
<td>Spider Game</td>
<td>UNO I</td>
</tr>
<tr>
<td>April</td>
<td>Animal Rummy I</td>
<td>Animal Rummy II</td>
<td>UNO II</td>
</tr>
<tr>
<td>Apple Game</td>
<td>Apple Game</td>
<td>Line-Up-5s I</td>
<td>Tapatan</td>
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<tr>
<td>May</td>
<td>To-the Left</td>
<td>Go Fish</td>
<td>Line-Up-5s II</td>
</tr>
<tr>
<td>Blink I</td>
<td>Blink I</td>
<td>UNO I</td>
<td>Making Families I</td>
</tr>
<tr>
<td>June</td>
<td>Picture Domino</td>
<td>Making Families I</td>
<td>Making Families II</td>
</tr>
<tr>
<td>Go Fish</td>
<td>Go Fish</td>
<td>UNO II</td>
<td>Blink II</td>
</tr>
</tbody>
</table>
2 small squares with a rough surface
2 big squares with a smooth surface
3 small squares with a smooth surface
2 sheets of colored paper.

Procedure

Steps in Free Sorting Part

Step 1: Place the 20 objects in front of the child.
Step 2: Show two different cutouts (big and little, rough and smooth, and circle and square) at a time and ask, “How are these different?” If the child was unable to identify the differences, he or she was told how they differed.
Step 3: Ask the child to put together all the things that are alike.
Step 4: Ask the child, “How did you know to put these together like this?”

Steps in Dichotomy Part

Step 1: Place the two pieces of paper in front of the child.
Step 2: Mix the shapes in front of the child.
Step 3: Ask the child to put together all of the shapes that are the same on one sheet of paper and all the other ones on the other sheet of paper.
Step 4: After the child completes the task, ask, “How did you put these on this sheet and those on the other sheet?” If the child did not make a dichotomy, the task was ended.
Step 5: If the child’s sorting resulted in a dichotomy, say, “The last time you put all the big circles on one sheet and the little circles on the other. Can you do it a different way?” If the child demonstrates another dichotomy, ask, “How did you know to do that?”
Step 6: If the child has sorted the objects by two different attributes, repeat Step 6 and determine if the child can make a third dichotomy (texture, shape, and size).

Data Analysis

Because each child was videotaped during the pre- and posttest, the videotapes were viewed and analyzed by the principal researcher, coresearcher, and doctoral student. When there was a disagreement about the level of a child’s thinking, the tapes were reviewed multiple times by all three researchers, followed by additional discussion to reach consensus.

Levels on Free Sorting Part

Level 1. Children at Level 1 used the objects to make such configurations as trains, circles, or pairs.
Level 2. Children at Level 2 sorted the objects into eight groups.
Level 3. Children at Level 3 sorted the objects into four groups.
Level 4. Children at Level 4 sorted the objects into two groups.

**Levels on Dichotomy Part**

Level 1. Children at Level 1 were unable to make any dichotomy.
Level 2. Children at Level 2 sorted the objects by one attribute (texture, shape, or size).
Level 3. Children at Level 3 made two dichotomies.
Level 4. Children at Level 4 made three dichotomies.

**RESULTS**

The researchers scored each child’s pre- and posttest and then assigned each child a change score. For example, if the child scored at Level 1 on the free sorting part on the pretest and Level 2 on the posttest, he or she was given a score of +1 for the change. If the child scored at Level 1 on the dichotomy part on the pretest and Level 3 on the posttest, he or she was given a score of +2. In this example, the total change score for the combined parts would be +3. The results for the experimental group are shown in **Table 2**.

As noted in **Table 2**, seven (28%) children progressed one full level, nine (36%) progressed two full levels, three (12%) progressed three full levels, and two (8%) progressed four full levels. Four (16%) children made no progress at all, and there were no children who regressed.

As noted in **Table 3**, three (12%) children progressed one full level, four (16%) progressed two full levels, and two (8%) progressed three full levels. There were no children in the control group

**TABLE 2**

<table>
<thead>
<tr>
<th></th>
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<th>+2</th>
<th>+1</th>
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<td>Age 5</td>
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</table>

**TABLE 3**

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<tr>
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<td>4</td>
<td>3</td>
<td>12</td>
<td>3</td>
<td>1</td>
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</tbody>
</table>
who progressed four full levels. Twelve (48%) made no progress. Three (12%) regressed one full level, and one (4%) regressed two full levels.

To summarize, 84% of the students in the experimental group progressed at least one level, but only 36% of the control group progressed at least one level. Interestingly, only four (16%) individuals in the experimental group made no progress, whereas 12 (48%) individuals in the control group made no progress. Additionally, none of the individuals in the experimental group regressed levels, while four (16%) individuals in the control group regressed at least one full level.

Limitations

A number of factors could have served as limitations in this current investigation. These limitations are listed in greater detail below:

- Case selection bias could have occurred because the children who participated in the study were constrained to those whose parents returned consent forms
- This study was conducted over the course of 5 months; a longer period of time would have been preferable
- It was assumed that all teachers were teaching the regular mathematics curriculum recommended by the OSR (2009-2010) and NAEYC (2010); therefore, the researchers relied on self-reported data by the teachers that the recommendations related to implementation of the curriculum were followed
- The researchers depended on self-reports by the teachers that the experimental group played the games and activities for 30 minutes each day.

DISCUSSION

Based on constructivist research, playing games is good for young children, because games allow children to voluntarily engage in activities that reflect elements of logico-mathematical development (Ozaki, Yamamoto, & Kamii, 2008). When children are playing games, such as card games and physical knowledge activities, they perform many critical actions, including acting on the object, observing reactions, making decisions, working with peers, and having discussions. With regard to learning, Piaget (1974) stated:

The child may on occasion be interested in seriating for the sake of seriating, in classifying for the sake of classifying, but in general, it is when events or phenomena must be explained and goals attained through an organization of causes that operations must be used most. (p. 17)

Further, Piaget noted the value of social interactions when children are playing games and participating in thinking activities. Through social interaction, children begin to decenter and regard the perspectives of other children. Their thinking becomes more sophisticated as they explain their ideas to one another. According to Piaget (1932/1965), when children agree and disagree with each other, it is indispensable because there is cognitive and sociomoral development.
Currently, traditional preschool curriculum is limited to children counting and engaging in more pencil/paper rote activities (Kohn, 2011). Based on the results of this study, implementing a higher order of thinking activities could result in improved logico-mathematical thinking in preschoolers.

CONCLUSIONS

The NAEYC and the National Council of Teachers of Mathematics (NCTM) do not prioritize the value of thinking or understanding the nature of logico-mathematical knowledge and its importance in their position statements (Kato, Honda, & Kamii, 2006). Currently, Curriculum Focal Points for Prekindergarten Through Grade 8 (NCTM, 2006) and Developmentally Appropriate Practice (Copple & Bredekamp, 2009) have three separate instructional goals in their model math curricula for preschoolers: geometry/spatial relationships, measurement, and number and operations. These curricula recommend activities such as counting objects up to 10, finding different shapes in the environment, and measuring length and weight of objects, to teach these topics. However, when we more clearly understand the undifferentiated nature of preschool children’s thinking, we know that these fragmented objectives are not the way young children construct logico-mathematical knowledge. Young children cannot think logically about geometry, measurement, and number in isolation. In contrast to the narrowly defined math curriculum recommended by NAEYC and NCTM, children need activities that encourage them to make decisions and tasks that challenge their thinking.

REFERENCES


