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Cylinders and spheres : toddlers engage in problem solving

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CYLINDERS AND SPHERES: TODDLERS ENGAGE IN PROBLEM SOLVING

An Abstract of a Dissertation

Submitted

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Education

Approved:

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ABSTRACT

Every day more six million infants and toddlers (children under 3 years of age) enter some kind of out-of-home care, with 22% of this group attending center-based programs. Studies on the quality of care in centers indicate that 40% of these children are in poor quality settings while 51% are in mediocre to medium quality settings. Two factors contributing to these low ratings are lack of age-appropriate materials and lack of learning opportunities. To address these data Piaget's theory of constructivism guided the design of a study to provide evidence of construction of knowledge that occurred when toddlers were provided with interesting objects and were allowed to play freely with those objects.

The study took place in one classroom of a child care center located in a small rural town in the Midwest. Eight children 18 through 24 months old participated in the study. Materials selected for the study (clear cylinders and plastic spheres) were available to the children for two hours each day during activity time. Children were allowed to play freely with the materials. Adults in the classroom provided support but did not direct the activity. Two video cameras and descriptive field notes captured children's actions with the materials. Data were analyzed to identify actions and sequences of actions that indicated construction of knowledge or problem solving.

Findings from this study indicated that children progressively organized their actions as they explored the objects, identified problems, and worked to solve those problems. When given time and allowed to play freely with the materials, children were tenacious in their problem solving, often working on one problem over several days. The

data revealed five components to the problem-solving process: exploration, contradiction, repetition, experimentation, solution. The types of problems children pursued were related to Piaget's categories of reality: space, time and causality. Based on the findings, implications are provided for teachers (both pre-service and in-service) and teacher educators.

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CHAPTER 1

INTRODUCTION

This study developed from my struggle to find a high-quality curriculum for the toddler program serving children 14 through 24 months old in the child care center where I served as director. Shortly after being hired, I made it clear to the Board of Directors that I believed all of the early childhood programs offered at the center were important, but at the toddler level we had a unique opportunity to build a solid foundation for later learning and development. It was at this age that children used their new mobility to explore the world around them. It was also at this age that staff had the most difficulty implementing an appropriate curriculum. Their teacher-directed approach conflicted with the toddlers' need to engage in child-initiated exploration. As director, I wanted the toddler program to offer a curriculum with rich experiences that invited the children to explore their world and engage in problem solving. If we did that, I believed our toddlers would be well on their way to becoming life-long learners.

This belief developed from my 30 years of experience as an educator. In my 18 years as a classroom teacher and 6 years as an early childhood consultant for 24 school districts, I had many conversations with educators who said the same thing. Children entering kindergarten already knew whether they were capable learners or not. If a child believed he or she was not capable, it was almost too late to change that view. At the same time I was engaged these conversations, I was hearing about research in the area of brain development that was shedding light on the rapid brain development in the first three years of life and the importance of the years before the start of formal schooling. I also had the opportunity to engage in reading, reflecting on and discussing the works of Jean Piaget under the guidance of Dr. Rheta DeVries. These readings and discussion focused on development during the first two years of life, the sensorimotor stage. All these experiences led me to believe that if we wanted children to have the best chance of reaching their greatest potential, we needed to start when they were eager learners. My goal as director, to foster in young children a desire to learn and a view of themselves as capable learners for life, led me to search for a toddler curriculum that would provide the rich experiences necessary for optimal development.

I was not ready for the difficulty I would have in finding a curriculum for our toddlers that would help me reach that goal. In reviewing toddler curricula I had three criteria. First, the curriculum needed to have a strong theoretical foundation. Based on prior experience I knew that without this there would be no guide to help make adjustments when problems in implementation arose. Second, the curriculum needed to be developmentally appropriate and include content consistent with what is known about the abilities of toddlers. This content needed to go beyond discrete teacher-directed activities that focused only on sensory experience or art projects typically found in many toddler programs (Katz, 2003; Rockel, 2009). Research on infants and toddlers burgeoned in the last two decades of the twentieth century (Cohen, Chaput, & Cashon, 2002) providing evidence that young children are capable problem solvers who need rich child-centered experiences that allow them to explore the materials, not just take in information. Finally, a curriculum needed to be practical and one that could be effectively implemented in the classroom setting of a child care center. If the curriculum does not take into account the reality of group care, with all of its complexities, the providers being asked to implement it would not embrace it (National Research Council, 2005).

My search for available toddler curriculum revealed three curricula widely used in the child care field. Each one had strong points, but no one curriculum met all three criteria. Creative Curriculum (Dombro, Colker, & Dodge, 1999) was very practical in its approach and addressed the reality of group care, but it did not have a strong theoretical base. It presented brief summaries of multiple theories but did not connect those theories to the activities or to teacher practice. In addition, the content and experiences provided appeared to be activities designed to teach discrete skills. The High/Scope (Post & Hohmann, 2000) curriculum had a strong theoretical base and discussed activities in terms of what we know about toddlers' actions and developmental levels but it did not provide enough practical support for the staff in the typical toddler classroom. The Program for Infant and Toddler Caregivers (WestEd, 2005) had a strong theoretical base and was relevant to the practitioners. However, it did not provide any guidance for the content or types of activities that would promote children's explorations and cognitive development. After searching for and analyzing the three widely-used infant curricula I concluded that none of them met the three criteria I set for selection. In discussions with other child care center directors it became clear they felt a similar dissatisfaction with the current curricula available for toddlers. This lack of appropriate curricula raised concerns among all directors engaged in these conversations.

Statement of the Problem

According to Zero to Three (2009) six million American children under the age of three years old experience some type of out-of-home care. Twenty-two percent of this under-three population is cared for in center-based child care, with the remaining seventy-eight percent cared for in day care homes or by relatives. As more parents enter the workforce, the number of toddlers placed in out-of-home care is expected to increase.

Most young children in child care are not exposed to optimal learning experiences. Phillips and Adams (2001) reported that the exposure of young children in child care to the lower end of the quality continuum is not rare. More than 40% of infants and toddlers in child care are in settings that are of poor quality (Zero to Three, 2009). Infants and toddlers in the lower-end centers have little access to age-appropriate educational toys and spend much of their time wandering, not engaged with adults or materials. Children in centers exceeding this minimal threshold of quality do not fare much better. Hegland, Peterson, Jeon, and Oesterreich (2003), in a study of child care in four Midwestern states, found that toddler classrooms scored low in learning experiences and were in the *poor* category for offering enough age-appropriate play materials for the children present. In addition, adults in the room controlled the activities and the schedule, often with little regard for the needs of the children (Leavitt, 1994). Early learning standards for toddlers do not offer much guidance. They often underestimate what children can do and "several significant areas of early learning and development have been left out of the standards" (Scott-Little, Lesko, Martella, & Milburn, 2007).

These studies lead to the conclusion that toddlers in child care do not have access to age-appropriate materials or high-quality learning experiences. This is occurring at a time in children's lives when experiences have a great effect on the developing brain (Diamond & Hopson, 1999) and lay the foundation for later learning. The current data on quality of child care at the infant and toddler level points to a need for a curriculum that provides access to age-appropriate materials and opportunities to engage with these materials. This data, along with the three criteria I set for selecting a toddler curriculum, led me to conduct this study. In the next section I present the theoretical framework that guided my study. This framework addresses the first two selection criteria (theory-based and developmentally appropriate).

Constructivism: A Theoretical Framework for Infant Curriculum

Piaget made a distinction between learning and development. He viewed learning as being provoked by certain situations or persons in the environment, such as a teacher presenting an activity in relation to a certain didactic point. He believed that learning was limited and occurred as a function of the process of development. He viewed development as "the process which concerns the totality of the structures of knowledge" (Piaget, 1964, p. 123). Development explained learning and was not just the "sum of discrete learning experiences" (Piaget, 1964, p.123). Most widely-used toddler curricula provide a series of discrete learning activities designed to address a specific goal or outcome (Katz, 2003) rather than provide experiences designed to support cognitive development (Hegland et al., 2003). In this section I present Piaget's theory of cognitive development. This discussion sets the context for looking at curriculum that may be developmentally appropriate for toddlers.

Piaget identified four stages of cognitive development that occur in a regular sequence: sensorimotor, preoperational, concrete operational and formal operational. According to Piaget, each stage has characteristics that "makes possible certain forms of reasoning, and . . . that place limits on reasoning possibilities" (DeVries & Kohlberg, 1987, p. 22). In this study I focused on children in the sensorimotor stage. Therefore, in the following discussion of Piaget's theory I focus on Piaget's work related to this stage.

Role of Action in Cognitive Development

Action is central to Piaget's theory of sensorimotor development. In *Origins of Intelligence* (1936/1963) he describes his theory of cognitive development during the first two years of an infant's life. This development occurs as children construct action schema. He defined schema as "the structure or organization of actions as they are transferred or generalized by repetition in similar or analogous situations" (Piaget & Inhelder, 1966/1969). Piaget believed that this mental structuring constitutes practical intelligence in the infant. He also believed that the preverbal child lacks symbolic function so action is necessary for the construction of schema and therefore intelligence.

He explains the process of constructing and organizing schema by referring to assimilation and accommodation. Assimilation takes place when the infant acts on an object and gives it meaning based on an action schema that already exists in his or her repertoire. The object is integrated into the schema and the schema is unchanged. An example is of the infant who grasps a rattle and immediately begins sucking it. The infant assimilates the rattle into the schema of sucking and gives it meaning as something that can be sucked. Accommodation involves changing the schema in some way. As the infant acts on the environment some objects cannot be assimilated into the existing schema. The infant then has to modify actions to adjust to the object. For example, the infant who already has an existing action scheme for grasping can pick up a rattle and shake it no matter how they position their hand (over or under the handle) or where they place hand on the rattle. When the infant begins to self-feed, the grasping scheme must be modified. In order to successfully get the bowl of the spoon to the mouth, the infant must adjust the grasp so the hand is placed on the correct end and is positioned so the spoon can be moved to the mouth.

In Piaget's theory, action has two meanings (Kamii & DeVries, 1993) based on two kinds of experiences. The first, physical experience, results from empirical, or simple, abstraction (Piaget, 1936/1963). This involves acting on objects, observing what happens, and drawing from the experience some knowledge about the objects. The source of knowledge in physical experience is the object itself. For example, the infant can pick up a block and draw from that experience knowledge about the block such as weight, size, texture, or color. The infant can also abstract information about the block if he or she performs an action on that block. The infant can let go of the block and abstract from that experience that the block drops or the infant can attempt to push the block on the floor and find out about the block's reaction to the push. Knowledge drawn from this kind of experience is referred to as physical knowledge. In this type of experience, action refers to the manipulative actions the infant performs on an object such as pushing, throwing, lifting, or dropping

In the second kind of experience, logical-mathematical experience, the knowledge is drawn not from the objects directly but from actions the individual performs on the objects mentally. The knowledge is constructed by reflective abstraction and is based, not on individual actions, but on coordination of two or more actions (DeVries & Kohlberg, 1987; Piaget, 1964). When the infant pushes the block on the floor and the block moves, he or she notices an individual action. If the infant pushes the block a second time but with more force and notices that the block moves farther, the infant has made a connection, or mental relationship, by coordinating the two actions and the two reactions. The source of knowledge is in the knower (the infant) and not in the object itself.

The types of experiences and actions are, in reality, inseparable (DeVries & Kohlberg, 1987). All knowledge comes from some type of action the child carries out on objects in the environment and any experience that results in construction of knowledge implies activity on the part of the child (Sinclair, Stambak, Lezine, Rayna, & Verba, 1989). The infant cannot construct knowledge from a physical experience without a logical-mathematical framework, nor can the infant have a logical-mathematical experience without objects to put into relationship with each other. In both types of experience concrete objects are necessary for cognitive development. Eventually, toward the end of Piaget's sensorimotor period, the actions become internalized and the objects need not be present. Piaget viewed this internalization as a form of logic of actions that support later formal thought and logic (Piaget & Inhelder, 1966/1969).

Elaboration of the Universe

In addition to the development of practical intelligence, Piaget talked about a second accomplishment of the sensorimotor period. This accomplishment, elaboration of the universe, occurs simultaneously with the development of practical intelligence. According to Piaget, newborns' actions are egocentric because the universe is centered on their own bodies. They do not view the universe as existing beyond this and they do not perceive themselves as an object within a larger universe. During the sensorimotor period this gradually changes as the children decenter and construct a view of themselves as existing among other objects in the universe. This happens as a result of the construction of four broad categories of action, or schema. Piaget identified the four broad categories as object concept, space, causality and time (Piaget, 1937/1971) that develop as children act on objects, observe the reactions, and experiment with new ways of acting on the objects. These categories will be discussed in more detail in Chapter 2.

Equilibration

In the process of acting on objects and constructing their world, children encounter contradictions to their expectations and experience a sense of disequilibrium, or an imbalance between what was expected and what really happened. Children then act to get back into a state of balance, or equilibrium. Piaget viewed this process of equilibration as being essential to cognitive development (Piaget, 1977). He distinguishes the process (equilibration) from the state (equilibrium). Piaget borrowed the term equilibrium from physics and modified it to fit his theory of human intelligence (Ginsberg & Opper, 1969). In physics, the term refers to a state of balance between two elements. Piaget, when referring to human intelligence, uses the term to describe the state that exists when person interacts with the environment and can take in all new information or can compensate for any perturbations (Montangero & Maurice-Naville, 1997). This state is not static as the organism continually interacts with the environment and achieves higher levels of equilibrium as more information is taken in. Piaget used the term equilibration to refer to this dynamic process.

Summary of Constructivism

The three aspects of Piaget's theory discussed above are relevant to the purpose of this study. These aspects are: (a) the importance of action for cognitive development, (b) the elaboration of the universe by acting on objects, and (c) the role of equilibration in cognitive development. Piaget's research (Piaget, 1936/1963; 1937/1971) on development during the sensorimotor stage, or the first two years of life, provides insights into how toddlers construct knowledge and can guide decisions about developmentally appropriate materials and activities.

Relevance of the Study

A number of studies (Hegland et al., 2003; Phillips & Adams, 2001; Zero to Three, 2009) have documented the low quality of experiences for infants and toddlers in child care. These studies found that children did not have access to age-appropriate materials that would allow for high-quality learning experiences. These data, coupled with the increasing numbers of children entering child care at a time when brain development is most rapid (Zero to Three, 2009) underscores the urgency of designing a curriculum to raise the quality of toddler experience.

In this study I addressed the need for age-appropriate materials by providing 18- through 24-month-old children with interesting objects and allowing the children to play freely with those objects. Guided by Piaget's theory of constructivism I selected objects that invited children to act on the materials, explore, experience disequilibrium, and solve problems in an attempt to return to equilibrium. My experience working with older children on building ramps also guided my selection of materials. Children ages 3 years old through 8 years old were fascinated with the movement of the marbles on inclines. Based on these experiences I wanted materials that would be age appropriate and allow younger children to observe the movement of spheres in a track. I selected clear cylinders and blue plastic spheres because young children could easily manipulate them, the materials offered a variety of possibilities for exploration and play, and they met safety guidelines for toddler toys. I conducted the study in a classroom setting where children had the choice of the research materials or any of the other classroom materials available. It is my hope that the data gathered from this study can provide information for the development of a toddler curriculum that is based on constructivism, offers age-appropriate materials and is practical for the classroom setting.

Research Question

The purpose of this study was to observe 18- through 24-month old children for evidence of construction of knowledge as they engaged in free play with clear cylinders and plastic spheres. I focused on children's actions as they engaged with the materials and then analyzed those actions, using constructivism as a lens, for evidence of construction of knowledge. Three questions, based on Piaget's theory of constructivism, guided the study:

1. What actions can be observed as toddlers (18 through 24 months old) engage with the research materials (clear cylinders and plastic spheres)?
2. What types of problems do toddlers set for themselves?
3. How do toddlers go about solving those problems?

CHAPTER 2

REVIEW OF LITERATURE

In this chapter I review the literature in the three areas related to the questions that guided my study: (a) children's actions as they interact with the objects in the environment, (b) types of problems children work on as they elaborate their physical world, and (c) the process children demonstrate as they work on solving problems they have chosen to pursue. For each area I present Piaget's research followed by studies that applied Piaget's theory to children 18 through 24 months of age.

Children's Actions and Cognitive Development

Piaget believed that physical experience with objects in the external environment was indispensable to cognitive development (Piaget, 1977). As children act on objects and mentally reflect on those actions they develop cognitive structures, or intelligence (DeVries & Kohlberg, 1987). In this section I discuss the research related to children's actions and the progression of cognitive development during the first period of development, the sensorimotor period.

The Sensorimotor Period

Piaget observed the behavior of his own three children (Laurent, Lucienne, and Jacqueline) during the first two years of their lives. Using a naturalistic and part informal-part experimental method (Ginsburg & Opper, 1969), Piaget carefully watched his children and documented their movements, eye gazes, and expressions in very detailed field notes. At times he would set up situations to see how the children would react. His extensive observations and notes documented the cognitive development of children in the first two years of life. In his book, *Origins of Intelligence* (1936/1963), Piaget described this early cognitive development in terms of six sensorimotor stages.

Stage 1: Reflexes (Birth-1 month). Children are born ready to learn. Heredity provides the newborn with the invariant functions of assimilation and accommodation (discussed in Chapter 1) and with reflexes allowing them to begin acting on the environment. Children first use the reflexes for the sake of using them (functional assimilation), extend the use of the reflex to include a variety of objects (generalizing assimilation), and eventually use the reflex more selectively in an early form of recognition (recognitory assimilation). As this assimilation takes place, the infant simultaneously accommodates by developing new, more efficient patterns of acting on objects. By the end of stage 1 the reflexes are no longer automatic, but are organized into more complex psychological structures that have incorporated the child's experiences (Ginsburg & Opper, 1969).

The example Piaget used was that of sucking. In a newborn, sucking is a reflex that functions immediately. The newborn performs sucking actions in between feedings in a type of functional assimilation or will suck on any objects (fingers, thumb, blanket, etc.) that come into contact with the lips (generalizing assimilation). If the infant is not hungry, the sucking continues. However, if the infant is hungry, objects that do not provide the desired nourishment are rejected and the infant will actively search for the nipple and once found will latch on and suck (recognitory assimilation). During this stage, the infant's use of the reflex still depends on chance encounters with the object. For example, the infant does not coordinate the movement of the hand to bring the thumb to the mouth in order to suck, but once the thumb happens to make contact with the mouth the infant recognizes it as something to suck.

Stage 2: Primary Circular Reaction (1 month-4 months). During the second stage, the infant coordinates actions to prolong an interesting or pleasurable result. In the example of thumb sucking in Stage 1, the infant sucked on the thumb if, by chance, the thumb came into contact with the mouth. When the thumb moved away from the mouth, the infant turned its head back and forth as if searching for the thumb but did not move the hand in such a way as to bring the thumb back to the mouth.

In Stage 2, the infant immediately tries to rediscover the actions necessary to keep the pleasurable result going. Piaget viewed this as a primary circular reaction or an "active synthesis of assimilation and accommodation" (Piaget, 1936/1963, p.61). It is assimilation in the sense that it prolonged the use of the sucking reflex, and accommodation because it was a new coordination not originally present in the reflex. Piaget did not view this as an intentional act on the part of the child but rather as an event that occurred fortuitously and the child then attempted to recreate that event.

Stage 3: Secondary Circular Reactions (4 months-10 months). In primary circular reactions, children's actions were focused on their bodies. In stage 3, secondary circular reactions, the infant attempts to reproduce and prolong interesting effects discovered by chance while acting on objects in the external environment. While acting on objects, the infant notices an interesting reaction and attempts to reproduce the event. The infant's desire to recreate the event becomes a goal and the infant's actions are directed toward reaching that goal. In Stage 3 the goal is simple repetition of an event that just occurred.

The infant does not set the goal first and then act to reach that goal (Chapman, 1988). The infant acts, observes an interesting reaction, and then acts to recreate the same event.

Although the infant is acting purposefully toward a goal, Piaget did not believe that the actions of Stage 3 constituted true intelligent behavior. According to Piaget a true act of intelligence must meet two criteria. First, a need or desire precedes any action and this need serves as a motivation to act. Second, in acting to reach the goal the infant goes beyond mere repetition of an interesting event and instead varies actions in some way to lead to new result. In the current stage the infant's need arises after the actions when the infant notices an interesting reaction. The need does not exist prior to the actions. Second, the motivation to act was a desire to merely repeat the same event.

Piaget provided an example of actions typical of this stage when he described Lucienne's attempts to recreate an interesting event. Lucienne was lying in her basinet and Piaget dangled a doll above her feet. On seeing the doll Lucienne began to shake her body, an action she had performed earlier while in the bassinet. As she shook her body her foot came in contact with the doll causing the doll to move away. Lucienne looked at the doll with delight. Piaget then varied where he placed the doll, sometimes placing it above Lucienne's head. Each time, Lucienne moved her foot in an attempt to recreate the event of the doll moving. When Piaget returned to placing the doll above Lucienne's foot he varied the height. Each time Lucienne moved her foot as if to strike the doll. If she missed, she tried moving her foot again but more slowly. With repeated attempts Lucienne was eventually able to make contact with the doll each time Piaget placed it by her feet. Lucienne succeeded in creating the desired outcome.

In Stage 3 the infant goes beyond primary circular reaction by assimilating external objects into existing schema in an attempt to prolong an interesting event. In the example above, Lucienne assimilated the doll into her schema of things that could be kicked. The infant in Stage 3 is transitioning to Stage 4 and the first intentional acts of true intelligence (Piaget, 1936/1963).

Stage 4: Coordination of Secondary Schemata (10 months-12 months). Piaget identified the criteria for Stage 4 actions when he stated that "the subject must aim to attain an end which is not directly within reach and to put to work, with this intention, the schemata thitherto related to other situations" (Piaget 1936/1963, p. 211). In Stage 3 the infant's goal was to recreate or prolong an interesting event. In Stage 4 the infant attempts to prolong the interesting event but is met with an obstacle that prevents success. When faced with this obstacle the infant must keep the goal in mind and must apply familiar schemata to a new situation. By keeping the goal in mind the infant's need or desire precedes action, the first of Piaget's criteria for intelligent acts. In order to overcome the obstacle the infant must try new ways of applying familiar actions, thus meeting Piaget's second criteria of going beyond mere repetition of an event. This separation of goal and action, or ends and means, is a significant characteristic of this stage. In order to reach the goal the infant must coordinate two or more secondary schemata, or actions, that had previously been used to simply maintain an interesting result.

Piaget described an example of this when he presented data on his daughter, Jacqueline. Piaget presented Jacqueline with a familiar toy duck. Jacqueline reached for the duck but Piaget grasped it, preventing her from taking it. At this point, Jacqueline kept in mind her goal of getting the duck but had to vary her actions and find a new means for reaching that goal. She used a known schema, pushing things away from her, to push Piaget's hand away and grasp the duck. This example illustrates the characteristics of Stage 4 actions. The goal was set (grasping the duck) and Jacqueline applied a familiar schema (pushing) to a new situation. She coordinated her actions of grasping the duck with the action of first pushing away an obstacle.

In addition to applying familiar schema to new situations, children in Stage 4 also apply familiar schema to unfamiliar objects. When an object is new to an infant, the infant has no prior experience and thus no known schema for dealing with the object. Piaget (1936/1963) noted that when confronted with unfamiliar objects the infant "cannot set himself any definite goal except 'understanding' them" (p. 253). The infant does so by exploring what can be done with the object and fitting it into known schema. The infant does this by using actions that are familiar. Piaget used the example of his son Laurent encountering a notebook for the first time. Laurent touches it, grasps it, shakes it, rubs it against the wicker crib, and transfers it from hand to hand. These are all actions Laurent used previously with other objects. Laurent defined the notebook by what he could do with it and came to understand it on practical, or sensorimotor, level. This type of exploratory action involves assimilation of the new object into existing schema and is an early form of classification. The infant classifies the object as "belonging to a generic class of objects that can't be acted on by that scheme" (Chapman, 1988, p. 90). In the example of Laurent, he classified the notebook as something to be touched, grasped, shaken, rubbed, and held. He has also put the new object into a relationship with other objects: his own body (transferring from hand to hand) and the crib (rubbing the notebook against the crib).

Stage 5: Discovery of New Means Through Active Experimentation (12 months-18 months). Piaget explained that in Stage 4 children are limited in their actions to familiar schema, which changes in Stage 5. Two behavior patterns emerge and distinguish Stage 4 actions from Stage 5 actions: tertiary circular reaction and discovery of new means through active experimentation.

Two characteristics identify the tertiary circular reaction. First, the infant's attention changes from focusing on the action to focusing on the result of the action. Second, the infant varies actions to see what will happen to the object. The infant will "provoke new results instead of being satisfied merely to reproduce them once they have been revealed fortuitously" (Piaget, 1936/1963, p. 266). Piaget identified this type of action as an "experiment in order to see" (p. 266). The infant varies the actions performed on an object and focuses on the reaction of the object. Piaget's son, Laurent, demonstrated this when he was lying on his back playing with his toys. Laurent grasped a toy, lifted it and then let it drop. He watched where the toy fell and then repeated the lifting and dropping but he varied the toy selected or the position of his arm. Laurent's attention was not on his action of dropping but was on the position of the toy as it fell. Laurent initiated variation in his actions that caused variation in the result.

This variation of action, or experimentation, leads to the second behavior pattern, discovery of new means. When the actions of Stage 4, using existing schema, do not work to reach a goal, the infant attempts different ways to reach the desired outcome. Piaget referred to this as groping. It builds on the experimentation of the tertiary circular reaction (experiment in order to see what would happen) as the infant now experiments in order to make something specific occur. The infant attempts familiar actions and when those are met with resistance the infant then tries varying the action, always with the goal in mind. In the process of attempting the various actions, or groping, the infant eventually discovers an action that leads to success. Piaget used the example of children learning to obtain a toy by pulling a support to illustrate discovery of new means. The problem presented to the infant was a toy that was just out of reach but was placed on another object (pillow or blanket) that was within the infant's reach. The infant first tried reaching out an arm to grasp the toy. Not being successful, the infant then leaned over and reached out an arm. Eventually the infant, by chance, pulled the supporting object and the toy moved within reach. The infant first tried an action that had previously resulted in getting the toy (reaching). When that failed, the infant applied schema (leaning, pulling the support) that had not previously been used when the goal was to reach the toy. By groping and trying a variety of actions in this new situation, the infant discovered a new means of reaching the goal.

Stage 6: Invention of New Means Through Mental Combinations (18 months-24 months). In the final stage of the sensorimotor period the infant demonstrates behavior that "characterizes systematic intelligence" (Piaget, 1936/1963, p. 331). In Stage 5 the infant's actions were a type of experimentation in order to see what would happen. They were a form of groping and trying varied actions in order to discover a way to reach a goal. In Stage 6 the infant does not demonstrate the groping actions when trying to reach a goal. The solution is identified before the infant physically acts on the objects, not afterwards as in Stage 5.

Piaget used the term invention to define the actions of Stage 6. The infant invents new means of arriving at a goal by mentally combining schema before acting on objects. The actions and the probable consequences are represented cognitively, and the infant is able to select the correct action before it is actually performed (Chapman, 1988). Jacqueline demonstrated invention of new means when she wanted to get a watch chain that had been placed inside a matchbox. Piaget placed a watch chain inside the matchbox then closed the box most of the way. Jacqueline had played with the matchbox before and used two actions to get an object out of the box. She turned the box over in an attempt to empty it and she inserted her fingers into the small opening and reached for the object. She did not pull open the matchbox so this was not an action she was familiar with when Piaget offered the box with the chain inside. Piaget stated that Jacqueline was not aware of how the matchbox functioned. When he held to matchbox to her she looked at it, opened and closed her mouth, and then quickly put her finger in the slit; rather than reach in for the chain as she had in previous experiments, she pulled open the matchbox and grasped the chain.

The defining characteristic of Stage 6 is the infant's ability to mentally represent possible actions before actually performing them. For the infant, thought is becoming freed from the physical action on concrete objects. This stage forms the transition to the next period of development in which the infant is able to mentally represent absent objects and use words to refer to those objects.

Piaget's sensorimotor stages describe his theory of cognitive development that takes place during the first two years of life. He believed that there could be no cognitive development or construction of knowledge without direct action on the external environment. As the infant interacts with the external environment actions become more organized and progress from the simple reflexes centered on the self to intelligence that allows the infant to anticipate outcomes before performing actions.

Piaget explained that as children progress to a new stage there are elements of earlier stages still present. It is not a matter of one stage replacing another but rather of each stage being possible because of the organization of mental structures that took place in prior stages. Piaget also stressed that the ages he ascribed to each stage were not set in stone. Variations occurred depending on several factors, for example physical development or social context. However, the order of the stages did not vary. He believed that an infant could not move to a new stage until the schema, or mental structures of earlier stages are in place. It is through the progressive organization of actions and schema that development takes place.

Infants and Objects: The Progressive Organization of Actions

Sinclair et al. (1989) reported on three studies that followed up on Piaget's work with children in the sensorimotor period. The studies focused on how children applied their knowledge as they interacted with objects during the second year of life when the transition from action-based intelligence to conceptualized thought takes place. In this section I present their first study that was designed to observe children's actions and determine if a progressive organization of behaviors existed at an early age.

Stambak, Sinclair, Verba, Moreno, and Rayna (1989) conducted a longitudinal study of 9 to 24 month-old children in child care centers in Paris and Tehran. The study involved 69 children and included 47 observations over a 14-month period. Each 20-minute observation took place in an isolated area in the classroom. Children were placed on the floor with a variety of objects (six nesting cubes, six nesting bowls, small cork balls, wooden cylindrical rods, and balls of modeling clay) and invited to play. Two researchers were present at each session. One researcher sat by the children and observed children's actions but did not intervene unless a child made a direct request. The second researcher operated the video camera. Researchers reviewed the tapes and transcribed object manipulation, noting children's actions in order as they occurred. Analysis of the transcriptions indicated three periods in the organization of behaviors.

In the first period, between 9 and 12 months, children performed a variety of actions on the objects (e.g., touching, hitting, throwing, and lifting). The actions were indiscriminate in the sense that any object provoked any of the actions. As children continued to act on the objects they started to link their actions, performing several actions on one object or repeating one action over several objects. By the end of this period children matched their actions to the object. For example, they waved the cylindrical rods in the air, rolled the balls, or put a ball into a cup. Children's attention appeared to be focused on the action and how the object fit into that action schema.

Beginning around 12 months of age, children's repetitions became more focused. During this second stage the researchers noted two types of more focused, or iterative, actions: collection and distribution. When children demonstrated collection their repetitive actions resulted in a grouping of dissimilar objects placed in a container. For example, children repeated the action of putting into by putting different kinds of objects (rods and balls) into one nesting cube. When children engaged in distribution they repeated the same action on several objects, similar to behavior in the earlier stage, but during this stage the action was repeated on objects from the same class. The children used the rod to touch all the cups, ignoring the balls. In this stage the children's attention appeared to be focused on the results of their actions not just on the action itself.

The final stage, from about 16 months to 24 months, children's attention appeared to be focused on a desired result first and then they organized their actions to achieve the result. For example, a child held a cup and looked around at the objects. He then picked up only the rods and placed them into a nesting cube. The researchers concluded that children organized their actions in more and more complex ways beginning with indiscriminate actions and ending with actions organized to reach a goal.

This progressive organization of actions aligned with the sensorimotor stages typical for children of this age, stages three through six. The researchers viewed this organization of actions as pre-logical, indicating that it occurred before the truly logical operations of older children and it laid the foundation for later logico-mathematical reasoning (class inclusion, seriation and whole numbers).

Langer (1986) also studied children in this age group as they manipulated objects. His study included 12 children, evenly divided by gender, at each of four age levels (15 months, 18 months, 21 months, and 24 months) for a total of 48 children. Children were selected from the enrollment at a university child care center. Materials used in the study included: solid geometric forms, (circular column, square, etc.), outlined geometric forms (rings, square), realistic objects (miniature cars and dolls), PlayDoh and tongue depressors.

The study took place in a research room at the child care center. Children were seated in the room with one researcher present. Each session involved a three-part procedure. The researcher first allowed the children to engage in spontaneous manipulation of the objects. During the second phase of the procedure the researcher used nonverbal prompts to elicit a grouping activity. In the final phase the researcher provided objects that could be grouped into two categories but included one object that did not belong. Using nonverbal probes the researcher prompted the children to group the objects. Video- and audio-tape, in an adjacent room with a one-way mirror, captured the children's actions and any vocalizations. Each child's actions on the objects and the transformations made to those objects (either in shape or position) was noted and analyzed for spatio-temporal relationships, relationship between child's different actions, and relationship between the child's actions and the transformation of the objects. The results reported here are based on the session of spontaneous play.

Langer identified four stages of development as children acted on the objects. In the first stage, 15-month-olds performed a sequence of actions on a variety of objects as if trying to figure out the properties of the objects and to confirm the rules that govern the reaction of the objects. For example, one child held a small block, set the block down, touched the block with one finger, pushed down on the block with one finger, rotated the block, and then used two fingers to push the block away. The child learned about the properties of the block by performing a variety of actions on one object. Another child performed one action on a variety of objects and observed how the objects reacted. The child put a fork into a cup and the cup tipped over. The child righted the cup and proceeded to insert several different forks into the cup, each time knocking it over and having to right it again. He then tried different cups, repeating the actions of inserting a fork, watching the cup tip, righting the cup and inserting more forks. Langer identified these as phrase-like routines that did not serve as a means to a goal but explorations of different actions that could then be mapped to different objects.

In the second stage, 18-month-olds combined phrase-like routines into more complex routines and appeared to anticipate the reaction. He presented the example of a child who inserted a spoon into cup and watched as the cup and spoon tipped. The child then held a cup steady with the left hand, inserted a spoon into the cup with the right hand, removed the spoon, put it back into the cup, and then repeated this with different spoons. His action of holding the cup indicated that he anticipated the action of the cup tipping over. The child combined the phrase-like routines of uprighting the cup, holding the cup, and inserting the spoons into the cup. Langer identified this combination as sentence-like routines because the actions occurred more quickly in sequence and indicated the beginning of a means-end routine. The end goal (putting the spoon into the cup) could only be accomplished if the child held the cup (means). Children in this stage demonstrated many acts of negation as they repeated routines (for example, filling and emptying containers).

Children in the third stage (21 months old) combined routines and their actions seemed to be carried out with a plan in mind ahead of time. Actions often overlapped. For example the child said, "Boat, boat" and set a small wooden cylinder upright in the middle of a rectangular block. He then lifted the cylinder with his right hand, moved it to another rectangular block and used his left hand to pick up another cylinder and place it on the first rectangular block and stated, "Toot, toot." His words signified that he had a plan in mind before he started his actions. As he acted on the blocks his action of creating the boats overlapped as he moved the cylinder to a new rectangle and, at the same time, added a new cylinder to the original rectangular block.

In the fourth stage 24-month-olds planned, carried out the actions to implement the plan and corrected their actions, often with variations. He used the example of the child who, while playing with the rings, stacked four rings to make a tower. The child dismantled and reconstructed the tower twice: each time he stated, "Do dat again." This verbalization indicated the child's plan. During a third repetition the child stacked three rings then picked up a block and set it on top of the three rings. He looked at the new construction, picked up the fourth ring in his left hand and brought it near the tower. He then removed the block with his right hand, replaced it with the fourth ring, set the block on top of the four rings and added two more blocks, creating a variation of the original tower. When the child picked up the fourth ring and noticed the block, he corrected his actions so he could create the original tower. He then varied his actions by adding the blocks to make a new construction and expanded the original plan.

Both studies (Langer, 1986; Stambak et al., 1989) found that children progressively organized their actions as they acted on objects. This organization followed a progression consisting of exploratory actions (a variety of actions on a variety of objects), focused exploration (one action on a variety of objects or a variety of actions on one object), and planning (setting a goal and carrying out action to reach that goal). As children moved from focused exploration into planning they often experimented by varying their actions and observing what happened. They continued to experiment until they reached the desired outcome or, as they varied their actions they observed the results and set new goals.

In the first study (Stambak et al., 1989), the researchers presented the objects to the children but did not direct their activity. The researchers reported that the children seemed to raise their own questions to answer or identified problems to solve as they worked at reaching desired goals. In the second study (Langer, 1986), the researcher allowed some free play but also set some problems for the children to solve. Both studies identified some similar problems children pursued. In the next section these problems are discussed in terms of Piaget's (1937/1971) four dimensions of reality.

Elaboration of the Universe: Problems to Solve

During the sensorimotor stage as children act on objects they learn about the properties of objects and about the relations between them (Ginsburg & Opper, 1969). Through their actions they develop a type of practical intelligence that helps them understand external reality. Using the same data gathered for his study of cognitive development discussed above, Piaget (1937/1971) identified four dimensions of external reality that children elaborated during the sensorimotor stage: object concept, space, causality, and time. In this section I first present Piaget's findings on how each of these dimensions develops during the sensorimotor stage. I then present studies that look at the types of problems children solve related to these dimensions.

Piaget's Dimensions of External Reality

According to Piaget (1937/1971) a newborn's activities are centered on the self and the "universe presents neither permanent objects, nor objective space, nor time interconnecting events as such, nor causality external to the personal actions" (p. xi). This egocentrism is gradually eliminated as children gain experience and construct an external world of permanent objects governed by space, time and causality.

One of the major accomplishments of the sensorimotor period is the construction of the concept of object permanence (Piaget & Inhelder, 1966/1969). Piaget defined an object as something of substance that is permanent and has constant dimension (Piaget, 1937/1971). An object exists in reality even when it is not directly perceived. According to Piaget, newborn children do not conceive of objects as existing beyond immediate perception. When a newborn acts on an object, the object is assimilated into the action schema but when the action stops, the object ceases to exist for the infant. It is only through many experiences with objects that the infant gradually develops a concept of an object as separate from his or her actions. When this occurs children act on objects and begin to put them into relationship with each other. At first children put objects into relationship with their own bodies but with experience they construct relationships between two or more objects separated from their bodies. This leads to the understanding that objects have substance and exist separate from actions or from self. This understanding continues to develop as children learn to visually track an object, often anticipating the path, and to search for objects that have moved out of sight. When children actively searched for a fully hidden object, Piaget concluded that they had constructed an understanding of object permanence.

The schema of permanent object is closely related to Piaget's second broad category, the schema of space. Space is defined by the relationships of objects in the environment. The infant learns to conceive space "only as a function of the construction of objects" (Piaget, 1937/1973, p. 110). Newborn, non-mobile children are initially limited to constructing relationships among objects in near space, or the space within their immediate area of prehension. This initial spatial knowledge is egocentric; children construct spatial relationships centered on their own bodies and actions. For example, children play with toys and bring them to their mouth in the initial stages of developing a sense of containment. With the onset of mobility (crawling and walking) children gradually become less egocentric and construct relationships involving objects separate from their bodies. The children now experiment with inserting a variety of objects into containers as when the infant places a block into cup. Rather than center relationships on their bodies, they are able to put objects into relationship with each other. At the end of sensorimotor stage children extend their concept of space and are able to place their own bodies into relationships with other objects around them. They are capable of detouring around obstacles and they experiment with placing their bodies in relationship to things in the environment. Extending on the previous examples, they now play around with placing their bodies inside boxes, cubbies, and other openings they see. They also continue to form more complex relationships between objects and are able to put several objects into relationship with each other. For example, they move all objects from one category into a group as when they gather all the dolls together or put all the toy cars in one spot.

The schema of time, like space, is constructed "little by little and involves the elaboration of a system of relations" (Piaget, 1937/1971, p. 362). Piaget described the development of time during the sensorimotor period. The infant begins by perceiving time as simple duration of actions. As the infant separates action from the object's reaction, noting that the action happens first, the infant begins to understand time as an ordinal sequence. This understanding is at first tied to the infant's immediate actions and direct perception of the event. Gradually the infant who is able to hold mental images of actions also is able to repeat the action after a passage of time, constructing a relationship between past events and present events. By the end of the sensorimotor period Piaget explained that the infant had constructed a schema of time as duration, ordinal sequence of events, and existing beyond the immediate present.

The schema of causality develops as children construct relationships between objects, objects and actions, and between actions. Causality develops gradually during the sensorimotor period and the "initial phases are centered on the child's own action, while he is still unaware of the spatial and physical connections inherent in material causal schemes" (Piaget & Inhelder, 1966/1969, p. 17). Piaget referred to this egocentric sense of causality as magical-phenomenalist. Two events occur simultaneously so as to appear causally related (phenomenalist). The word magical is used "because it is centered on the action of the subject without consideration for spatial connection between cause and effect" (Piaget & Inhelder, 1966/1969, p. 18). Piaget used the example of the infant who squints when a light is turned on. Later the infant looks at the darkened bulb and squints as if to turn it on. As the infant continues to structure space and time, this magical-phenomenalist view changes and the infant constructs the schema of cause based on order of events (cause happening first) and on spatial connections. For example, observing a toy that is out of reach but is sitting on a blanket the infant recognizes the need to pull the blanket first (cause) to get the toy. The infant also recognizes the need for the toy to be in contact with the blanket. If the toy falls off the blanket, the infant will not pull it to get the toy.

According to Piaget, these four categories of action schema represent major accomplishments of the sensorimotor period. Although Piaget presented each category of action schema separately, he stressed that they develop in conjunction with each other. As the infant reaches a hand out and hits a ball and then watches the ball roll, several schema are present: causality (hitting causes the ball to roll), space (contact between the hand and the ball, path of the ball), time (sequence of hitting first, duration of ball rolling) and object (the ball exists even if it rolls away and out of sight). These schema develop as children solve problems or seek answers to questions raised in the course of acting on objects.

In the next section I present studies that looked at the problems children addressed as they engaged with a variety of objects. Problems, as discussed in this paper, are defined as a goal children set and pursued. This problem may arise from the desire to explain a discrepancy between an expectation and what was observed, a question raised when noticing an object's reaction, or a goal set in the course of interacting with the environment. In reviewing the research I focused on space, time and causality. I do not present the literature on object permanence because most children this age already have an understanding of the object as something permanent and existing in space and time.

Problems Children Pursued

In the study presented earlier (Stambak et al., 1989) the researchers studied the children's progressive organization of actions. The researchers also noted that as children acted on the objects they seemed to identify problems to solve or goals to reach. Analysis of the videotapes revealed three types of problems children identified: collecting, nesting, and establishing one-to-one correspondence.

Children from 12 months of age to approximately 16 months of age worked on collecting by gathering any objects together in a group. This collection of unlike objects was often placed in some type of container (nesting cubes or nesting bowls). After placing objects in the container, children looked into the container as if to make sure the objects remained inside. When the container was full they looked inside again before taking each object out or turning the container to empty it. By the end of this stage (approximately 16 months) children no longer looked inside the container before tipping it over to empty it. This action indicated that children had developed a concept of the object as still existing even when not directly seen. In the later stage (approximately 16 months to 24 months) children's collections consisted of objects of the same class. Children gathered together all the balls, all the rods, all the bowls or all the cubes. They created their collections by adding elements one by one leading to a temporal relationship (adding one and then adding one more), a numerical relationship (each action of adding one more results in a larger group), and a spatial relationship (placing like objects next to each other in a designated space).

The second type of activity, nesting, involved all six cubes or bowls. Children attempted to put the nesting objects in a series that contained all the objects in correct order. This required children to solve the problem of equivalent differences in size, a spatial problem. Children started with the objects that had obvious differences, resulting in nesting of a partial set of either bowls or cubes. For example children placed the smallest cube in the largest cube. Children then nested the cubes or bowls in sets of three, leaving out the remaining three. These three were then nested separately. Eventually, through a process of trial an error, the older children (24 months old) successfully nested all six objects in the series.

In the final activity, one-to-one correspondence, children created pairs of different classes of objects (e.g., putting each rod into a different clay ball or putting one ball into each cup). This problem evolved from early distributive actions (performing one action on multiple objects in a class) and from making collections. As children performed an action on several objects they started putting similar objects in close spatial relationship to each other (grouping all the balls and all the rods). When objects were grouped, children then started pairing one object from each set together (putting a rod next to a ball). This pairing involved spatial relationships of putting into (pairing a ball and nesting cube or bowl by placing the ball into the container) and putting into contact (placing paired objects next to, on top of, or end-to-end).

The findings of this study revealed not only a progressive organization of actions discussed in the previous section but also more complex use of materials as children pursued ideas or solutions to problems. Once children set a goal of obtaining a desired result they persisted in reaching that goal trying one idea and then "they started again, they tried once more a little differently, and they did not tire of trying" (Stambak et el., 1989, p. 58). They pursued problems related to spatial concepts, object concept, and some temporal concepts. The researchers also observed some causal reasoning but not frequently enough to address in the findings. Materials used in this study may have limited the types of reasoning observed. The researchers pointed to a need for further research in the area of causal reasoning and spatio-temporal reasoning using materials selected to suggest these types of reasoning.

Langer (1986), in the study discussed earlier, did analyze children's causal reasoning. In observations of children during spontaneous play Langer identified two main categories of problems children pursued: spatial and causal. He referred to these problems as means-end transformations, or actions that occurred when children were "creating, orienting to, or solving some goal, object, or problem" (Langer, 1986, p. 11).

Problems that Langer identified as causal in nature involved movement or energy relations. As children acted on objects they constructed a relationship between their action and the object's reaction (type of movement or change in movement). This construction of relationships followed a developmental sequence aligned with the stages of Piaget's (1937/1971) sensorimotor period and the development of categories of schema. Children started by connecting simple actions to the minimal effects. For example, they used one object to bang on another object and observed the result. Then children started to vary their actions in a series of small ordered steps. They repeatedly banged one object against another, banging harder with each hit and observing the variation in effect (more movement of the object acted upon or a louder noise). The most complex causal reasoning related to problem solving occurred when children anticipated and predicted effects and adjusted their actions. He used the example of children pushing on objects to get them to roll away. At first, children randomly pushed objects that rolled away (cylindrical blocks) and objects that did not (square blocks). With experience, children increasingly avoided the square blocks and pushed only on the cylindrical blocks, anticipating that they would roll. Children then used one object to push another object to make it move. For example children used a long block to push the cylindrical block away. They also used the long block to extend their reach and pull an object toward them. Langer concluded that the connections, or logico-mathematical relationships, constructed during this type of problem solving supported the development of causal schema.

Langer (1986) identified spatial problems as "dependent placement relations" (p. 13). He observed three types of activity related to spatial problems: alignment, envelopment (a form of content-container relationship), and translation (rotation of objects). In actions related to alignment children first worked only in one dimension and aligned objects on a horizontal plane (table top or floor). They then placed one object vertically at a right angle to the object on the horizontal plane. This led to vertical constructions made by stacking objects on top of each other and figuring out the spatial relationships required for the objects to stay balanced.

Envelopment actions started with simple content-container relationships (placing objects inside a cup or box) but changed when children tipped the container upside down and released the objects inside. With the container still upside down children lowered the container over the objects and enveloped them inside, isolating them from objects outside the container. Children constructed the relationship of the container as passive (something to be filled) or as active (something to place over and around objects to isolate them).

In actions involving translation children rotated objects in order to accomplish their goal. They filled cups with objects, turned the cup over (translation) and let the objects fall out, then turned the cup upright and looked inside. Seeing it was empty they started over and filled the cup again. Once the cup was full, they accomplished their goal of emptying the cup again by tipping it over. In stacking object children often tried to place a large rectangular block on top of a smaller square block by setting the larger block on its narrow edge. They watched the large block fall, picked it up, started to place it in the same position, rotated it and placed it on the smaller block so it laid flat. This translation of the objects allowed children to view the object from a new spatial orientation and note the differences of the various views. The action involved in translation indicated children's understanding of the need to change some spatial aspect of the situation in order to accomplish a goal.

In the two studies presented in this section (Langer, 1986; Stambak et al., 1989) children played spontaneously with the objects. One study (Miyakawa, Kamii, & Nagahiro, 2005) required children to solve a specific problem presented by the researchers. The study looked at the development of logico-mathematical knowledge related to spatial relationships.

The subjects were 50 Japanese children from 1 year through 35 months old. Children were taken to a game room and presented with the materials (cylindrical blocks, cubic blocks, a long rectangular block and a board). After a brief period of free play, the interviewer demonstrated how to construct an incline and then rolled the cylindrical block down the incline. The interviewer asked the children to watch and then prompted them to roll the cylindrical block in the same way. If children succeeded in rolling the cylinder down the incline correctly, the interviewer took the incline apart and asked the children to construct their own incline. A video camera captured the children's actions.

Analysis of the children's actions in rolling the cylinder down the incline revealed that younger children (1.0 to 2.5 years of age) responded to the demonstrations in a wide variety of ways (with some correct responses) and older children (2.5 to 3.5 years of age) responded with only correct, or nearly correct, actions. Analysis of actions in making an incline showed similar results but there were no correct responses until 1.9 years of age. All children 3.2 years of age and older responded with only correct actions.

In attempting to make the incline, younger children placed the materials in a variety of spatial relationships even though they had a visual model in front of them. The researchers identified four response levels to the request to recreate the incline. The first level (Level 0) indicated that there was no response. In a Level 1 response children demonstrated the spatial relationship of next to, as they placed the boards side-by-side, flat on the floor, but they did not create an incline. Children at the next level of response (Level 2) placed the larger board (the piece that needed to be inclined) horizontally on the smaller support board, putting them into the relationship of on top of. In the final level (Level 3) children correctly put the two boards into a spatial relationship with one end of the larger board resting on the support board and the other end on the floor, creating the necessary incline. The researchers noted that in all attempts to create the incline children did put the objects into a spatial relationship that closely matched the model but incorrect responses focused on only one aspect of the model. For example, the response of putting the objects next to each other was correct in putting the objects in contact but did not take into account the need for one end of the larger board to be on top of the smaller board.

In a related study (Kamii, Miyakawa, & Kato, 2007) researchers found similar levels of responses when children were asked to recreate a model of a lever. Participants included 73 children ranging in age from 12 months through 53 months of age. All children attended private child care centers in Japan. Children were taken individually into a game room with an interviewer. The interviewer demonstrated how to make a lever by placing a small tube horizontally on the floor and then placing a flat board on the tube. The interviewer placed a beanbag on the lower end of the lever and then hit the higher end, causing the beanbag to fly off. The interviewer then asked the child to try it. Analysis of children's responses showed a progression of responses from Level 0 (no response) through Level 3 (correct response). These levels were similar to those in the earlier study (Miyakawa et al., 2005) and showed a correlation to age. The younger subjects demonstrated more Level 0 responses and older subjects more Level 3.

Based on the results of these two studies (Kamii et al., 2007; Miyakawa et al., 2005) researchers concluded that children gradually constructed logico-mathematical relationships, or mental relationships. As the network of children's mental relationships increased it allowed them to notice the spatial relationships required for a correct response. Until the necessary relationships were constructed, children seemed satisfied with their attempts and did not seem to notice that they were incorrect. When children noticed the discrepancy between their construction and the modeled incline they seemed dissatisfied with the results of their actions. This was an indication that they had progressed in constructing the necessary spatial relationships that allowed them to notice more details in the model and realized that their attempt did not match that model. They then varied their actions and tried to find new ways to make their construction more like the model.

The four studies presented in this section (Kamii et al., 2007; Langer, 1986; Miyakawa et al., 2005; Stambak et al., 1989) provided data on the types of problems children pursued related to these four schema. When children were allowed to play spontaneously with the objects provided as in the first two studies (Langer 1986; Stambak et al., 1989) they identified problems related to object concept (filling and emptying containers), space (e.g. nesting, placing objects next to each other, enveloping objects), time (adding objects to a collection one at a time), and causality (pushing an object to make it move away). Older children in the studies (16 to 24 months old) pursued more problems related to space, time, and causality. This may be because they had already developed the concept of object as permanent and used this foundation to construct knowledge about how those objects fit into the external world.

In the last two studies (Kamii et al., 2007; Miyakawa et al., 2005) children did not play spontaneously. They were asked to perform a specific task that involved construction of spatial relationships. The researchers described children's development in their ability to create a correct incline. A major finding of the studies was that children were satisfied with incorrect constructions until they had constructed the necessary mental relationships that allowed them to notice all the details in the model. When children noticed the discrepancy they indicated their dissatisfaction by attempting to correct their incline. At this point of dissatisfaction, children were in disequilibrium and they worked to get back to equilibrium by pursuing the problem of making a correct incline. In the next section I discuss Piaget's (1936/1963) theory of equilibration and then present studies that show how children, when experiencing disequilibrium, engage in problem solving.

Equilibration and Problem Solving

In *Origins of Intelligence* (1936/1963) Piaget discussed equilibration as it occurred during the sensorimotor period. The process begins when the infant experiences a disruption in equilibrium causing disequilibrium. Piaget referred to this as a perturbation or "anything creating obstacles to assimilation or to achieving a goal" (Piaget, 1975/1985, p. 16). This perturbation is something new in the environment that the infant has never experienced or something unexpected that happens as the infant interacts with the environment. The resulting disequilibrium causes a desire, or need, in the infant to get back to equilibrium (Piaget, 1936/1963).

When faced with a perturbation the infant acts in one of three ways in response to disequilibrium (Ginsburg & Opper, 1969; Montangero & Maurice-Naville, 1997; Piaget, 1964, 1977, 1985). The first response, *alpha,* results in no modification of the system. In this type of response the child chooses to ignore the perturbation or moves the object responsible for the perturbation away so it is no longer a problem (Piaget, 1975/1985). For example, a toddler playing with a shape sorter (a toy that requires the child to match the shape of the block to the shape of the opening in order to insert the block into a container) tries to insert the circular block into the cross-shaped opening. When the circular block does not go into the container the toddler throws the circular block away from the play area, or the toddler abandons the shape sorter and finds something else to play. A second possible response to disequilibrium, *beta*, occurs when the child easily assimilates the perturbation into existing schema. The perturbation becomes a new variation of the original action. Using the example from above, after the initial attempt to put the circular block into the cross-shaped opening, the toddler rotates the circular block and keeps trying. When the toddler, by chance, holds the circular block vertical to the shape sorter so it aligns with one line of the cross-shaped opening, the circular block falls into the container. The toddler deals with the contradiction by adjusting the position of the circular block but does not envision the possibility that there are other openings to try. Both alpha and beta responses result in the toddler returning to equilibrium at the same level as before the perturbation. A third possible response, *gamma*, takes place when the schema is modified and adapted to the perturbation. This response results in equilibrium at a higher level than before the disruption and as a result of that reequilibration children anticipate and predict results of actions. A toddler with the shape sorter, in a gamma response, picks up the blocks and easily finds the correct opening for each block.

Piaget's theory of equilibration explains the process children experience as they work at solving problems. When children are able to assimilate new external data into their existing schema they are in equilibrium. They are also in equilibrium when they do not notice discrepancies as in the Miyakawa et al. (2005) study when children were satisfied with their incorrect incline. When children are not able to assimilate the external data into their existing schema they are in disequilibrium and work to get back to equilibrium. They can ignore the discrepancy or they can confront the discrepancy by engaging in problem solving. The studies discussed below describe the processes children demonstrate when engaging in problem solving.

Problem-solving Process

After observing children in an earlier study (Stambak et al., 1989) three of the researchers (Rayna, Sinclair, & Stambak, 1989) designed a new study to look at what questions children asked themselves and how they went about answering those questions as they engaged with physical objects. Eighteen children from 11 through 26 months of age were videotaped in their day care classroom for 20-minute sessions as they interacted with a collection of objects (tube, beads, paper balls, string, cardboard, a metal grid, cubes, a piece of cloth, a pipe cleaner, cotton balls, plastic chips, wooden board, sticks, rubber bands, paper, uncooked spaghetti noodles, and a ball of clay). An observer was nearby and would show interest but did not intervene. No other adults interacted with the children. The objects were placed on the floor and the children were allowed to come to the area by choice.

Analysis of the tapes showed that children demonstrated two phases of action: exploration and experimentation. These two phases were evident across a variety of problems (e.g., envelopment, threading, constructing) and across all ages. However the researchers noted that younger children engaged for longer in exploration while older children moved more quickly into experimentation. Within each phase children's actions became more organized as their focus changed.

During early exploration children applied "their principal action patterns indifferently to any object they grasped" (Rayna et al., 1989, p. 63). They performed many different actions on a variety of objects. For example, one child picked up the clay ball showed the investigator, put it down, picked up the paper and put it in his mouth, dropped it, picked up the bead and looked at it, picked up the chip, and then handed the objects to the investigator. In another form of early exploration children performed many actions but focused on one object as if to determine its properties. As they focused their attention on the object they gradually matched their actions more closely to the properties of the objects (e.g., rolled the beads, pulled apart the cotton balls, or reshaped the clay). Children seemed more deliberate as they chose objects to act on rather than indifferently acting on all objects within their grasp. These actions indicated that children were assimilating the objects into existing action schema. Eventually, as a part of exploration, children combined two or more objects and observed to see what would happen. For example they inserted the spaghetti into the tube or they stuck various objects into the ball of clay. This was observed toward the end of the exploration phase and led into a phase of experimentation.

During experimentation children first repeated their actions as to confirm that they would always get the same result and that the observed reaction was reproducible and regular. In addition, they went beyond repetition and started to vary their actions as if to relate cause and effect. In the process of repetition children often encountered surprises or reactions that they did not expect. When this occurred children paused before resuming their actions. They first tried to make the objects act according to the original expectation. After several attempts they instead varied their action to take into account the discrepancy. Researchers reported the actions of one child who inserted spaghetti into the tube. When the child's hand turned the spaghetti fell out. The child paused, reinserted the spaghetti and watched as it slid through the tube and to the floor. He repeated this several times before he varied his actions and placed his hand at the end of the tube before reinserting the spaghetti. These actions illustrate how, during this experimentation, children first assimilate objects into their existing schema but then are in disequilibrium when they are confronted with a discrepancy. They continued their attempts to assimilate the object by repeating their actions. Once convinced that their current actions were ineffective children varied their actions and accommodated to account for the discrepancy. In the later stages of experimentation children went beyond acting on objects to see what would happen and instead seemed to have a goal in mind that guided their actions.

Acquisition of Problem-solving Strategies

In this study (Rayna et al., 1989) children were allowed to play freely and set their own plan for what to do with the materials. The researchers were interested in how children went about answering questions raised in the course of their play. In other studies on children's problem solving, researchers were interested in how children acquired the strategies to solve problems. In these studies, researchers defined the problem for the children and then noted the steps involved in the process of solving the problem. Two of these studies are presented here.

McCarty, Clifton, and Collard (1999) presented a task to older infants and toddlers that was designed to show how children developed strategies to solve a problem. The task involved children picking up three objects that had a handle end and a goal end (a spoon with applesauce in the bowl section, a partially filled bottle, and a bell). Participants included thirty-six children, 12 at each of three age groups: 9-month-olds, 14-month olds, and 19-month olds. Researchers presented each object several times to each child, each time with the object oriented in a different direction, and videotaped the children's grasping and using the object successfully (getting the applesauce in the mouth, putting the nipple of the bottle in the mouth, and holding the handle of the bell to ring it).

Analysis of the tapes revealed that children exhibited four stages in the development of a successful strategy. In the first stage, feedback-based strategy, children completed the tasks but the goal was not initially met (for example, putting the handle end of the spoon into the mouth or grasping the bell rather than the handle). They then manipulated the object and held it in the correct position. In the second stage, partially planned strategy, they initially grasped the object incorrectly and then perceived the relationship of the object to the hand. They adjusted their hands before completing the action sequence and were successful. In the third stage, fully planned strategy, children grasped the object correctly at the outset and successfully reached the goal. However, the children hesitated before starting the action and looked at the object for several seconds. In the final stage, habitual solution, children easily completed the task with no hesitation and they never returned to earlier strategies.

The researchers concluded that in the first two stages children attended to only a single element of the task rather than to the whole problem. For example, with the spoon task they only took into account grasping the spoon to bring it to the mouth. They did not take into account the two ends of the spoon. This is consistent with the findings of Miyakawa et al. 2005). Children noticed only what their current logic-mathematical structures allowed them to notice. The researchers (McCarty et al., 1999) also noted that children's hesitation during the third stage indicated an understanding that their initial attempt was incorrect. They were beginning to take into account all the relations involved in the task and varied their actions so they could be successful, similar to what Miyakawa et al. (2005) reported as children's dissatisfaction with their incline before trying new ways of making an incline to match the model. Children's hesitation, or dissatisfaction, is an indication of disequilibrium.

In a similar study, Chen and Siegler (2000) presented children with a task and analyzed how children went about solving the problem associated with that task. The researchers conducted a microgenetic study of toddlers working on solving a series of problems that had similar structure but different surface details. Eighty-six children between the ages of 18 and 35 months participated in the study. The task, a toy-retrieval task, required children to select a tool to obtain a toy that was just beyond the child's reach. Researchers set a toy just out of reach of the child and then presented six tools of different lengths and colors. One tool, the target tool, was long enough to reach the toy and had an end that allowed children to "hook" the toy and pull it toward them. Researchers prompted the children to get the toy. Children participated in three toy-retrieval tasks, four trials per task, with new toys presented for each task. Each time a new toy was presented, the color was changed, and the end of the target tool was different (rake, ladle, cane).

Researchers analyzed data by looking at four different measures. For the first measure, general strategy, researchers noted whether the child leaned forward to reach for the toy, looked to an adult and asked for help, or used the tools. Researchers used a second measure, specific tool use, to identify which tools a child used to try to reach the toy. Using the third measure, success in obtaining the toy, researchers figured the percentage of correct solutions in which the child used the target tool. A final measure, solution time, examined the time it took children to obtain the toy. The analysis of over

1000 trials, using these four measures, resulted in a database that allowed researchers to examine the processes involved in toddler's problem solving and learning.

Chen and Siegler (2000) found that children used several problem-solving strategies and continued to use less effective strategies even after they had demonstrated a more effective one. With more experience over the number of trials, children refined their strategies and increasingly used the target tool to successfully retrieve the toy. Chen and Siegler described the progress of children's acquisition of problem-solving strategies using five component processes suggested by Siegler's (1996) overlapping waves theory.

The first component, acquiring new strategies, occurred when children explored the materials and first attempted to solve the problem. They tried using ineffective tools as well as the correct tool in a type of exploration. When they were successful, they repeated their action with the correct tool. After acquiring the new successful strategies, children began mapping, or using the strategies in a new situation (with the new toy and new tools), trying both effective and ineffective strategies as they experimented with the new materials. Children then engaged in strengthening the strategies by repeating them in new tasks and trials. Although effective strategies occurred more frequently, children still attempted some ineffective strategies, reverting to the attempts observed in the earlier component. Children demonstrated the fourth component, refining choices, when they employed the most effective strategy of using the target tool, and other strategies were discarded. The final component, increasingly effective execution, was observed when children's accuracy and speed of choosing the target tool increased and other ineffective strategies were abandoned. These components were sequential, but children retained strategies from earlier components and did not totally give up ineffective strategies until they reached the final component.

The components Chen and Siegler described are similar to the stages reported in the McCarty et al. (1999) study. Children's attempts to solve the given problem were, at first, ineffective but with repeated attempts children gradually refined their actions and successfully solved the problem. In both studies when children reached the final stage, the end of the problem solving, their actions were accurate and carried out without hesitation. However, Chen and Siegler noted that children, until reaching the final component, often reverted to earlier ineffective strategies even after it appeared they had acquired an effective strategy. Piaget (1936/1963) also reported that children retained vestiges of earlier stages and often tried actions that they had previously found ineffective.

Chapter Summary

The studies presented in this chapter provide a foundation for understanding the role of children's actions in cognitive development, the problems children pursue, and the process children engage in as they solve those problems. The studies included in this chapter used two different procedures when observing children's actions. In one procedure the researchers (Langer, 1986; Rayna et al., 1989; Stambak et al., 1989) allowed children to play spontaneously with the materials and investigators did not interact with the children. Two of these spontaneous play studies (Rayna et al., 1989; Stambak et al., 1989) were conducted in a classroom but the children were isolated from their classmates and given only the research materials. The third study (Langer, 1986) was conducted in a lab setting.

In the second procedure, researchers (Chen & Siegler, 2000; McCarty et al., 1999; Miyakawa et al., 2005) provided a specific problem for children to solve or gave them a task to complete. One study (Miyakawa et al., 2005) was conducted at a child care center but children were taken out of the classroom and worked only with the investigator and the materials provided by the investigator. The other two studies were conducted at a site separate from the child care center setting.

While these studies are useful in addressing my criteria of theoretical base and age appropriateness they do not provide data on the use of similar activities in a classroom setting. None of the studies were conducted in a classroom setting where children were exposed to the distractions of the classroom routines, had access to materials other than the research materials, and interacted with peers and adults. The current study attempts to address that gap by conducting the research in a classroom of toddlers.

CHAPTER 3

METHODOLOGY

The focus of my study was similar to that of Sinclair et al. (1989) in their study of infants and objects. The quasi-naturalistic methodology they used in their study matched my aim of observing what children would do with specific materials when given the opportunity to explore and experiment. I was not looking for pre-determined actions or behaviors that could be counted. I was observing to see what children would do when given the materials and allowed to play freely, guiding their own engagement.

Research Design

The classroom provided the context for data collection. In previous studies, discussed in Chapter 2, researchers investigated children's actions with objects in laboratory settings or isolated from the classroom. However, early childhood experts have pointed out the need for curricula that are based on the dynamic relationship between research and practice (National Research Council, 2005). The current study attempted to meet that need by conducting curriculum development activities in the classroom setting with child care providers. The classroom setting provided a more comfortable environment for the children, allowed more time for exploration and experimentation with the materials, and allowed me to observe how the children engaged with the research materials within the routine of the classroom. This information, which is missing from current literature, is critical to the development of curriculum activities that are effective in typical early childhood settings.

Pilot Study

To determine the effectiveness of materials and procedures I conducted a pilot study in two classrooms with children 16-24 months old. Sixteen children participated in the pilot study. My role was that of participant observer. The materials were presented during the 30-minute activity time, and children were allowed to play with the materials as they chose. I videotaped 10 activity times in each of the classrooms. Because of classroom schedules the videotaping occurred every other day in each classroom. The materials used in the pilot study included clear cylinders with colored rims and spheres of the various sizes and colors (see Table 1). These materials were selected to meet the criteria set by DeVries and Zan (1994) of offering activities that captured children's interest and inspired experimentation.

The following observations, from review of the videotapes and field notes during the pilot study, guided the selection of the materials and procedures used in the final study.

- The 5" white ball was not used by any children after the first day.
- Children focused on the color of the sphere when deciding which sphere to try to insert into the cylinder. They would walk around the room and pick up all the spheres of one color. It was not evident that they were taking size into consideration.
- Children did not use the longest 2 ½" diameter cylinder and the longest 4" diameter cylinder after the first day. Those cylinders were heavier and harder for the children to manipulate.

Table 1

Materials

Cylinders

Length (in inches)	Diameter (in inches) and color 2" White	3" Blue	4" Red
12			
14	c-p, f	c-p,f	c-p,f
16		c-p,f	
27	c-f	c-p	c-f
27 Capped	c-p,f		

Spheres

Color	Diameter (in inches) 1.5	2.5	3	3.5	5
Blue	s-p, f	s-f		s-f	
Yellow			s-p		
Red				s-p	
White					s-p

Note. c = cylinder. s= sphere. p=pilot study. f= final study

- In the classroom where providers offered supportive interactions during activity time (sitting near the children, commenting on what the children were doing, and helping when children indicated they wanted help), the children independently engaged with the materials for longer periods of time.
- In the classroom where providers were present but did not actively engage with the children in a supportive way there was less independent engagement and more dependence on the researcher (for example, children bringing materials to the researcher and watching the researcher play with the materials but not engaging with the materials themselves).

- Some classroom staff seemed unsure of what they were to do. They stood away from the children and watched the activity rather than engaging with the children. They reported they were afraid of interfering with the results.

<u>Site Selection</u>

Several criteria, informed by the literature on constructivist classrooms and by the pilot study, were identified to use in selecting the site for the proposed study. The classroom must have a schedule with free choice activity time for a large portion of the day to allow adequate time for engagement with the materials. Teacher-child interactions should be supportive with teachers engaging in, but not directing, children's play. The staff should be available for some pre-project professional development to explain the study and the role of the adults in the study.

Wee Care Child Care Center (pseudonyms are used for all proper nouns), the site selected for this study, fit all the above criteria. The Wee Care Center is located in a small rural town in the Midwest and is part of a K-12 private school system. I worked with this center in previous years as part of my early childhood consultant responsibilities, which facilitated my entry into the site. I visited with the director and the classroom staff to explain the project, answer their questions, and describe the role of adults in the study. This was done during a 2-hour professional development session. I also visited with parents and obtained the necessary signed permission forms for those who agreed to have their children participate in the study.

Babies 2, the classroom where the study took place, is one of four classrooms housed in the center. Babies 2 is the center room in a cluster of three classrooms serving

6-week through 36-month old children. All three classrooms are open and face a common hallway and laundry area. The laundry area is directly across from the Babies 2 classroom (see Appendix A). All rooms in the center are designed with the same colors. The walls are white, the carpet is grey, and the window trim and exit doors are blue. Staff in Babies 2 have added color to the room by hanging brightly colored fish wall hangings, putting out red and blue soft cubes for the children to climb on, and purchasing chairs that are brightly colored.

The open design of the room creates challenges to the staff. Noise from the other rooms, particularly babies crying and the buzzer on the dryer, often distract the children in Babies 2. They stop their activity and look toward the sound and comment, "Uh oh" or "All done." The greatest challenge is that the children wander out of the room to go see what is causing the noises or to visit other rooms.

To avoid this, the center staff have instituted a rule that the children have to stay on the carpeted area of each room. The carpet in Babies 2 covers most of the room but there is an area with cement flooring for eating and art activities. Jenny and Stacy (the staff in Babies 2) remind children of the rule several times during the day by stating, "We stay on the carpet so we don't get in the way of our friends walking in the hall." If a child moves off the carpeted area Jenny and Stacy gently place a hand on the child's back and turn him or her back to the classroom saying, "We stay on the carpet." In spite of the rule and their redirection, several times during the day Jenny or Stacy have to chase after a child and return him or her to the classroom. During the study Jenny and Stacy were more flexible and did allow children to play on the cement floor so they could compare the actions of the objects on two different surfaces. When children were on the cement area, my role became more participant than observer so that I could monitor the open side of the room to redirect children who may try to run into the hallway.

Free choice and activity time are the main part of the schedule and allow ample time for children to have their choice of activities and to have the opportunity for small group time. The schedule includes 60 minutes of free choice time between breakfast and snack when children are allowed to play with any of the materials in the room. Activity time is offered for the 45 minutes after snack until outdoor play (see Appendix B). Teacher-directed or small group experiences take place during this activity time and include a table activity and story time. Children may choose not to participate in table experiences and story time. Table experiences include art activities or games that are appropriate for this age level. Story time takes place after the table activity and the children are invited to "Come and see the book I have today." Most children gather around and see the book, but they are free to wander in and out of the group as they engage in other activities. If children choose not to participate they can choose any of the toys in the room to play with.

Jenny and Stacy are veteran staff and have been with the center in Babies 2 for over 10 years. Neither of them has an education degree but both have participated in several locally offered professional development opportunities. They also work closely with early childhood consultants from an education support agency for their region. When Jenny and Stacy are not carrying out routine care (diaper changing and hand washing), they are engaged with the children. During activity time they sit on the floor and interact with the children. Their interactions show that they respect the children and are interested in what the children are doing. They often comment on a child's activity and support children's language by describing what they see children doing. It is evident the children feel attached to them. Children often share what they are doing by running to them and showing what they are working on, calling out "Jenny, Stacy!"

Jenny and Stacy are accepting of children's conflict and handle it by explaining what they saw happen and then redirecting the children. Observations of the interactions between staff and children support that Jenny and Stacy provide a cooperative classroom atmosphere similar to that described by DeVries and Zan (1994). They offer a program of activities that allows children to explore their environment, facilitates conflict resolution in a manner that respects all children, and enforces age-appropriate rules by providing an explanation. The relationships in the classroom match what Piaget (1932/1977) called "cooperation whose characteristic is to create within people's minds the consciousness of ideal norms at the back of all rules" (p. 395).

Jenny and Stacy were open to the research being conducted in their room. Their openness to the research project and their classroom atmosphere of respect toward the children provided an appropriate setting for me to introduce new materials and let the children have the opportunity to engage with them.

Participants

Twelve children were enrolled in Babies 2 at the beginning of the study. One child moved to a new room three days after the study started. Three children missed several days due to illness or family vacation. Data for these four children are not included in the results, but the children did participate in the activity on the days they were in attendance. Table 2 lists the pseudonyms of children whose data were used. The children listed in the table attended Babies 2 full time.

Table 2

Participants

Participant	Age in months
Anne	18
Kate	18
Brad	18
Eva	20
Andy	21
Jason	22
Kim	22
Lea	24

Procedures

The pilot study and previous research designed to study children's actions on objects (Sinclair et al., 1989; Stambak et al., 1989) informed procedures for the study. Based on these studies, the following procedures were used in this investigation.

Materials

Objects used in the study were clear cylinders and blue spheres of various sizes (See Table 1). Most of the cylinders were open at both ends with a colored plastic rim around the edges. Two 2" diameter cylinders were capped on one end and did not have the plastic rim. Based on observations in the pilot study, spheres were all the same color.

The only variable was size. The smallest sphere fit in all the cylinders, the medium sphere fit in the medium and large cylinder, and the large sphere fit in only the largest cylinder.

Conduct of Activities

Before introducing the materials, I spent five mornings in the classroom during the free choice and activity times, as a participant-observer. I began by observing and collecting field notes to describe the classroom and the routine. Over the five days my role varied as I often interacted with the children in activities they had chosen to pursue. This gave children the opportunity to see me in the classroom and addressed the possibility of any stranger anxiety they may have had. By the end of the five days children in the room included me in their play and approached me to ask for help. This indicated that they viewed me as part of the classroom and gave me reason to believe my presence would not interfere with their activities. With this established I was able to introduce the research materials.

I introduced the research materials over a period of three days during six videotaping sessions (free choice and activity time each day). I presented only the spheres for the first three sessions and then only cylinders for the last three sessions. This introductory period allowed the children to explore the novelty of each set of objects. Data from the pilot study indicated that when both sets were presented together the children were over-stimulated and threw the spheres around the room, banged the cylinders on the floor, or ignored the materials. These actions indicated children might have had too many variables to think about at one time. For the remaining 11 days of the study I presented both sets of materials, cylinders and spheres, during each session.

Materials were placed in a tub on the floor near the toy shelf. I invited children to see what they could do with the objects. The materials were presented at the beginning of the free choice time and then were put away during snack time. After snack, during activity time, materials were again presented once the teachers started the table activity and had finished the routine care activities. Research materials were removed from the room at the end of the second activity time and were not presented again until the next day. During the free choice and activity sessions children guided their own activity with the research materials. Staff interacted with the children, offering feedback and support, but did not ask the children to complete any specific tasks with the materials. As a participant-observer I commented on children's actions, modeled actions that could be done with the materials, and invited children to participate in activities with me.

Data Procedures

The plan for data collection in this study was based on qualitative work done by other researchers investigating children's actions on objects (Kamii et al., 2007; Miyakawa et al., 2005; Sinclair et al., 1989; Stambak et al., 1989).

Data Collection

Children were videotaped as they engaged with the materials. Taping took place for 19 sessions over 11 days. I was not able to videotape three activity sessions due to center-wide events that involved Babies 2 children. Videotaping offered the advantages of viewing the activity several times to allow for more careful study and being able to capture unexpected actions (Gall, Gall & Borg, 2003). The recorded tapes were viewed after each session to guide planning of the activities throughout the study and were used to analyze the children's actions.

Descriptive and reflective field notes (Bogdan & Biklen, 2003) were used daily to capture the setting and the emerging ideas and concerns. Descriptive field notes captured significant details of the setting that video recording missed. These notes were recorded on site or immediately after leaving the field for the day. I reviewed the descriptive field notes after each day in the classroom and used reflective notes to record the subjective aspect of the study: problems encountered, suggestions for change, emerging ideas, and my own learning. This blend of descriptive and reflective field notes guided modifications that were made as the study progressed.

Data Analysis

I used the constant-comparative method (Bogdan & Biklen, 2003) to analyze the data. I reviewed the videotapes each night and noted children's actions with the materials. Using criteria from Sinclair et al. (1989) I also noted sequences of actions that indicated a child was organizing actions to work toward a goal or solve a problem. I then categorized these event sequences into the types of goals and problems children pursued. Categories of goals and problems evolved over the length of the study as I added new data each night and refined the categories.

Reliability and Validity

Reliability and validity were addressed in several ways. I used multiple data-collection methods (Gall et al, 2003). Data were collected through videotapes, descriptive field notes, reflective field notes, and conversations with the caregivers in the classroom.

I reviewed the videotapes and noted times of engagement for each child. Time of engagement began when the child was visible on camera acting on the materials. Time of engagement ended when action stopped or the child was no longer visible on camera. Three coders, not involved in the design of the study, watched 20% of the video tapes and coded the times for the beginning and ending of action sequences for each child (see codes in Appendix C). Their coding was compared with the coding I did on the same tapes. All four coders were in agreement on beginning and ending time for 90% of the sequences. Based on this high rate of agreement, I then created DVDs of each child's action sequences.

I then coded each child's DVDs for individual actions within the sequence. Two coders, not involved in the design of the study, coded each child's individual actions within a sequence (see codes in Appendix D). Coders watched 20% of the DVDs and coded each action the child performed within each sequence. Coding was recorded on a table that required the coders to mark actions occurring at every 10-second interval. I used the 10-second coding intervals to compare across coders. If coders recorded at least one similar action within a 10-second interval, they were in agreement. Review of the coding sheets indicated that there was an 88% agreement among coders.

I analyzed the action sequences to determine when children identified a problem. I used work by Sinclair et al. (1989) to establish how to code when a child identified a problem. They used the criteria of a pause in action followed by a coherent sequence of actions to reach a goal. I analyzed the individual actions as well as the sequences of actions to identify the types of logico-mathematical relationships children constructed within the problem-solving process. I used two criteria, based on work by Kamii et al. (2007), to determine if children had constructed a mental relationship. First, the child's attention (judged from where the child's eyes were directed) was on the object being acted upon so the child observed what happened to the object when he or she acted on it. Second, after noticing the reaction the child paused or hesitated and then repeated the action. I used the research literature and discussions with colleagues to verify and refine my analysis of action sequences, problem solving, and logico-mathematical relationships.

CHAPTER 4

RESULTS

The purpose of this study was to observe what children 18 through 24 months old would do when given research materials (clear cylinders and plastic spheres) during activity time in a classroom setting. Earlier studies (Kamii et al., 2007; Langer, 1986; Miyakawa et al., 2005; Sinclair et al., 1989; Stambak et al., 1989) provided evidence of construction of knowledge and problem solving that occurred with this age group when children were given interesting materials and allowed to play on their own without adult direction. However, these studies isolated children from the routines of the child care classroom and limited the children's choice of objects by providing only the research materials.

In the current study children remained in the classroom and had access to all classroom toys and materials. The results presented in this chapter describe how eight children, ages 18 months through 24 months old, interacted with the research materials in this setting. The discussion of the results is organized around three research questions:

1. What actions can be observed as children explored the materials?
2. What problems do children set for themselves?
3. How do children solve problems they set for themselves?

My findings in this chapter are based on the 11 days (Day 4 through Day 14) when children had access to both the cylinders and the spheres. I did not include the first three days of introduction to the materials because the questions guiding this study ask about actions on both sets of objects. Any actions observed during the introductory phase were also observed during the remaining eleven days of the study and are represented in the data.

Throughout this chapter I use vignettes to support the text. When presenting vignettes I highlight one child but the actions of that child are typical of the majority of the children in the study. In this vignette, and all others that follow, the format is similar to that used by Sinclair et al. (1989). The example is identified with the child's name, age in months, day of the study, and length of the activity. Length of time is noted as minutes and seconds. For example, 1:15 indicates the activity lasted one minute and 15 seconds. When several children are included in the example names are listed alphabetically. Objects are identified with the codes listed in Table 3.

Table 3

Codes for Vignettes

	2" diameter	3" diameter	4" diameter
Cylinder	c1	c2	c3
Sphere	s1	s2	S3

Actions Observed as Children Explored Cylinders and Spheres

Sinclair et al. (1989) explained, "All knowledge derives from some action of the subject on his or her environment" (p 3). Children's actions, a major variable in this study, provided insight into children's construction of knowledge. A challenge in working with children of this age level is that their current level of language development did not allow them to explain their thinking. I had to infer construction of knowledge by observing their actions. Inferring children's thinking based on observation of action is consistent with Piaget's theory of constructivism, which proposes that it is on the plane of action that children make their intelligence most evident (1936/1963; 1937/1971). This practice is also established in the research literature (Kamii et al., 2007; Miyakawa et al., 2005; Sinclair et al., 1989; Stambak et al., 1989).

Analysis of children's actions in this study indicated that children applied a variety of actions to the objects. Often, children varied their actions on any objects within their reach. They did not have a preset goal in mind but explored the materials to see what they could do with them (Sinclair et al., 1989). In the next two sections I describe children's actions during their exploration of the materials. I present three phases of exploration that children demonstrated. In the first section I discuss how children applied a variety of actions to objects, first on all objects and then focusing on one class of objects. In the next section I discuss how children kept the action constant but varied the objects.

Varied Actions on Materials

Children often engaged with the objects to explore what could be done with them. This exploration began with a variety of actions applied to any research object that happened to be nearby. Children acted on these materials using already constructed action schema, or "patterns of actions that can be reproduced in different circumstances and in different ways" (Montangero & Maurice-Naville, 1977, p. 155).

The following three vignettes provide examples of how children varied their actions on objects during exploration.

Vignette 1

Emma, 20 months; Day 4 (1:27) Emma pushes c3, which is upright on the floor, and watches it fall to the floor. She pushes c3 again and watches it roll away from her. She picks up c3 and throws it. She picks up s2 in her right hand and s1 in her left hand. She throws s2, picks up another s1 in her right hand and bangs the two s1 together in front of her. She stops, turns her hands back and forth watching the two s1 as she does so. She puts the s1 from her left hand under her chin, picks up a third s1 with her left hand and reaches for c1, sets it upright, knocks it over with her left hand, releases the s1 from her chin and then bangs the two s1 in her hands together.

Emma did not seek out specific objects but acted on any object that happened to be within her visual field and within her reach. She explored all objects to see what she could do with them.

These early action sequences became more focused and children applied a variety of actions on one class of objects, either the cylinders or the spheres. When activity time started on Day 4, Annie stood away from the group and watched as the children grabbed the research materials and started playing. When all the children were engaged in play, Annie looked at the remaining cylinders and spheres scattered on the floor and then picked up two s1. The following then occurred.

Vignette 2

Annie, 18 months; Day 4 (1:54) Annie holds an s1 in each hand, bangs them together in front of her, holds them both cradled between her left arm and her chest, holds them one in each hand, sets one on the floor, sets the second one on the floor, picks up both s1 and walks across the room to the shelf. She sets both s1 on the shelf, returns them to the floor holding one hand on each one, rolls them back and forth on the floor, pushes them and rolls them away from her. She watches them roll away, walks to them (stepping over a c2 that is on the floor in front of her), picks them up and bangs them together, swings them at her sides, places them behind her back, swings them at her sides, bangs them together in front of her, and then places one s1 under her left arm while holding another s1 in her left hand and walks away.

Annie varied her actions but she focused on one class of objects, the spheres. Other children chose the cylinders and ignored the spheres. In this vignette, Brad explored just the cylinders and applied actions typical of all children in the study.

> Vignette 3
> Brad, 18 months; Day 6; (0:47) Brad sets c3 upright on the floor and then hits it, knocking it to the ground. He looks around and sees a c2 standing upright, walks to the c2 and hits it to knock it over. He picks up c2, puts one end near his eyes and points the opposite end to Jenny. He laughs when Jenny puts her face near the end. He then lowers his end of c2 and inserts his right arm into c2, wiggling his fingers. He loses his grip and c2 falls to the floor. Brad kicks c2 and it rolls. Brad walks to the c2 that rolled and stands, one foot on each side of c2. He then sits on c2 and rolls back and forth. Standing, he lifts c2 and straddles it as he walks around the room. Jenny laughs and says, "It's your horse!"

Although Annie and Brad used a variety of actions, similar to Emma, their explorations differed from Emma's because they focused on one class of object to find out all the things they could do with those objects. Instead of random selection, as seen in Emma's vignette, Annie and Brad deliberately selected the objects they explored. This selectivity indicated that they classified objects. Annie classified by sphere and not sphere. Brad classified by cylinder and not cylinder.

These three vignettes illustrate two phases of exploration observed. First, children used a variety of actions on any object near them. Next, they focused their actions on one class of object. During these two phases children appeared to seek answers to a question they raised, "What can I do with these objects?" In the next section, I describe how children engaged in a form of distributed action (Sinclair et al., 1989), performing the same action on several different objects. They appeared to seek the answer to the question, "What happens when I do this (action) to this object?"

Distributed Action

After children explored what they could do and how the objects reacted, they changed focus from the object to their action. They performed one action and distributed it over several objects. The next four vignettes provide examples of how children distributed an action as they explored.

> Vignette 4
> Jason, 22 months; Day 5 (0:15) Jason stands holding a c2 upright on the floor. There is an s2 inside. He smiles and releases c2 letting it fall to the floor. The s2 rolls out and stops near c2. He looks at c2, kicks it and watches as it rolls. He pauses, looks at s2 then kicks s2 and shouts, "Jenny, Jenny, go ball go!" He turns and sees an s1 next to a c1 lying horizontally on the floor. After walking to the s1 he stops, looks at s1 and kicks it. He then quickly kicks the c1, stops all action and watches the two objects roll away from him. The s2 rolls into a c3 then rolls through and out the other end. Jason watches and exclaims, "Tunnel!"

Jason is distributing one action, kicking, across a variety of objects. Unlike the earlier explorations seen in Vignettes 1 through 3, Jason utilized only one action and observed the results on various objects. Later that day Jason continued his focused exploration but changed his distributed action. He walked around the room picking up spheres and cylinders and throwing them toward the open hallway. In the next vignette, Jason further refined his exploration and matched his actions more closely to the properties of the objects and rolled the spheres through the cylinders (as he had observed on Day 5).

> Vignette 5
> Jason, 22 months, Day 7 (0:40) Sitting on the floor holding an s2 Jason looks around the room. His eyes focus on a c3 lying horizontally on the floor near him. He crawls to c3, places s2 at the open end and pushes it through c3. As he watches s2 roll through he squeals. He crawls to retrieve s2 and sees a c2 next to him. He sets s2 at the open end, pushes it through and exclaims, "Okay!" He stands, walks to an s1 sitting near the opening of a c1 lying on the floor. He pushes the s1 through c1. He retrieves c1 and continues to push it through several more cylinders, stopping when the c1 rolls under the cots.

Annie showed the same progression of refining her exploration by focusing on one action and then matching the action to the properties of the object. After her actions in Vignette 2 (exploring only spheres), Annie continued to play with the two s1 but focused on placing them in relation to her body. She put them behind her back, under her arms and behind her head. As she put the two spheres, one in each hand, to the top of her head she looked down and saw several spheres on the floor. She placed the two s1 under her left arm and picked up an s2. She placed this under her right arm. Squatting down, she continued to place spheres under her arms and holding them in place close to her body. She used her body as the container and the spheres served as the contents. The next day Annie moved her exploration of the spheres, using the action *putting into*, away from her body and started putting the spheres into other objects.

> Vignette 6
> Annie, 18 months, Day 5, (0:55) Annie carries three s1 across the room to the sensory table. She slowly places one s1 in each of the three indentations on the table and then stands and looks at the three s1. She turns and pulls a toy cart closer to her. She picks up an s2 and places it inside the cart. She walks around the room picking up two more s2 and places one in the cart and one on the handlebar of the cart (there is an indentation that holds the s2 in place). Returning to the sensory table, she lifts one s1 and tries to put it in the cart but the cart is full. She turns and drops the s1 into a c2 standing upright on the floor.

Annie distributed the action of *putting into* using the spheres as content. She distributed this action by putting the sphere into relationship with her body, the sensory table, the cart and finally a cylinder. She constructed a mental relationship of the sphere as content and the other objects as containers. Over the next five days Annie continued to explore the spheres as content and found many different places and objects to serve as containers. On Day 11 she stood in the corner of the room and dropped an s2 into a c2 standing upright on the floor. Her next action led to a fortuitous event (Piaget, 1936/1963) that led her to add to her knowledge about the cylinder.

> Vignette 7
> Annie, 18 months, Day 11, (0:23) Looking at the s2 inside the c2 (standing upright on the floor) Annie slowly lifts c2. She looks at the bottom of c2 and pauses for 3 seconds. She then looks at the floor and sees the s2 still sitting there. She sets c2 back down to the floor, upright, bends and picks up s2 and drops it into c2. This time she lifts c2 and keeps her eyes on s2. She pauses, holding the c2 in both hands in the air, and looks at s2 for 6 seconds. She then slowly lowers c2 over the s2 and looks inside c2. She looks up, makes eye contact with Stacy, and looks back down at s2 inside c2. She repeats the lifting and lowering two more times, each time looking inside the c2 at the s2 and then looking at Stacy.

Up to this point Annie knew the cylinder served as passive container "which receives various contents" (Stambak et al., 1989, p. 31). In this vignette she is confronted with new information. The container, c2, did not keep the s2 contained as it had in the past when Annie held the cylinder to the floor. She paused before repeating her actions of putting s2 into c2 and lifting c2, but the second time she lifted c2 she expected s2 to remain on the floor as indicated by the fact that she kept her eyes on s2. Her long pause this time allowed her to consider her next action and to revise her knowledge of the cylinder. She accommodated by modifying her view of the cylinder as passive to the view of the cylinder having a dual role; passive as a receptacle and active as means of enveloping to contain the sphere. Her distributed action of putting into has led to her identifying a problem to be solved.

Summary of Actions

Children's engagement with the research materials started with a period of exploration that became progressively refined. Early exploration consisted of applying a variety of actions to any research objects that happened to be nearby. These materials were novel and children applied their existing action schema to determine what could be done with objects. This early these new exploration soon led to a more focused phase and children used many actions on one class of objects. As children observed their actions and the reaction of the objects during this phase of exploration, attention shifted from the object to the action. Children then explored by distributing one action over a variety of objects (objects from both classes of materials or different sized objects within one class of materials). Children demonstrated all three types of exploratory actions but the process was not linear. Children moved back and forth between types of explorations.

For most children in the study this exploration occurred early in the course of the study and most often at the beginning of activity time. However, children frequently returned to exploration throughout the study, perhaps as a reprieve from other activities that challenged them or a transition to a new activity. When children explored the materials, they encountered surprises when the materials did not respond in the way children expected. This put the children into disequilibrium and moved them from exploration into problem solving. In the next section I describe problem solving and present the three main types of problems children chose to pursue.

Problems Children Identified

Children identified their own problems when, in the process of exploration, they experienced disequilibrium, as seen in Vignette 7 with Annie when the sphere did not remain in the cylinder. When children experienced disequilibrium they paused their actions and looked at the objects. Children's actions after the pause determined if they chose to pursue the problem. Children responded in one of two ways after pausing.

Some children walked away when confronted with the discrepancy. Kate demonstrated this response on Day 5 when she tried to put s2 into c1. She set s2 at the opening of c1 and pushed. She looked at s2, pushed again, stopped and just looked at s2. After several seconds she looked at Jenny, threw the s2 and c1 to the floor and walked away. She chose to ignore the problem and play with other materials in the room. By ignoring the problem Kate returned to equilibrium.

Other children, after pausing, continued to work with the objects, trying to get the materials to do what they wanted. Children's attention and actions focused on this goal. They engaged in problem solving. In reviewing the videotapes I identified problem solving by using criteria used in the studies by Sinclair et al. (1989). I observed for pauses in children's actions followed by a coherent sequence of actions that made clear the children's goals.

The problems children set for themselves in this study are grouped into three main categories of activity children pursued: nesting the cylinders, containment of spheres in cylinders, and movement of spheres inside cylinders. Each activity presented unique problems and children responded to the problems differently. Kate, 18 months, and Eva, 20 months, walked away if they could not solve the problem immediately. They moved on to other activities and did not pursue their original goals.

The remaining six children walked away but returned later to try to work on the problems again. They walked away and returned several times as they tried to solve their problem. All six of these children engaged in each of the three categories of problems, to some extent, during the study. However, they did not all successfully solve each type of problem. Each child focused on one problem they kept returning to for several days. In the following sections I present examples of the three categories of activities and show how children solved problems to reach their desired goal. For each category, I present data on the child who pursued the problem until it appeared that he or she was satisfied the goal was met.

Nesting

The three sizes of cylinders provided the opportunity for children to observe differences in size and figure out combinations of cylinders that could be nested, or seriated. Kamii et al., (2007) defined seriation as "the ordering of objects according to relative differences" (p. 46). When nesting the cylinders, children had the opportunity to construct logico-mathematical relationships of seriation based on size.

Four combinations were possible: c1 into c2, c1 into c3, c2 into c3, or a full nesting of c1 in c2 in c3. Nesting c1 into c2 presented a greater challenge than the other combinations. The plastic rims varied in size and to get c1 inserted into c2 was a tight fit. Children did not have the motor control or strength to perform this action on their own. When the children showed interest in nesting and became frustrated with trying to nest c1 into c2, I added a new cylinder: a c1 without the plastic rim. This allowed children to easily nest the new c1 into c2. This cylinder also had a yellow removable cap for one end. It is noted as ycc1 in the discussion.

The following vignettes provide examples of how one child worked on nesting the cylinders. Prior to Vignette 8 Andy watched as Stacy set four c2 end to end and created a long tunnel. Stacy rolled a ball through the whole length of the four c2. After watching this, the following took place.

> Vignette 8
> Andy, 21 months, Day 8 (0:18) Andy sits on the floor holding c1. He looks at a c3 lying in front of him. He pushes the c1 so the end of the c1 touches the end of c3. He looks back and forth between the two cylinders, not moving his hands. Then standing, he tips both the c1 and c3 vertically and looks at the two cylinders standing side by side. He releases c3, leaving it upright on the floor. With both hands he lifts the c1 and slowly inserts it into the c3. He looks up at the researcher and smiles.

Andy started out to make a tunnel similar to the one Stacy created. When he pushed the two cylinders together he noticed the difference in size. He observed both ends carefully, stopping all action except looking back and forth. The ends of the cylinders did not match and did not make a tunnel like Stacy's. He handled this disequilibrium by setting a new goal. His deliberate actions after a brief pause provide evidence of this goal. He wanted to see if the c1 would fit inside c3. Further evidence that this was Andy's goal came when he smiled at the researcher after successfully putting c1 into c3, creating a new structure.

He played with the new structure by lifting the c3 and then dropping it back into place. He repeated this until the c1 fell to the floor. After looking at the long narrow cylinder, the following took place.

> Vignette 9
> Andy, 21 months, Day 8 (0:25) Andy sets the c3 vertically on the floor and lifts the c1 with both hands. He moves the c1 so the end is placed over the opening of the c3, aligning the openings. He stops and looks up and down the length of the c1 then focuses on the end that is aligned with the c3. He moves the c1 slightly and drops it into the c3. He looks up and smiles.

Andy spent the next few minutes lifting and dropping the c1 into the c3 or lifting the c3 and dropping it back over the c1. By repeating the action he confirmed the regularity and constructed a seriation relationship between the c1 and c3: c1 is smaller than c3 and can be nested inside c3.

He repeated the action of putting c1 into c3 the next day.

> <u>Vignette 10</u>
> Andy, 21 months, Day 9 (023) A c3 containing one s3 and one s2 stands vertically on the floor. Andy holds a c1 vertically in both hands, lifts it, and inserts it into the c3. He looks at the researcher and smiles exclaiming, "ohhhhh!"

Andy seemed pleased to rediscover that, after a passage of time, c1 again fit into c3. He knocked his structure over and walked away. The next day he applied his knowledge to a new set of cylinders.

> <u>Vignette 11</u>
> Andy, 21 months, Day 9 (0:41) Andy stands by a c3 placed vertically on the floor. He lifts a c2 and sets it on the top edge of the c3. He moves the bottom edge of the c2 over the top opening of the c3 and drops the c2 so it falls inside the c3. He drops an s2 into c2, looks at s2 then lifts the c2 and drops it back into the c3. He repeats this three times then bends over and looks into the c2. Lifting the c2 completely out, he looks into the c3. He inserts the c2 back into the c3, inserts his hand into the structure and smiles, "awwwww."

Andy constructed a new seriation relationship: c2 fit into c3. Andy continued to apply this knowledge for the remainder of the study. He figured out all possible combinations of nesting of two cylinders. Although Andy nested the ycc1 into the c2 and, in a separate event, c2 into the c3, he never made a construction that put the three cylinders into one structure.

Andy's problem solving started when he noticed the difference in the size of two cylinders. He responded to his disequilibrium by setting a new goal rather than pursuing the original goal of making a long tunnel. He worked on this goal until he figured out all possible combinations of nesting except the one that included all three sizes of cylinders.

Brad, 20 months, focused on the activity of nesting over several days and tried to solve a problem that was impossible. On Day 4 Brad inserted one end of c2 into one end of c3 creating a long cylinder that sat horizontally on the floor. He inserted five spheres of different sizes into the structure. Another child walked over to Brad's structure and tried to take one sphere out of the end of c2. To prevent the child from taking the sphere, Brad reached his left hand to the end of the structure, blocking the other child's ability to take a sphere. In doing this, Brad pushed the end of c2 so c2 is pushed farther into c3 and the two ends on Brad's right aligned evenly. This action drew Brad's attention to the relationship between the ends of both cylinders and he noticed a problem. The c2 is slightly longer than c3 so now the c2 extended beyond the edge of c3 on Brad's left.

> <u>Vignette 12</u>
> Brad, 20 months, Day 4 (1:07) Brad pats the right end of his structure where the two ends are even with each other. He looks at the right end and then looks at the left end. At the left end he notices that c2 now extends beyond the end of c3. He pushes the left end of c2 so the ends on left are now even, and then notices that the ends on the right are not even. He crawls to the right end of c2 that is sticking out of c3 and pushes it back so it is even with the right end of c3 and he claps. He then looks at the left end of the structure and pauses. He tries four more times to get the ends even.

Brad's goal of fully containing one cylinder inside another will not work. Adults can see that easily, but Brad does not. He focused on one end of the cylinder structure each time and did not take into account that his action of pushing on one end of c2 caused the other end to also move. He seemed surprised each time he saw that c2 stuck out on the opposite end. Brad only noticed what his current logico-mathematical structure allowed him to see (Piaget 1945/1951). He had not yet constructed the necessary relationships to allow him to see that acting on one end caused a reaction on the other end. He experienced disequilibrium and could not assimilate the new information into his existing schemata.

He continued to experiment to reach his goal and get back to equilibrium. Later, on Day 4 and again on Day 5, he created more two-cylinder structures, keeping them on the floor horizontally, and tried to fully contain the inside cylinder in the outer cylinder. This is not possible because c1 is the longest cylinder, c2 is shorter than c1 but longer than c3, and c3 is the shortest cylinder. No matter how he paired the cylinders, the inside cylinder was always longer. Brad did not see this and continued pushing each end of his structures trying to get them to fit.

On Day 6 he tried a new position with the structures and he used the ycc1 that was added that day. The ycc1 is the same length as the original c1.

> <u>Vignette 13</u>
> Brad, 21 months, Day 6 (2:52) Standing, Brad holds ycc1 in the air in his right hand. He holds a c3 vertically on the floor with his left hand. He inserts ycc1 into c3 and sets the structure in a vertical position resting on the floor. He grasps the outside of c3 in both hands and lifts up, looking into c3. He sees that ycc1 does not move. He drops c3 back down and places his hand on top of ycc1 and pushes, He looks around and finds the teacher, scowls and again pushes on ycc1. He then sits, pulling the structure into a horizontal position, pushes on the right side of the structure to get the right ends even and looks immediately to the left end. He pushes the left end of ycc1 so the left ends of c1 and c3 are even. He repeats this several more times, each time pushing one end and looking at the other.

Brad took into account both ends of the structure and realized that when he pushed one end the other also moved. He indicated this by pushing and then looking immediately at the opposite end. After this experience when Brad placed the cylinders horizontally, he did not try to fully contain the inner cylinder. In the horizontal position Brad could see the two ends move in relation to each other.

However, he could not see this relationship when the cylinders stood in an upright position. When the two cylinders stood upright he continued to try, as he did in Vignette 13, to push the inside cylinder fully into the outer cylinder. The floor prevented the opposite end from moving and Brad could not get the inner cylinder contained. Brad experimented for several more days as he tried to solve this problem. He varied the cylinders he used and varied how hard he pushed. On Day 10 Brad tried once more to fully contain a c1 in c3 standing upright on the floor. As he pushed harder and harder on c1 the structure fell and created a long tunnel. Brad smiled and looked at Stacy. Stacy handed him an s1 and Brad pushed the s1 into the long tunnel and squealed as it rolled through.

Although Brad did not achieve his original goal, he returned to equilibrium when he constructed the logico-mathematical relationship between the two ends of the inner cylinder when placed horizontally. He accommodated by modifying his earlier schema. This allowed him to see the relationship between the length of the inner cylinder and the length of the outer cylinder when building a tunnel. Once Brad had these structures in place and accommodated to the new information, he did not try fully containing cylinders in the upright position.

Like Andy, Brad modified his goal based on this new knowledge. He focused his actions on creating long tunnels by inserting one end of a cylinder into the end of a larger cylinder and rolling spheres through the structure. He smiled when the spheres traveled through the entire structure. If a sphere stopped part way through the structure Brad adjusted the cylinder or rearranged the order.

Jason, Lea, Kim and Annie also worked on nesting the cylinders and trying to get the inner cylinder fully contained. They created structures by nesting only two cylinders at a time even though they figured out all combinations of cylinders necessary to create the three-cylinder nested structure. They accomplished their goal, putting one cylinder inside another, with two cylinders. Nothing happened during their problem solving with nesting two cylinders that provoked them to consider nesting three cylinders. They also did not pursue fully containing the inner cylinder to the same degree as Brad. They tried a few times to push on the inner cylinder but chose to abandon that goal and continue to work on nesting.

Children's work on nesting allowed them to construct seriation relationships by noting size difference in the objects. In the next section I discuss children's problem solving with containment. Work on containment also required children to take into account size differences.

Containment

All children in this study used cylinders as containers and spheres as contents. This action of putting a sphere into a cylinder demonstrated children's interest, common for this age, in "the spatial interrelations of objects" (Piaget, 1954/1971, p 219). The three cylinders, each size with a different colored rim, invited children to use them as containers. The three different-sized spheres presented a challenge, as they were all one color. Children had to attend to size of the sphere in relation to the diameter of the cylinder to be successful in containing the sphere in the cylinder. Once children constructed this relationship, they worked on filling and emptying the cylinders. In the next two sections I provide examples of how children figured out the size relationship required for successful containment and then how they used that knowledge to fill and empty the cylinders.

Fitting spheres into cylinders. Sinclair et al. (1989) observed that play with contents and containers resulted in children creating complex objects, being able to localize objects, and comprehending relations of bigger-smaller. One of the first discrepancies children faced with the materials occurred when they tried to insert a sphere into a cylinder and it did not go. The next vignette describes how children typically reacted.

> Vignette 14
> Kate, 18 months, Day 4 (0:12) Kate stands holding c2 in her left hand and s3 in her right hand. She moves c2 so it is cradled between her left arm and her body and she places the s3 in her right hand to the top open end of c2. She pauses and then pushes on s3. She stops, looks at the researcher, drops the c2, and then stretches her right arm with s3 toward the researcher. The researcher encourages her to find one that fits. Kate turns, kicks the cylinder out of her way and walks away.

In this very brief event Kate experienced a contradiction to her expectation. The sphere she chose to use, larger than the cylinder she selected, created an obstacle to her being able to reach her goal of putting the sphere into the cylinder. She tried twice to reach this goal, first in putting the s3 at the opening of c2 and then when she pushed on s3 to get it to go in. She expressed her confusion by looking at the researcher and then holding the sphere out to the researcher. When she did not get immediate help in getting the materials to do what she wanted, she walked away.

Other children varied their strategies to try to reach the same goal of getting the sphere into the cylinder. Brad tried two approaches to get the sphere into the cylinder.

Vignette 15

Brad, 18 months, Day 4 (0:32) Brad sits on the floor holding c1 upright on the floor in his left hand. He leans over and picks up s3 in his right hand. He puts s3 to the top opening of c1. He holds s3 in place and looks at s3 sitting on top of c1. He removes s3, still holding it in his right hand, and tips c1 to a horizontal position on his lap. He moves s3 to the open end of c1 on his right and pushes. He pulls s3 slightly away from the opening, uses his left hand to flip c1 so the ends switch positions. He then places s3 to the opening on his right and tries again to push. He moves s3 away, turns and sees a c3 standing upright next to him and he drops s3 into c3. Jenny, who has been watching, remarks, "That one fits!" Brad, still holding c1 in his left hand, picks up s3 that is near him and drops it into c3. Stacy rolls another s3 to him and Brad picks it up, still holding c1 in his left hand, and drops s3 into c3.

After Brad's first attempt failed he changed the position of c1 from vertical to horizontal and tried again. When s3 still did not go into c1, he pushed. Brad then tried a new strategy. He flipped c1 and used the opposite end to try to get s3 to go in. This reaction, similar to the one seen in Vignette 12, demonstrated that Brad considered only one end of the cylinder at a time and had not constructed a relationship between the two ends. His action of pushing suggested that he expected s3 to go into c1. When his attempts did not work, Brad still managed to reach his goal of putting a sphere into a cylinder. He found a new cylinder, a c3, and successfully inserted his s3. He repeated this action two more times with two new s3. Brad confirmed the spatial relationship of content (sphere) to container (cylinder).

All eight children worked on the problem of getting a sphere to go into a cylinder. Three children handled the containment problem differently than their peers. When the sphere did not fit into the cylinder, Kate, Kim and Emma tried few strategies before they walked away. They set the sphere at the end of the cylinder, pushed on the sphere, twisted the sphere and then, holding the cylinder still, banged the sphere several times on the end of the cylinder. When these strategies did not work, they dropped the cylinder and walked around the room trying the sphere in all cylinders until, by chance, they found one that worked. After they succeeded in getting the sphere inside a cylinder they walked away and pursued other activities. Over the course of the study, each time they tried to insert a sphere into a cylinder they demonstrated the same distributive action of trying the sphere in any cylinder available.

Annie, Lea, Brad, and Andy tried the same strategies but carried the problem solving further. After they found a combination of sphere and cylinder that worked they removed the sphere and then tried it in several other cylinders of different sizes. They selected cylinders randomly and often returned several times to a cylinder they had just tried unsuccessfully. As a variation to this, they kept the cylinder constant and tried several spheres. By Day 6 this experimentation led them to figure out that s1 fit into all the cylinders. Children often ignored s2 and s3, walking around the room until they found an s1 to use in their play. They gathered several s1 and kept them until activity time ended, often causing conflict when there were not enough s1. After observing several conflicts, I added 10 more s1 at the second activity time on Day 6.

Jason approached the problem of figuring out which sphere would fit into which cylinder in a more systematic manner. The following vignettes and comments describe his actions over the course of the study as he worked on this problem.

> <u>Vignette 16</u>
> Jason, 22 months, Day 4 (0:40) Jason sits on the floor with c2 upright in front of him, holding s1 in his right hand. He drops s1 into c2 and watches as an s2 rolls to him. He picks up s2 and drops it into c2. He pauses and then says, "Whoa!" Tilting the top of c2 toward him, he looks into c2. He lifts c2 releasing s1 and s2. He sets c2 upright on the floor and picks up s2, drops it into c2, picks up s1 and

> drops it into c2. As he drops each sphere he counts, "One, two." He lifts c2, releasing the spheres, stands up and walks away leaving c2 upright on the floor with s1 and s2 next to c2.

Jason walked off camera but returned 13 seconds later. He repeated his actions of putting s1 and then s2 into c2. He again released them by lifting c2. By repeating his actions, he confirmed that s1 and s2 served as contents and they always fit into c2. In the next vignette, Jason added a new variable as he continued to work on fitting spheres into cylinders.

> Vignette 17
> Jason, 22 months, Day 4 (1:13) Jason sets c2 upright on the floor, picks up s2 and drops it into c2. He picks up s1 in his right hand, carries it near the opening of c2 then pulls his hand back. With his left hand he lifts c2, releasing s2 and quickly picks s2 up in his left hand. He looks at c2, holding s1 in his right hand and s2 in his left hand. He sees c1 lying on the floor near him. Placing s2 from his left hand onto the floor, he lifts c1 to an upright position, placing it next to c2. He picks up s2 in his left hand and places it on the top opening of c1. He turns s2 a quarter turn on top of c1 then removes it. He reaches over with his right hand, still holding s1, and touches the top opening of c1 with s1 but then quickly moves it away. He again places s2, in his left hand, on the top opening of c1. He turns s2 back and forth and then pushes it against the opening of c1. He then removes s2 from c1 and drops it into c2. He lifts c2, releasing s2 and again picks s2 up in his left hand. He sets s2 on the top of c1 and pushes. He removes s2, looks at s2 and then at s1 in his hands. He lifts his left hand and throws s2 away from him exclaiming, "Oh no!" He watches s2 roll away and then drops s1 into c1. He looks at s1 inside c1, lifts c1 (releasing s1) and lets c1 fall to the floor. He crawls away.

In Vignette 16 Jason used two sizes of spheres but kept the size of the cylinder constant. In Vignette 17 Jason continued with the same two spheres and c2, but then he added a variable: c1. He set c1 next to c2 allowing him to compare the results of his actions. Jason focused on s2 as he experimented with the relationship of content to container. He placed s2 on c1 two times, turning and pushing each time to try to get s2 to go into c1. Confronted with this discrepancy, he returned to his earlier action of putting s2 into c2 and confirmed that s2 could be contained. His actions allowed him to compare the two cylinders as containers: s2 fit into c2 but not into c1. After one more try at putting s2 into c1 Jason looked at both spheres and eliminated the sphere that did not fit into both cylinders. He threw s2 away from him, eliminating a variable.

Later on Day 4 Jason set c1, c2, and c3 upright on the floor in front of him. He picked up any sphere that happened to be close to him and dropped it into a cylinder. If the sphere fit, he lifted up the cylinder, retrieved the sphere and tried the sphere in a different cylinder. If the sphere did not fit, he pushed and turned it before removing it and then dropped it into a different cylinder. Using this process, Jason quickly realized that s3 only fit into one cylinder. He showed this realization by pushing away any s3 that was on the floor by him. He continued to work with s1 and s2. After several attempts to put s2 into c1 Jason stood up and kicked c1 out of his way. He dropped s1 into c2 and s2 into c3 and walked away.

Over the next several days Jason continued to experiment in this way with different combinations of spheres and cylinders. He first dropped the spheres into cylinders standing upright on the floor. His strategies remained consistent. He set the sphere at the opening of the cylinder and if it fit, he lifted the cylinder to retrieve the sphere and then tried another cylinder. When he encountered a combination that did not work he turned the sphere back and forth on top of the cylinder, pushed it, removed it and tried again. When a sphere did not work after three or four attempts he threw the sphere away from him and avoided picking up that size sphere again. When he held a sphere in each hand and tried each one on a cylinder, he eliminated the cylinders that did not hold both spheres. Using this method, Jason eliminated s3 and c1. The remaining s1, s2, c2 and c3 ensured successful containment.

Jason also experimented with the position of the cylinders. He held the cylinders vertically in the air and dropped spheres through. If a sphere did not fit he used the same strategy as when the cylinder stood upright. He turned the sphere on top of the cylinder and then pushed. He then used the same strategy Brad used in Vignette 15 and flipped the cylinder end to end to try the opposite opening. Jason also placed the cylinders horizontally on the floor and pushed spheres through and watched them roll across the room. Each time Jason changed the position of the cylinder he started his experimentation over and tried each sphere with each cylinder. The next vignette illustrates Jason's experimentation on the eighth day of working on the problem of containment. This is the first day he tried the cylinders horizontally on the floor as containers.

> Vignette 18
>
> Jason, 22 months, Day 11 (0:52) Jason sits on the floor with c3 lying horizontally in front of him. He pushes s1 into c2 and exclaims, "Go!" as he watches the ball roll through. He retrieves s1 and repeats this two more times, each time exclaiming, "Go!" as the sphere rolls through. On the last push, s1 rolls away and under the cots. Jason picks up s3 and pushes it through c3. When he retrieves the s3, he sees c2 lying horizontally on the floor and he crawls to it. He pushes s3 toward the opening of c2 and watches as s3 hits the opening and bounces back. He reacts with, "Uh oh" and tries again, getting the same result. He picks up s3, holds it in his lap and turns it in his hands while looking at it. He sets s3 on the floor, pushes it away saying, "Whoa!" He picks up s1 pushes it through c3 saying, "Go, go ball!" as he watches it roll through

Vignette 18 shows that he continued to use strategies that he earlier found ineffective. Jason had already eliminated s3 when he held the cylinders upright on the floor and vertically in the air. With the different perspective of the cylinders being on the floor he had to again reconstruct the spatial relationships necessary for successful containment. His experimentation involved errors, revision of strategies, eliminating variables, and setting a new problem (changing the position of the cylinders). He grappled with this for ten days before finding a combination of sphere and cylinder that guaranteed success.

The next vignette occurred early in the activity time on Day 13. Jason engaged in functional play with the materials: lifted the cylinders in the air and dropped them, mouthed s2, and inserted his arm into c2. He did not focus on the objects he acted on but watched Stacy set out some of the research materials for the other children. As Stacy set out the cylinders Jason stopped his activity and looked at the cylinders. The following occurred.

> Vignette 19
> Jason, 22 months, Day 13, (2:36) Jason sits on the floor watching Stacy put out the cylinders. He drops the cylinder he had been playing with and picks up two s1, one in each hand. He looks at both s1 and says, "Great, ball, great!" He stands and walks to c3 that Stacy has set upright on the floor. He squats down, tips c3 so it lands on the floor horizontally. He sits with his legs spread, placing c3 in front of him. He looks at each s1 in his hands, looks at c3 and says, "Oh, I have tunnel." He sets one s1 on the floor and pushes it into c3. As s1 rolls through c3 he squeals, "Great tunnel! Great tunnel!" He pushes the second s1 through c3 and says, "Great tunnel." He stands, runs to pick up an s1 but another child has retrieved it. There are several cylinders and spheres lying on the floor. He looks at the other cylinders and spheres but does not pick them up. He walks around the room looking at the materials on the floor until Stacy hands him an s1. He runs back to c3 and pushes s1 through c3 says, "Stacy, I got tunnel!"

Jason's problem solving over the ten days (Day 4 through Day 13) did not proceed in a linear progression. He began on Day 4, Vignette 16, and engaged in a type of exploration involving distributed action. He kept the cylinder constant but distributed the action of dropping the sphere into the cylinder by using two sizes of spheres. His repetition of the actions of dropping in and then lifting the cylinder to release the spheres confirmed that he would get the same results each time. When he added a new variable, c1, he encountered a different reaction. The sphere he tried to insert did not fit. He reacted to this discrepancy by varying his actions to try to accomplish his goal of inserting the sphere into the cylinder.

When a sphere did not fit after several attempts, he eliminated for the duration of the session either the sphere or the cylinder that caused the discrepancy. When he left the session and returned to the problem later, either the same day or the next day, he repeated many of the same sphere-cylinder combinations he had previously eliminated. It took six days of experimenting with the cylinders in an upright position before he consistently avoided the most limiting of the variables, c1 and s3. This changed when he varied the position of the cylinders and placed them horizontally on his lap or on the floor. He again included all sphere-cylinder combinations in his experimentation until Day 13 when he constructed a relationship between the smallest sphere, s1, and the largest cylinder, s3. This made a "great tunnel" and ensured containment no matter which s1 or c3 he picked up.

After figuring out the great tunnel, Jason picked up several more s1 and rolled them through c3. Once he constructed the great tunnel relationship of small sphere to large cylinder and confirmed it through repetition, he transferred that knowledge to all combinations. For the remainder of Day 13 and all of Day 14, the last day of the study, whenever Jason worked to contain spheres in cylinders he selected a sphere that was smaller than the cylinder. Review of the video shows that he did continue to place a larger sphere to the opening of a cylinder that was smaller, but as he placed the sphere he said, "Too big" or, "Uh oh" and then quickly threw the sphere away. He did not turn or push the sphere to get it to go in. His actions appeared to be part of a routine he had established, but he indicated with his words that he knew ahead of time that the combination would not work. As he threw the sphere away he picked up a sphere that would fit and quickly dropped it into the cylinder. Although Jason did not establish a one-to-one correspondence (matching each sphere with the corresponding sized cylinder) he did construct a relationship between content and container: the diameter of the sphere (content) had to be smaller than the diameter of the opening of the cylinder (container).

Andy, Brad, Lea and Anne also experimented with containing the spheres in the cylinders. They figured out that c1 held only s1 and c3 held all spheres, but they continued to make errors throughout the study when using s2 or c2. These two objects varied only slightly in size from the other objects. The four children needed to have physical contact between the sphere and cylinder before they could determine if the content/container relationship work.

Filling and emptying. In the process of working on containment and trying different spheres in different cylinders children often paused when a sphere dropped into a cylinder. They looked into the cylinder, lifted the cylinder to empty it, retrieved the released sphere and repeated. After three or four repetitions, children left the sphere in the cylinder and tried a new sphere. They repeated this until the cylinder held several spheres.

After filling the cylinder with several spheres, children worked on emptying the cylinder. They tried three strategies: lifting the cylinder to release all the spheres from the bottom, reaching in and removing spheres one at a time, or tipping the cylinder. Two variables affected whether or not the children succeeded in emptying the cylinders using the first two strategies. The size of the cylinder and the cap at the end of one cylinder both determined if either strategy worked. The next three vignettes of Anne illustrate a typical sequence of actions children demonstrated as they worked on filling the cylinder and then developed strategies for emptying.

> Vignette 20
> Anne, 18 months, Day 5 (0:36) Anne holds one s3 in each hand. She looks into an empty c3 standing upright on the floor and drops s3 from her right hand into the cylinder. She looks inside then drops in the second s3. Holding the cylinder in place she looks around on the floor, bends down and picks up another s3 and drops it into the cylinder and looks at the three spheres inside c3. She then walks forward, moving the cylinder containing three spheres with her. As she moves forward she lifts the cylinder slightly with each step she takes. She is looking into c3 as she moves forward. On her fifth step she lifts c3 higher than in previous steps and one s3 is released. She pauses. Then she lifts c3 higher releasing all the spheres.

Anne's repetition of dropping in a sphere, looking, and then dropping in another sphere allowed her to see that the more spheres she added the higher the pile became inside the cylinder and the less space available for her to fill. Sinclair et al. (1989) identified this iterative action as a practical motor level understanding of cardinality (adding one object each time to get more) and ordinality (first one and then another and then another). Anne worked at filling the cylinder by adding one then one more in a series of very deliberate actions.

At the end of Vignette 20 Anne moved forward, trying to move the filled cylinder with her. She lifted c3 as if to carry it, an action that had worked with other containers (toys, tubs, etc.). As she moved forward, watching the spheres inside c3, she accidentally released the sphere when she lifted c3 higher than her previous lifts. Her pause indicated that this was an unexpected result. She looked at the spheres on floor and returned to her activity of filling c3 as described in the next vignette.

> <u>Vignette 21</u>
> Anne, 18 months, Day 5 (0:37) Anne picks up s3 that had been in c3 and she drops it into the c3 standing upright on the floor. She looks inside c3. She looks around on the floor and picks up another s3 and drops that into c3 with the other s3. She looks inside, then reaches in and removes one s3. Holding the s3 she looks inside the cylinder and drops s3 back in. She then picks up a third s3, drops it in, removes it, looks in the cylinder, and drops the sphere back into the cylinder. She repeats the action of removing a sphere, looking inside, and dropping the sphere back in. Then she lifts the cylinder releasing the spheres.

In this vignette, Anne continued to observe the change in space inside the cylinder as she added more spheres, but she then removed spheres one at a time, negating her action of putting into. This immediate negation allowed her to experience the reversibility of actions. She put one sphere in to make a bigger pile. She took one sphere out and the pile returned to the same level as before. She did not try to remove all the spheres using this strategy but compared the difference in space inside the cylinder as a result of each action. When she wanted to completely empty the cylinder she lifted it, using the action that in Vignette 20 had been accidental, providing evidence that she had assimilated this strategy into her schema of ways to empty the cylinder.

For the next two days Anne filled cylinders by dropping spheres in one at a time, looking into the cylinder, removing the sphere, looking in the cylinder and dropping it back in. She then looked around the room for another sphere and repeated the process until the cylinder was full. After she filled the cylinder she lifted it up releasing all the spheres with one action.

On Day 8, the first time Anne encountered the ycc1, she had to vary her strategy of emptying the cylinder. The remaining cylinders (c1, c2 and c3) were open on both ends and could be emptied by lifting up and releasing the spheres as she had done in the above vignettes. The cap on ycc1 prevented the spheres from rolling out when she lifted the cylinder. Anne, based on her prior experience, tried the strategy of lifting up to release the spheres but adjusted her actions when confronted with a contradiction to her expectations.

> Vignette 22
> Anne, 18 months, Day 8 (3:17) Anne is standing by ycc1, which is vertical with the cap on the bottom. Anne has put five s1 into ycc1. She reaches in with her left arm and grasps one s1 and attempts to remove it from the cylinder. She is unable to remove the sphere because her arm is inside the cylinder. She cannot bend her arm to remove the sphere. She tries three more times and then walks with the ycc1, including five s1, on her left arm. She removes her arm from ycc1and picks up two more s1 and drops them in, looks inside and then tries once again to remove the spheres one at a time. When she cannot, she tries holding the ycc1 at the top end (open end) lifting up and then and shaking it. She looks at c1 with the seven s1 inside. She moves her hands so one is on each side of the upright yccc1 and continues shaking. The spheres bounce inside but do not bounce out. She pauses, looks inside, and then lifts and tips the yccc1 so the open end is on her right and all the spheres roll out. She watches as the spheres roll away, holding ycc1 inclined in the air in front of her.

Anne's previously successful strategy of taking spheres out one at a time, a form of emptying, did not work because the narrow cylinder restricted the arm movement needed to bend her elbow and lift the sphere. Anne had experience with filling and emptying c1, also a narrow cylinder, and had tried lifting spheres out one at time. When she wasn't successful she returned to lifting c1 to empty it. In Vignette 22 she was again faced with the challenge of emptying the cylinder and finding it too narrow. She responded by trying the strategy that had been successful. She lifted the cylinder. The cap stopped the spheres and Anne was faced with a contradiction to her expectation. The spheres remained inside. Seeing that the spheres remained inside she tried a new strategy of shaking.

The strategy of shaking to remove objects had worked in another situation. One classroom toy, a drum with a removable lid, contained several blocks. To remove the blocks the children had to tip the drum upside down and shake it because the top was narrower than the bottom and only one block at a time could slide out. Anne transferred her experience with the toy drum to this situation and tried to shake the cylinder to release the spheres. When the spheres did not come out using this same strategy on the cylinder, Anne paused and looked at c1 with the s1 inside. She then lifted c1, tipped it and let the spheres roll out. Anne transferred her experience with the toy drum to this situation. She shook ycc1 to try to empty it. When shaking did not work, she turned c1 over, just as she had to do with the toy drum to start releasing the blocks.

After Day 8, Anne continued to fill cylinders with spheres, dropping them in one at a time and removing them before dropping them back. Whenever Anne filled an open-ended cylinder she emptied it by lifting the cylinder. When she had the ycc1 she tipped the cylinder. She modified her earlier scheme of emptying (lifting the cylinder) and added the strategy of lifting spheres out one at a time and finally added the strategy of tipping the cylinder. She constructed a relationship between the type and size of cylinder and the strategy needed to reach her goal of emptying it. All children in the study, except 18-

month-old Kate, demonstrated similar actions as they solved the problem of filling and emptying the cylinders.

Movement of Spheres Inside Cylinder

During their work on filling and emptying, children often tried to keep the spheres contained in the cylinder while they moved the cylinder. Anne demonstrated this in Vignette 20 when she tried to move forward with her filled cylinder. Other children tried to hold the filled cylinder horizontally and carry it with them. When holding the cylinder horizontally, the sphere stayed inside and rolled back and forth for a few steps before rolling out one end of the open-ended cylinder. Children stopped and watched as the sphere rolled away. This led them to two problems. How could they keep the sphere in the cylinder? How could they control the movement of the sphere inside the cylinder? In this section I describe how children worked at solving these two problems.

Keeping the sphere inside the cylinder. On Day 4, the first day I presented both cylinders and spheres, the children acted surprised when they dropped a sphere into a cylinder and the sphere did not stay in the cylinder. They expressed this surprise by pausing their actions, looking at the sphere roll away, and then repeating the action of dropping the sphere into the cylinder. Some children, after pausing and watching the sphere roll away, looked to one of the adults in the room. The next vignette of Lea illustrates actions typical of all children in the study as they observed the sphere roll out of the cylinder.

Vignette 23

Lea, 24 months, Day 5 (0:46) Lea holds c2 vertically in the air in her left hand and s1 in her right hand. She inserts her right hand, still holding s1, into c2 and walks forward. She stops, looks at c2 with her hand inside and pulls her hand and

> s1 out of c2. She looks at s1 and reinserts her hand into c2, tipping c2 so it is inclined. Looking at s1 she slowly releases s1 and tips c2 to an upright position in the air and looks inside. She lifts c2, tips her head and looks to the bottom of c2 and then looks around and sees s1. She picks up s1 and drops it into c2, pauses, looks around for s1 and again retrieves it. She walks to Jenny, holding c2 upright in her left hand and s1 in her right hand. She extends both objects to Jenny, pulls them back to herself and then places s1 at the opening of c2 but does not drop it in. She then extends s1 to Jenny. She pulls s1 back and inserts it part way into c2 but does not release it. She then hands Jenny c2 and says "You." Jenny responds "You want me to hold it?" Jenny holds c2 vertically in the air. Lea drops s1 into c2 and watches as it drops through and rolls away. She retrieves s1 and drops it into c2, held by Jenny, five more times. Each time she looks more quickly to the bottom of c2 and follows s1 as it rolls away. The last time she drops s1 into c2 she looks to the bottom of c2 before dropping s1. She then takes c2 from Jenny and walks to retrieve s1.

Lea explored the relationship of s1 to c2 by first inserting her hand with s1 into c2 but not releasing s1. When she released s1 she expected it to be contained in c2 as indicated by her looking into c2. She did not see s1 in c2 so tried looking from another angle. Not seeing s1 in c2, she looked around and picked up an s1 from the floor and repeated her action of dropping s1 into c2. Her actions on this attempt indicated that she changed her expectation. She paused rather than looking inside c2 first and then she looked around on the floor for s1.

After her first two actions of dropping s1 into c2 Lea sought the help of an adult, Jenny. Lea first extended s1 and c2 to Jenny and then she demonstrated what she wanted done by placing s1 part way into c2. Lea then handed c2 to Jenny who held c2 so that Lea could drop s1 into it. This allowed Lea to focus her actions on dropping s1 into c2 and watching how it moved through c2. Lea refined her action of looking each time. She first dropped s1 and then looked to the bottom of c2. By the last attempt, her fifth, she looked to the bottom of c2 before dropping s1. She anticipated the path of s1. After she walked away, she retrieved s1 and continued to experiment. Before dropping s1 she looked to the bottom of c2 and then after dropping s1 her eyes followed its path from the bottom of c2.

After several minutes of experimenting in this way Lea sat on the floor and moved c2 to a horizontal position. She again encountered a contradiction to her expectation. She looked to the left end of c2 and inserted s1 into the right end of c2. When she released s1 it did not roll out. She looked around on the floor. In her experimentation up to this point, these actions led to her finding s1. When she did not see s1 on the floor, she looked back at c2 and her eyes focused on s1 inside. She smiled. After several seconds of looking at s1, she started to slowly tip c2 up and down and watched s1 roll back and forth.

> <u>Vignette 24</u>
> Lea, 24 months, Day 5 (1:09) Sitting on the floor with c2 held horizontally Lea looks at s1 and then tips c2 so the right end is higher. She watches s1 roll to the left inside c2. Lea's hand is grasping the left end of c2 with her fingers curled, creating a block so s1 does not roll out. She then tips c2 so the left end is higher and watches s1 roll to the right. Her right hand is grasping c2 with fingers curled, stopping s1 from rolling out. As she tips c2, her head moves back and forth as she follows the path of s1. She tips c2 up and down two more times. On the second repeat, she moves her right hand and s1 rolls out. Lea drops the right end of c2, looks at s1 for 3 seconds. Setting c2 upright on the floor, she picks up s1, drops it into the top end of c2. She looks at s1 inside c2 and tips the top of c2 down to the left using her left hand. With her right hand she reaches for the bottom end of c2 and lifts it up so c2 is horizontal. She looks to the middle of c2, but s1 is not there. It remained on the floor. She looks around, sees s1, picks it up and inserts it into the right end of c2. She again tips c2 up and down watching s1 roll back and forth until she moves her hand and s1 rolls out. She stops tipping c2, looks for s1, retrieves and puts it back into c2 held horizontally. Lea repeats this sequence (insert s1, tip c2) four more times before dropping c2 and playing with another toy.

In this vignette Lea observed the reaction of s1 inside c2 when she tipped c2. She did not yet construct the relationship between the position of the cylinder and keeping s1 contained. She demonstrated this when she dropped s1 into the upright c2, lifted c2 and looked inside for s1 expecting to see s1. When she didn't see it inside, she picked up s1 from the floor, inserted it into c2 and continued to experiment with tipping. She focused on the movement of s1 and did not attend to the placement of her hands. Containing s1 in c2 became less of a focus as she played with the movement of s1 inside c2. She seemed content to let s1 roll out as she played. This changed the next day with addition of ycc1. The following vignette describes how Lea learned to keep the sphere inside the cylinder.

> Vignette 25
> Lea, 24 months, Day 6 (1:21) Lea stands holding ycc1 horizontally with her right hand on the outside of ycc1, held so that the open end is on her left With her left hand she inserts s1 and grasps the open end of ycc1 by curling her fingers inside the cylinder. She leans her body to the right, tips ycc1 to the right and watches as s1 rolls to capped end of ycc1. She then leans left tipping ycc1 to the left and follows s1 with her eyes. She leans to the right again. This time her eyes move to the capped end of ycc1 before s1 hits the capped end. She continues to focus her eyes on the cap as she tips ycc1 seven more times. She then tips ycc1to the left and opens her left hand, reaches in with her thumb and forefinger to grab s1. She cannot grasp s1 in the limited space so she opens her left hand, keeping it at the end of c2, and s1 falls into it. She reinserts s1 into ycc1 and continues tipping the cylinder and watching s1. She moves her eyes from the capped end to the end with her left hand curled. After tipping ycc1 several times, she stops and looks at her left hand. She opens her hand slowly tipping ycc1 and watches s1 roll to her hand. Looking at s1 she tips ycc1 further so the capped end is on top and her hand is completely covering the open end on the bottom. She moves her hand away and watches as s1 drops to the floor and rolls away.

Lea observed the capped end of the cylinder as she tipped it and kept her eyes focused on that end rather than on the sphere as she had before. Each time she tipped ycc1 she saw s1 hit the cap and roll back. When she wanted to remove s1 she tried grasping it to pull it out. Limited by the space, she happened to open her hand as she withdrew her thumb and forefinger and s1 fell into her hand. In her last sequence of tipping c2 she applied the new action of opening her hand and controlled when s1 fell.

The next day she applied this action to a new cylinder. On Day 7 she held c1 with s1 inside. She held one hand, curled on the edge, at each end. She walked around the room swinging c1 from side to side watching s1 roll back and forth. During one swing her left hand slipped and s1 fell out. Lea looked at s1, picked it up, put it back into c1 and returned her hand to the left end. She started to swing c1, stopped and then opened her left hand to cover the opening and continued to swing. When s1 reached her right hand during one swing she stopped, looked at her right hand and opened it to cover the end of c1. She now had both hands open and covering the openings. Lea shared her learning with Stacy. She walked to Stacy, tipped c1 up and down and said, "I did it."

To reach her goal, Lea revised her actions over the four days that she worked on this problem. She first constructed the knowledge that s1 always dropped out of c2. She revised this when she changed the position of the cylinder to horizontal and when she had her hands at the ends of a cylinder. Under these conditions, s1 stayed inside the cylinder but Lea did not attend to her hands and how they affected the reaction of the sphere. She focused on the movement of s1. When she happened to use ycc1 to contain s1 she observed that s1 did not roll out of the capped end. She applied this knowledge, after more experience, to the position of her hands. She constructed the knowledge that s1 would stay in motion until stopped by either the cap or by her hand. She reached her goal (as indicated by her announcement of "I did it").

All eight children in the study dropped spheres into the open-ended cylinders and watched the spheres roll away. Seven of the eight children (all except Kate) set the goal of getting the sphere to stay inside the cylinder. They followed a sequence similar to that of Lea in solving the problem to reach their goal. Once they constructed the relationship between the placement of their hands and the sphere remaining inside the cylinder they easily inserted a sphere into a cylinder, placed their hands at the ends to block the sphere, and walked around the room tipping or swinging the cylinder and watching the sphere move inside. They did, at times throughout the study, engage brief episodes of holding a cylinder upright in the air and dropping spheres through to the floor but they quickly returned to placing their hands on the ends to contain the spheres.

Controlling the direction of the sphere's movement. Four of the children, after figuring out how to keep the sphere contained in the open-ended cylinders, set a new problem. Andy, Brad, Lea and Jason worked at controlling the direction of the movement of the sphere inside the cylinder. They started by holding a cylinder horizontally in front of them, inserting a sphere and then reaching their hand in to push the sphere in the desired direction.

Seeing their interest in this, at the end of Day 5 Jenny placed a c1 with one end elevated on an 18" cube and the other end on the floor. She called the children's attention and then dropped s1 into the higher end of c1. Brad quickly retrieved s1 and tried the same action but he inserted s1 at the bottom of c1. When it did not move Andy, Brad, and Lea looked at the s1 and then Andy reached down and pushed s1 into c1. The three children watched as s1 rolled back down and out of c1. Brad again retrieved s1 and as he put it into the lower end of c1 Andy grasped the lower end and lifted it. The s1 rolled to the opposite end and rolled out. Lea retrieved s1, grabbed the upper end of c1. Andy still held the opposite end. Lea inserted s1 and Andy and Lea tipped their ends up and down, watching s1 roll back and forth until it rolled out. This experience, a variation of one child tipping a cylinder, led children to try to figure out how to get the sphere from one person to another.

In the next set of vignettes, I highlight Andy's actions as he worked on this problem. His actions represent the problem solving actions also carried out by Lea, Brad and Jason.

> Vignette 26
> Andy, 21 months, Day 6 (1:13) Andy holds the ycc1 with s1 inside in a horizontal position, the capped end close to his body and the open end facing out. He walks to the researcher who is holding a c1 horizontally with one end pointing forward. Andy aligns the open end of his ycc1 to the end of the researcher's c1. As he pushes the two ends together s1 rolls through both cylinders and drops to the floor. He laughs at the unexpected result. The researcher inserts s1 into her end of the double-cylinder structure and raises her end so the sphere rolls to the capped end of Andy's cylinder. The researcher asks if Andy can get the sphere to come back to her. Andy looks at the sphere and pushes his ycc1 forward. The sphere moves part way through his cylinder and then returns to the capped end. The researcher lowers her end of the structure causing Andy's cylinder to also tip and the sphere rolls to the researcher and out the end of the structure. The researcher inserts another s1 into the structure, lifts her end so the sphere rolls to Andy's capped end, and again asks if Andy can return it. Andy again pushes his cylinder forward but does not tip it.

Andy, based on the request of the researcher, focused on getting the sphere to move through two cylinders. He pushed the cylinder toward the researcher, keeping the cylinder in a level position. The sphere did move forward but returned to Andy's end. Andy's action made sense based on his earlier experiences. He succeeded in getting a sphere out of ycc1 earlier when ycc1 sat on the floor in a horizontal position. Andy, sitting on the floor with the capped end of ycc1 facing him, pushed ycc1 away from him and s1 rolled out. He applied the same strategy in this vignette but he did not account for the length of the two cylinders together. Andy and the researcher engaged in this activity for seven minutes and 38 seconds on Day 6 but Andy never varied his action when he tried to get s1 to the opposite end.

Andy continued to pursue the goal of getting the sphere to move between two cylinders, one held by the researcher and one by him. Over the next three days he varied his actions. He continued to try pushing his cylinder forward to send the sphere to the researcher and tried pulling his cylinder backwards (even walking backwards with it) to get the sphere from the researcher's cylinder into his.

On Day 10, after carefully observing the researcher raise and lower her end to get the sphere to move in the direction she wanted, Andy tried tipping the cylinder. He acted according to his perspective of the movement of cylinder and sphere.

> Vignette 27
> 3.10.2 (6:18-6:39) Andy holds one end of c1 with s1 inside and the researcher holds the other. The researcher showed Andy how she lifted her end to get the sphere to go to his end and she also verbalized her actions, "See, I lift my end and it goes to you." Andy smiled and watched as the sphere rolled to him. The researcher lowered her end causing the sphere to roll back to her saying, "And when I put my end down it comes to me." She then asked if Andy could get the sphere back to his end. He looks at the sphere and at the cylinder and slowly raises his end.

Andy eliminated the second cylinder and focused on getting the sphere to move back and forth through one cylinder. He used the action of raising his end of the cylinder when he needed to lower it to get the sphere back to him. This made sense if looked at from Andy's perspective. In demonstrating how to get the sphere to roll to Andy the researcher verbalized that she lifted her end. When the researcher then asked Andy how to get the sphere from her end of the cylinder to Andy's end he lifted just as the researcher had done. Andy had the same response with the sphere on his end of the cylinder and the researcher asked Andy how he could get the sphere back to her. He lowered his end, just as the researcher had done to get the sphere to go to her.

Each time Andy returned to this activity he tried new actions but never got the relationship between raising his end and the sphere moving away from him or lowering his end to get the sphere to move toward him. On Day 11 he engaged in an activity with Jason and he made the connection. Jason, lying on the floor on his tummy, held c1 horizontally in front of him with one end near his face the other pointing outward. Andy placed himself on his tummy facing Jason and inserted s1 into c1. The s1 stayed near Andy's end. He looked at the s1 and then at Jason. Andy could not use his action of lowering his end because the floor only allowed him to raise his end and he could not push it forward because he would hit Jason. He did not pull it toward him because the sphere was already at his end. He then raised his end of the cylinder. The sphere rolled to Jason. Andy showed his pleasure with a loud, "Oh, awwwww, hey!"

Later on Day 11 Andy handed c1 to the researcher. Andy held the ycc1 with s1 inside. He aligned the open end of his c1 to the end of the researcher's c1, with s1 at the capped end by Andy. Smiling, he lifted his end and sent the sphere to the researcher. When the sphere reached the researcher he waited for her to raise her end and he lowered his end at the same time. He constructed the relationship between the angle of the cylinder and the direction the sphere moved. Throughout the remainder of the study Andy did not return to any of the earlier actions to get the sphere to move. He easily tipped the cylinder to move the sphere in the direction he wanted.

Brad, Lea and Jason demonstrated similar errors in their attempts to figure out how to get the sphere to move in the desired direction. They acted by lifting and lowering according to the actions the adult demonstrated when working with the child. Each of these three children solved the problem in a slightly different manner. Brad watched Andy working with the researcher successfully. He watched for several minutes, standing off to the side, and then took c1 to Stacy and worked with her to try it on his own, also successfully. Lea stood by Stacy during this activity and Stacy guided Lea's hand as both of them lifted and lowered the end of c1. After six of the shared actions, Lea pushed Stacy's hand away and Lea and Brad continued to tip c1 back and forth moving s1 in turn to each other. Jason, in the interaction with Andy described in the paragraph above, also figured out that he needed to raise his end to move the sphere away and lower his end to get the sphere to come to him.

Summary of Problems Children Identified

Children identified problems during the course of exploration of the research materials. As they acted on the materials to see what could be done with them the materials often reacted contrary to children's expectations. When this happened, children paused all action. The pause demonstrated children's recognition of a discrepancy or problem and indicated their sense of disequilibrium. After pausing they often smiled, looked at an adult in the room, took the materials to an adult for help, or verbally expressed surprise. Their actions after the pause indicated whether or not they chose to pursue the problem.

Kate (18 months) walked away and found other objects in the room to play with. When she returned to the research materials she engaged in exploration until encountering another discrepancy. If she did continue to engage with the materials after the discrepancy she repeated the actions several times as if to confirm she would always get the same response. She did not vary her actions to try to achieve a solution to the problem.

The remaining seven children also repeated their actions several times to confirm that they would get the same result each time. After confirming this, they then varied their actions to try to get a desired result. Their actions suggested that they changed their focus from seeing what the materials could do (exploration) to that of trying to get the materials to behave in a certain way. They organized their actions to reach a goal they had set.

Analysis of these organized actions revealed that children solved problems related to three activities: nesting of cylinders, containment of spheres inside cylinders, and movement of spheres inside cylinders. Not all children engaged in all three problem-solving activities. Brad, Andy, Jason, and Lea pursued all three problems over the length of the study. Anne, Eva and Kim chose to pursue some problems but walked away from others. Kate engaged with the materials but did not move beyond explorations. Table 4 identifies which children worked on each problem.

Review of the videotapes showed that within each session different children engaged in different problem solving activities and individual children, within a session, engaged in more than one problem solving activity. Review of the tapes over the length of the study showed that as children pursued their individual problem solving activities they progressed through a similar problem solving process. In the next section I describe the components of this process and provide examples to illustrate each component

Table 4

Problems Identified by Individual Children

	Nesting	Containment		Movement	
		Size relationship	Filling and emptying	Keeping in	Direction
Anne	x	x	x	x	
Kate					
Brad	x	x	x	x	x
Eva			x	x	
Andy	x	x	x	x	x
Jason	x	x	x	x	x
Kim	x		x	x	
Lea	x	x	x	x	x

Problem-Solving Process

Sinclair et al. (1989) noted "the tenacity and intellectual coherence the infants evinced when facing the problems they themselves raised and the meaning they themselves attributed to events" (p. 197). Children in their study often engaged in one problem-solving activity for the full 20-minute session and then continued working on the activity over the course of several days. Children in the current study exhibited the same tenacity and perseverance. They worked on problems of their own choosing, spending several minutes at a time on one problem and returning to the same activity over the course of several days.

Time of Engagement

Time of engagement, a major variable in this study, indicated children's interest in the material and their tenacity in pursuing solutions to the problems they set. Prior studies on children's actions with objects (Sinclair et al., 1989) also took place in classroom settings but children played in a separate area of the classroom and researchers provided only the research materials. Children did not get to choose other materials and did not experience distractions that take place in the typical classroom setting. In the current study, children remained in the classroom, had access to other materials and experienced the natural distractions of a classroom setting. Measures of time of engagement helped determine if the materials were inviting to the children and if the materials offered enough variety to sustain interest.

Table 5 provides data on the children's time of engagement. Time of engagement is noted as a ratio of minutes engaged to minutes the materials were available each day. The ratios represent the engagement time that could be verified on video. Each child may have engaged for longer. However, the time was not counted when the child moved off camera or the videographer moved the camera to focus on a different child even though the first child may have continued engagement with the materials.

The data on engagement show that children in the study, when given a choice of all materials and activities in the classroom, did choose to play with the research materials at least part of each day. Field notes and videotapes show that all children engaged in more than one event with the materials each day. Children played with the

Table 5

Children's Time of Engagement

Child's name	Age in months	4	5	6	7	8	9	10	11	12	13	14	Total
	Day	4	5	6	7	8	9	10	11	12	13	14	Total
	Time materials available	75 min.	90 min.	45 min.	45 min.	90 min.	90 min.	45 min.	90 min.	90 min.	50 min.	45 min.	755 min.
Anne	18	13 0.17	8 0.08	2 0.04	4 0.09	10 0.11	4 0.09	1 0.02	10 0.11	7 0.07	13 0.26	13 0.29	85 0.11
Kate	18	3 .04	5 0.06	2 0.04	4 0.09	5 0.06	1 0.01	4 0.09	5 0.06	--	5 0.1	17 0.38	51 0.08
Brad	18	18 0.24	19 0.21	11 0.24	12 0.27	7 0.08	19 0.21	21 0.47	22 0.24	12 0.13	9 0.18	9 0.2	159 0.21
Eva	20	1 0.01	1 0.01	1 0.02	2 0.04	2 0.04	2 0.04	2 0.04	7 0.08	--	--	--	18 0.03
Andy	21	3 0.04	9 0.1	13 0.29	7 0.16	15 0.17	29 0.32	14 0.31	14 0.16	27 0.30	6 0.12	12 0.27	149 0.20
Jason	22	21 0.28	22 0.24	21 0.47	5 0.11	2 0.04	14 0.16	8 0.18	6 0.07	13 0.14	15 0.3	13 0.29	140 0.19
Kim	22	--	3 0.03	1 0.02	3 0.07	--	19 0.21	5 0.11	12 0.13	14 0.16	2 0.04	18 0.4	77 0.13
Lea	24	11 0.15	11 0.12	6 0.13	4 0.09	5 0.06	--	--	--	--	--	--	37 0.10

Note: Time of child's engagement per day is noted in minutes on the top line of individual child's data cell. Ratio of child's time of engagement to time materials were available is rounded to the nearest hundredth and noted on the second line of each cell. Dashes indicate the child was absent that day.

materials, left, and then returned to the materials later. Review of the videotape shows that children left the materials or activities in the room, completion of the task they had been working on, or inability to solve a problem they had encountered while engaging with the materials. The fact that children returned to the materials provides more support to the idea that the materials were interesting to the children and offered enough challenge to sustain engagement over several days.

Two questions arose as the study progressed. First, would each child's engagement time decrease over the length of the study? If engagement time decreased it could be attributed to a loss of interest in the materials. Second, were there any days that all children showed an increase or decrease in engagement time? If all children showed a change in engagement time on the same day it could be attributed to factors that affected the classroom (addition of new materials, a substitute teacher in the room, etc.).

To answer the questions, I compared ratios to determine if individual children's engagement times revealed patterns or if there were specific days that all the children's times varied in the same direction. I used comparison of the ratios rather than ANOVA because the data did not fit the assumptions for ANOVA. The convenience sample was too small and was not normally distributed.

A comparison of each child's ratios of engagement across days did not reveal a pattern, with the exception of Eva and Lea. Eva had low ratios of engagement time but showed a steady increase over the seven days she was in attendance from .01 on her first day to .08 on her last day of attendance. Lea, who moved to a new room after five days, showed a steady decrease in time of engagement from .15 on her first day to .06 on her last day

All other children had inconsistent times of engagement, varying from day to day. Field notes and videotapes do not point to any clear factor that may have influenced the inconsistent engagement other than for Jason on Day 8 who was sick and Brady on Day 8 who had found a new toy and did not want to share with anyone so he held the new toy for most of the activity time. Both boys had noticeably decreased engagement on Day 8.

A daily ratio showing total minutes of access for all children (minutes available multiplied by the number of children present for each day) to total minutes all children engaged for that day provides data to answer the second question regarding factors that may have affected the whole group of children. Table 6 shows the daily engagement.

Table 6

Ratio of Engagement by Day

	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Total
Total minutes for all children	70	78	57	41	46	88	55	76	73	50	82	716
Total minutes available	525	720	360	360	630	630	315	630	450	300	270	5190
Ratio of engagement time	0.13	0.11	0.16	0.11	0.07	0.14	0.17	0.12	0.16	0.17	0.30	0.14

Note: Total minutes available = Minutes materials were available x number of children in attendance.

Only two days showed a difference that seems to be worth noting. Day 8 was the lowest day of engagement. This can be partially explained by looking at the individual engagement time in Table 1. Brad and Jason, discussed above, had decreased engagement time on Day 8. Both Brad and Jason on all other days had some of the higher engagement times. Their decrease in time affected the total engagement time for Day 8.

Day 14 showed a marked increase in overall engagement. This increase can be attributed to the addition of new material: a section of gutter. Videotape of Day 14 shows that all the children spent time exploring the gutter to see what they could do with it. Much of this engagement time took place in a group when the adult held the gutter and children took turns rolling spheres down the gutter and across the room. Data from Table 1 indicate that two children, Kate and Kim, had the largest increases in engagement time on Day 14. Kate and Kim extended their play with the gutter by adding cylinders at the end of the gutter and trying to roll a sphere down the gutter and through the cylinder. Data for this day would indicate that addition of new material increased engagement time, but this is not true in all individual cases.

The addition of new material on Day 14 increased overall engagement time, but on Day 6 when new material was introduced (a capped cylinder) the children's times did not change. This may be due to the fact the material added on Day 6 was similar to the cylinders that children had already explored. The gutter, which was added on Day 14, was a novelty and the children engaged more as they tried to figure out what they could do with it.

The data on engagement indicate that when children had access to the research materials they engaged with those materials daily, often engaging multiple times in one day. Children's engagement varied from day to day with no clear explanation for individual variance. Daily engagement time for the group was most influenced by the addition of a novel material that led the children to more exploratory activities.

Engagement time provides a measure of children's interest in the research materials and of their tenacity in solving problems. These data provide the context for discussion of the processes children displayed as they persevered in reaching their goals. In the next section I discuss the process children demonstrated as they organized their actions to solve problems and reach goals.

Components to Problem Solving

Analysis of the individual DVDs of the eight children in the study revealed a pattern to the problem-solving process. No matter which problem children chose to pursue this process included five components: exploration, contradiction, repetition, experimentation, and solution. Children's actions changed as they moved from one component of problem solving to another. In the following sections I describe the actions typical of each component.

Exploration. I will briefly present exploration here as it is discussed more thoroughly earlier in this chapter in the section addressing children's actions. Two aspects of children's actions during exploration distinguish this component from other components of problem solving. First, children performed isolated actions on many objects. This random acting started when children acted on any nearby object using a variety of actions. Children did not discriminate between cylinders and spheres but applied similar actions to both sets of materials. This led to a more focused exploration of one set of materials. Children still applied random actions but they applied them to one set of objects, either spheres or cylinders. Vignettes 1 through 3 describe this type of exploration. Second, children performed one action on random objects as seen in Vignettes 4 through 7.

Although exploration occurred most frequently early in the study, children often returned to exploration throughout the study. The seeming disorganization of their actions indicated a return to exploration. Jason demonstrated this as he worked on the problem of fitting spheres into cylinders. On Day 11 after Jason worked at matching spheres to cylinders when the cylinders were horizontal (see Vignette 18) he returned to exploration as seen in the following vignette.

> Vignette 28
> Jason, 22 months, Day 11 (2:03) Jason sits on the floor and watches s1 as it rolls through c3 and rolls away. He sees three spheres in front of him. He picks up c3 squeezes it, throws it and then picks up s2. As he picks up s2 his foot hits c1 that is lying on the floor. He kicks c1, sets s1 down and kicks s1. He picks up c1 that rolled but stayed near him. He looks into the end of c1, puts his arm in and wiggles his fingers, throws c1 and picks up s2 in his right hand and c3 in his left hand. He bangs s2 on the rim of c3 several times and then throws c3 behind him. He bangs s2 on his head and then throws it up in the air. He looks at two c1 and four spheres of various sizes on the floor in front of him. He moves both legs and kicks the objects away from him.

Jason had already explored the objects using similar actions early in the study. By Day 11 he had many experiences with the objects and had opportunities to construct knowledge about their physical properties and about what he could do with the objects. His return to this earlier form of exploration provided Jason a break from the problem solving he had been working on. His actions, typical of functional play, allowed him to act on the objects without trying to get them to behave in a certain way.

All children returned to exploration throughout the study. Early explorations served to help children learn about the objects and what they could do. Later explorations provided reprieve from working on problems and allowed children to act on the materials using a variety of actions without grappling with trying to figure out how to reach a set goal. During both types of exploration materials often reacted to children's actions in ways contrary to children's expectations. This unexpected reaction led to the second aspect of the problem-solving process, contradiction.

Contradiction. Children's actions during exploration occurred continuously with one action following another very quickly. When a contradiction occurred children paused their actions indicating that they had noticed the discrepancy between their expectation and the object's reaction. After pausing, children responded in one of two ways. One response was to ignore the contradiction by continuing to perform random actions or by walking away. Another type of response occurred when they focused on the contradiction and their actions became more organized as they tried to deal with the contradiction.

Kate, 18 months old, chose to ignore contradictions and did not engage in problem solving with the research materials. When she experienced a contradiction she ignored it. The next two vignettes describe the two ways Kate responded when faced with a contradiction.

<u>Vignette 29</u>
Kate, 18 months, Day 7 (0:14) Kate sits on the floor next to the researcher. She holds ycc1 upright in front of her with the capped end on the bottom. She picks up s2 and set it to the open-ended top of ycc1. She then threw it away from her and picked up an s3 from the floor. Kate held s3 there and looked at the researcher. The researcher responded, "That one won't work either?" Kate looks at the researcher, pushes on s3 and then lets ycc1 with the s3 still on top fall to the floor. She claps then gets up and walks to the toy push cart.

<u>Vignette 30</u>
Kate, 18 months, Day 10 (0:32) Kate squats on the floor and picks up s1 in her right hand. Standing, she pulls a c1 upright and drops s1 into c1. She bends down and picks up another s1 and drops it into c1. She looks at the two s1 in c1 and holds c1 at the top with both hands. She lifts and lowers c1 quickly, moving forward as she does so. She is looking ahead of her and does not notice that the spheres have rolled out. She lifts c1 three times and on the last lift she looks to the bottom of c1. She stops, holding c1 in the air and looking at the bottom end for 4 seconds. She lifts c1 so it is horizontal in front of her, lifts it over her head, and then drops it behind her back. She picks it up and throws it in front of her. Turning, she picks up c2 and inserts her arm into it. She swings her arm back and forth then lets c2 fall to the floor. She turns to ycc1 that is standing upright on the floor near her. The capped end is on the bottom and there is one s1 inside. She reaches her arm into ycc1, wiggles her fingers, lifts her arm with ycc1 still on it then swings her arm and ycc1 falls off. She kicks ycc1 away and then kicks a c1 away from her before walking off to play at the kitchen center.

In these vignettes Kate demonstrated both types of ignoring a contradiction. In Vignette 29 she walked away. She tried pushing s3 into ycc1 but when it didn't work she abandoned the materials and moved to a new activity. In Vignette 30 she expected the spheres to remain inside c1 even though she had lifted it up. She stopped all action for four seconds when she realized that the spheres did not stay in c1. Rather than look around for the spheres or try to refill c1 she returned to performing indiscriminate actions typical of exploration.

The other seven children in the study responded to contradictions by organizing their actions and trying to figure out how to get the materials to do what they wanted.

When they chose to deal with the contradiction children focused on the objects causing the contradiction and discontinued the random actions used during exploration. This focused activity started with repetition, the next aspect of problem solving.

Repetition. After pausing, if children chose to deal with a contradiction they repeated the actions that led to the contradiction. As they repeated their actions they focused on the objects. This focused attention allowed children to construct a relationship between their action and the reaction of the object and to confirm that they would get the same result each time (Piaget, 1952/1963).

Brad demonstrated this repetition in Vignette 12 when he experienced the contradiction of the inner cylinder not fully fitting inside the outer cylinder. After he first noticed the discrepancy between what he thought should happen and what really happened he repeated his action of pushing on the inner cylinder five more times. Later in the same session Brad tried again to fully contain the inner cylinder and continued to push on each end, in turn. As he pushed one end his eyes focused on the opposite end, indicating that he expected to see the end of the inner cylinder stick out beyond the end of the outer cylinder. This repetition allowed him to confirm the regularity of the cylinder's reaction.

Repetition occurred throughout problem solving, not just at the point of the initial contradiction. Andy, as he worked on getting spheres inside a cylinder to move in a desired direction, often repeated actions. This occurred each time he tried a new strategy for getting the sphere to move in the direction he wanted it to move. He first repeated the action of pushing or pulling the cylinder (see Vignette 26). This repetition lasted for four days before he confirmed that his strategy did not work. Each day that he tried the strategy of pushing and pulling he varied the cylinders he used. After four days he changed his actions to lifting and lowering his end of the cylinder (see Vignette 27). Again he repeated his actions but he varied the cylinders he used.

Brad and Andy illustrate the difference between repetition that occurred immediately after noticing a discrepancy and repetition that occurred during experimentation. In early repetition children kept the action and the objects constant, observing to confirm that the result would always be the same. After confirming this, they repeated actions and varied the objects, or they kept the objects the same but repeated the action varying it slightly each time. According to Piaget (1936/1963)

> The "experiment" always begins with repetition. In order to study changes in position, the trajectory of objects thrown or rolled, etc., it is always necessary to return to the same movements, with the intention of varying them little by little (p. 273)

When children returned to the same movement (repetition) but varied either the actions or the objects acted upon, it signaled that they had moved into experimentation.

Experimentation. Piaget (1936/1963) explained that in the fifth stage of sensorimotor development children experiment to produce a desired result. This experimentation begins as described above when children repeat the movements or actions that led to the fortuitous result, or discrepancy. After confirming that the actions always led to the same result children were no longer content to merely repeat the same actions. They varied their actions in some way and observed the change in the object's reaction. They used their observations to revise actions and get closer to their desired goal.

Variation of actions in experimentation differed from variation of actions in exploration. During exploration children used a variety of actions on any nearby object and observed the result but the actions appeared isolated. Kate's actions in Vignette 30 illustrate the isolated actions typical of exploration.

In experimentation children varied their actions but they used results of each action to determine the next action. Actions often varied only slightly as children adjusted to try to get a specific outcome. In the next vignette Eva worked on the problem of getting spheres out of ycc1. She first worked with c1 and noticed that when she lifted c1 all the s1 rolled out. Later she picked up ycc1 and inserted two s1. She lifted ycc1 but spheres stayed in. She lifted ycc1 several times. During one lift the following occurred.

> Vignette 31
> Eva, 20 months, Day 11, (0:18) Eva stands holding ycc1 containing two s1. As she lifts ycc1 it falls from her hands and makes a sound. She picks up ycc1 holding it vertically in her left hand and immediately starts striking it on the floor. She stops, holds the cylinder still, looks at the cylinder and the s1 inside and begins striking it on the floor repeatedly. She walks forward, striking as she walks, raising her arm higher each time she strikes. Her eyes are focused on the cylinder and the spheres inside. She stops, strikes the cylinder gently on the floor, looks at it and then releases it.

In this vignette Eva used the same action, striking ycc1 on the floor, but she varied the level of her arm each time. She focused on the spheres inside ycc1, noticing that they remained inside. Each time she struck the floor with ycc1 the spheres popped up inside c1 but did not come out. By varying the level of her arm each time she observed that the higher she raised her arm the more the spheres moved up in the cylinder. She also noticed the difference in sound. Raising her arm higher resulted in a louder sound. This type of variation, a slight gradation of a similar movement based on observations, distinguished Eva's experimentation from exploration.

In addition to varying actions during experimentation, children used their observations to vary the objects in some way. Brad (Vignettes 12 and 13) kept his action the same (pushing each end of an inner cylinder) but varied the cylinders he worked with and the position of the cylinders as he experimented. Jason (Vignettes 16 through 19) also experimented by varying the objects in some way. He tried different spheres in different cylinders as he worked on the problem of matching the sphere to the cylinder based on size. He also experimented by placing cylinders both vertically and horizontally.

As children varied their actions during experimentation they encountered more contradictions to their expectations. Children's response to contradiction during experimentation differed from their response to contradiction encountered during exploration. When children experienced contradiction during exploration they repeated the same action on the same objects. During experimentation children varied their actions or they varied the objects in some way and observed the reaction to determine their next action.

Experimentation did not occur in a smooth linear fashion. Often children reverted to an earlier action that they had already observed to be unsuccessful. Jason, as he worked on fitting spheres in to cylinders based on size, often repeated his attempts to get s2 into c1 as seen in Vignette 17. He determined it did not fit and eliminated c1 from his experimentation during that event. Later that day he tried s2 in c1 again although he had already rejected that combination. He repeated his attempts the next day but this time he did not try to twist or push s2. He just set it near the opening before eliminating c1 or s2. Further attempts at putting s2 into c1 appeared to be a means of checking. Jason would put s2 near the opening of c1 but quickly withdrew his hand with s2. This continued until he eliminated c1 altogether and did not include it in his experimentation. All children who engaged in problem solving exhibited similar reversions to earlier ineffective actions as they experimented. Each time they repeated an ineffective action they more quickly abandoned it for a more effective action.

Solution. Through this error-informed experimentation process children refined their actions, gradually eliminating the unsuccessful actions and reaching a solution. Once children reached this point, they did not revert back to earlier ineffective actions. They acted quickly and confidently in an activity they had previously struggled with during experimentation. They often shared their success by clapping, squealing, repeating the activity successfully or showing others in the room what they had done.

Brad, after working at nesting and revising his goal, sat by Stacy or Jenny and built long tunnels by inserting the end of one cylinder into the end of a wider cylinder. Jason announced, "Great tunnel." Anne filled ycc1 several times and tipped it over to empty it. Lea shouted, "I did it" and then ran to her friend Kim and put a sphere inside a cylinder, opened both hands to cover the opening, and tipped the cylinder up and down keeping the sphere inside. Andy ran to the researcher and showed her how he could tip the cylinder to get the sphere to back and forth the way he wanted. These celebrations marked the solution to the problem they had pursued.

After reaching a solution and celebrating, children did not return to earlier ineffective actions to work on the activity nor did they stop problem solving. They moved on to new problems. Often these new problems came from solutions they had just celebrated. Brad, after making a long tunnel with three cylinders, returned to exploratory actions that included the tunnel. He lifted one cylinder and looked through it, sat on the tunnel, banged the outside, pushed it to make it roll, and inserted spheres that would roll to him. As he rolled the s1 into his three-cylinder tunnel he squealed as it rolled all the way through. When he tried to do the same thing with s2 it stopped when it hit the rim of c1, the third cylinder in the tunnel. This suggested a new problem. He worked at figuring out which spheres would roll through the entire tunnel. To solve this, he had to solve the problem of size of each sphere in relation to the size of each of the three cylinders. He used the same process he had used to solve the problem of nesting.

Summary of Problem-solving Process

Data on time of engagement showed that children engaged with the research materials when those materials were placed in a classroom setting with other toys and objects available. Children played with the materials several times each day over the eleven days of videotaping, providing evidence that the materials held children's interest over time.

Analysis of children's actions provided evidence that the materials offered challenges and suggested problems for the children to solve. Seven of the eight children engaged in problem solving, often working on one problem for several days. When solving problems children exhibited a similar process that included five components:

exploration, noticing a contradiction, repetition, experimentation, and finding a solution. In the section above I presented each component separately and described children's actions that characterized each component.

In reality children did not exhibit the components in separate, isolated steps or phases. Until they reached a solution children moved fluidly between components and often returned to exploration after they had worked on a new action in efforts to solve a problem. Children also worked on more than one problem at a time. While working on filling and emptying cylinders some children also worked on the problem of keeping the sphere inside a cylinder held horizontally in the air and some children worked on the problem of fitting spheres into cylinders. As they moved from problem to problem children demonstrated several different components of the problem-solving process often within one session.

Observations of children's actions during this problem solving process point to children's ability to focus on a problem, ask questions, seek answers, and attend to a task until a solution is found. Children persisted in finding solutions to their own problems and communicated the results of their work through their actions and limited vocalizations. These results support the idea that in a classroom setting when children are given interesting materials that provoke problems children will choose to play with the materials and take on the challenges those materials present.

Summary

The purpose of this study was to observe the actions of 18- through 24-month old children as they engaged in free play with clear cylinders and plastic spheres and to analyze those actions for evidence of construction of knowledge. Piaget's theory of constructivism provided a framework for analyzing the data. The results reported in this chapter indicate that children's actions on the materials became progressively more organized as children engaged with the materials. During exploration children's actions provided insight into their existing schema as they tried to assimilate the new objects and makes sense of what they could do with them. In the process of exploration children encountered contradictions to their expectations when materials did not react in the way children expected. After observing the initial discrepancy, children repeated the original actions and observed the result to make sure that the same thing always happened. At this point of contradiction, or disequilibrium, children responded in one of two ways. Some children walked away and returned to equilibrium by ignoring the discrepancy. Other children identified the discrepancy as a problem to be solved and organized their actions to solve the problem. Once they solved the problem they returned to equilibrium by accommodating their existing schema to take in the new information.

Children identified three types of problems encountered in their work with the research materials: nesting, containment, and movement of spheres inside cylinders. Children persevered in their problem solving, often working on one problem for several days. Their actions organized around a common set of components in the problem solving process: exploration, noticing a contradiction, repetition, experimentation, and finding a solution. These components did not occur in a smooth sequence. Children moved back and forth between the five components, often repeating ineffective actions, until they reached the final solution. Once a solution was identified, children did not return to ineffective actions but instead moved on to new problems or to new challenges suggested by the solution to the problem.

Using constructivism as a lens for studying children's actions, the results of this study suggest that children did construct knowledge when provided with interesting materials and allowed to play freely with those materials in a classroom setting. In the next chapter I discuss the implications of these findings in relation to the development of toddler curriculum and I present suggestions for future research in this area.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

In this chapter I discuss how the findings from this study contribute to the literature on infant and toddler curriculum. I first summarize the study to provide a context for the chapter. I then present the findings based on the three research questions. Based on these findings I present implications for classroom practice, teacher education and future research. I conclude the chapter with a brief summary of the findings.

Summary of Study

This study originated from my own struggle to find a high-quality curriculum for toddlers. Commercially available curricula did not meet my three criteria of having a strong theoretical base, being based on what is known about how young children learn, and being practical for the typical child care center classroom. My goal was to develop a high-quality toddler curriculum that met those criteria. Using constructivism as a theoretical base, I designed this study to explore one possible activity for such a curriculum. The purpose of this study was to observe 18- through 24-month-old children for evidence of construction of knowledge as they engaged in free play with clear cylinders and plastic spheres in a classroom setting.

I selected the materials (clear cylinders and plastic spheres) based on my earlier experiences with older children's (ages 3 through 8 years old) interest in the movement of marbles on wooden ramps. The cylinders and plastic spheres provided an age appropriate alternative the ramps. Results from a pilot study with the materials indicated that young children (ages 16 months through 24 months) were interested in the materials and that the materials provided the opportunity for children to construct knowledge.

I conducted the study in one classroom that is a part of a private child care center located in a small rural town in the Midwest. Eight children ages 18- through 24 months participated in the study. I videotaped the children during two of their daily activity times over the course of 14 days. During activity time the research materials were available and children were invited to play with them but were free to choose any of the materials in the classroom. Videotapes were reviewed and children's actions were analyzed for evidence of construction of knowledge. The findings based on this analysis are discussed in the next section.

Findings

Three research questions, drawn from the theory of constructivism, guided this study. In this section I present the findings organized by these three questions.

1. What actions can be observed as children 18- through 24-months old engage with the research materials (clear cylinders and plastic spheres)?
2. What types of problems do the children set for themselves?
3. How do children go about solving those problems?

Children's Actions

The results of this study showed a progression in children's actions similar to the findings in earlier studies of children's actions with objects (Langer, 1986; Stambak et al., 1989). Children's engagement with the research materials started with a period of exploration during which their actions became progressively refined. Early exploration consisted of applying a variety of actions to any research objects that happened to be nearby. This early exploration soon led to a more focused phase and children used many actions on one class of objects, either the cylinders or the spheres. As children observed their actions and the reaction of the objects, attention shifted from the object to the action. Children then explored by distributing one action over a variety of objects (objects from both classes of materials or different sized objects within one class of materials). Langer (1986) and Stambak et al., (1989) described a similar exploratory phase in the actions of the children they observed. During this phase children learn about the properties of the objects and what can be done with the objects.

These actions were similar to those Piaget (1936/1963) described during Stage 4 when children applied familiar schema to unfamiliar objects. In Stage 4 he noted that children applied their actions to learn about the properties of the new objects and what could be done with the objects. Although Piaget identified this stage as occurring at a much younger age than the subjects in the current study, he also stated that at any one stage there are vestiges of earlier stages. Because the research materials were different from the materials normally available in the classroom, children in the study may have returned to behaviors typical of earlier stages and engaged in exploratory actions to learn about the objects. This exploration often did not last long, but did occur throughout the study as children encountered new challenges with the materials.

Problems Children Identified

In the course of exploration, children identified problems when they encountered a discrepancy between their expectations and the reality of how the materials reacted. At the point of this discrepancy, some children chose to ignore the contradiction and moved on to other actions. Other children focused on the contradiction and set a goal of figuring out how to get the materials to respond according to expectations. This goal setting was marked by a noticeable pause in action at the point of the contradicting.

Children in this study identified three main types of problems: nesting the cylinders, containment of spheres in cylinders (fitting spheres into the cylinders, filling and emptying), and movement of spheres inside cylinders (keeping spheres inside the cylinder, controlling the direction of the spheres movement). The first two types of problems are consistent with those found by Langer (1986) and Stambak et al. (1989). Children in both studies pursued problems of nesting and containment. The researchers identified these as spatial and temporal problems related to Piaget's (1937/1971) categories of reality that children construct as they elaborate their universe. The last type of problem in this current study, movement of spheres inside cylinders, is similar to the problems Langer identified in his study as causal problems, another category of reality (Piaget, 1937/1971). These results indicate that children, when provided with interesting objects and given the opportunity to guide their actions, identify problems to solve. These problems relate to Piaget's categories of reality that children construct as they elaborate their universe.

Problem-solving Process

In pursuing the problems they identified, children in the current study engaged in a problem-solving process that included five components: exploration, contradiction, repetition, experimentation, and solution. Children engaged in this problem-solving process across all types of problems. Piaget's (1975/1985) theory of equilibration explains the process observed in this study. Children experience contradictions as they act on the objects in their world. This contradiction causes disequilibrium. According to Piaget, children can ignore the contradiction and return to equilibrium or they can revise their actions, and their schema, and accommodate to the contradiction. This revision of action started with children first repeating their original actions to confirm that they would get the same result each time. When this was confirmed, children varied their actions in a form of experimentation. During experimentation children, often by chance, acted on the materials in a way that led to success: the materials reacted in the way children wanted. They had reached their goal and solved the problem. In this study, once children found a solution, they did not return to earlier ineffective strategies. Piaget (1975/1985) called this type of problem solving reequilibration, indicating that the child was again in equilibrium but now at a higher level. This higher level of equilibrium indicates that learning occurred.

As children engaged in this problem-solving process they did not always demonstrate all five components for each problem they chose to pursue nor did they demonstrate these components in a set sequence. Some children abandoned the problem after repetition when they realized that the results of their original actions were the same. Others experimented but stopped before arriving at a solution. In the process of working on the problem, children moved back and forth between the components. They often reached experimentation, tried varying their actions, and then returned to earlier ineffective actions. This seemed to be a form of repetition as if they needed to confirm, again, that their original actions did not work. Some children, after experimenting for a while, returned to exploration and tried a variety of actions on any materials in the area. This appeared to be a type of functional play that allowed children a time to step back from the challenge of experimenting.

The findings in this study are consistent with those found in prior studies (Chen & Siegler, 2000; Kamii et al., 2007; McCarty et al., 1999; Miyakawa et al., 2005). Results of these earlier studies found that children's problem solving process involved a series of components or stages, each stage or component progressively more advanced than the earlier stage. However, children often reverted to earlier stages or ineffective strategies until they reached a solution. Once children reached a solution and repeated their actions successfully, they did not return to ineffective strategies.

Another finding in this study that is consistent with findings from earlier studies (Sinclair et al., 1989; Stambak et al., 1989) is that children were persistent in pursuing solutions to the problems they identified. Children engaged in problem solving for long periods of time within each session (sometimes as long as 20 minutes) and over the span of several days. Within an activity period, children often worked on a problem, left it for a few minutes, then returned and continued with the problem solving. When children did not solve a problem by the end of the activity time, many of them immediately returned to the problem at the beginning of the next day's session.

Implications

The findings discussed in the section above are based on the results of observations of eight children in a rural Midwest child care center. The findings may not be representative of all toddlers but they do provide guidance for the following implications related to toddler curriculum. These implications are drawn from the results of this study, the current literature on children's actions with objects, and my experiences as a teacher, consultant, child care center director and teacher educator. I first present implications for teachers, both in-service and pre-service teachers. I then discuss implication for teacher educators.

Implications for Teachers

The toddlers in this study persisted in solving problems they identified. They worked for long periods of time within an activity period often returning to the same problem over the span of several days. One implication of this for teachers is that toddlers need to be supported in this type of problem solving by having open-ended materials available in the classroom during activity or free choice time. These materials should be left out, even though the clutter in the room maybe difficult to tolerate for some staff, administrators, or parents. Toddlers may drop the materials and move on to other activities, but will return to the materials if they are readily available. These materials must also be available over the course of several days or even weeks to give toddlers the opportunity to work on problems and continue to construct new knowledge.

A second implication is that teachers need to allow children to play freely with the materials. Well-meaning adults often lead the child and direct the activity. For example, teachers ask the child how many spheres are in the cylinder or ask about the color of the spheres. Children comply with the adult's request but then walk away and stop playing with the materials. The adults in the current study did not tell children what to do with the materials. The materials were set out in the room and the children were invited to see what they could do with them. Children were free to play with the materials as they wanted and adults observed, responded to children's request for help, or played alongside the child letting the child determine the action. This type of child-initiated experience provided the opportunity for children to explore, experience disequilibrium, and engage in problem solving.

A third implication for teachers relates to the problem-solving process that toddlers engage in when acting on open-ended materials. Teachers need to know the components involved in the problem-solving process and understand that children move back and forth between the components. Understanding this process forms a foundation for observation and assessment of toddlers. Observing toddlers' actions during problem solving provides insight into existing schema and knowledge (actions observed during exploration) and allows the teacher to assess the construction of new action schema and knowledge as the toddlers experience disequilibrium and reequilibration. This construction of new schema is not limited to the situation in which the toddler demonstrated the problem solving. Toddlers map their problem-solving strategies to new situations (Chen & Siegler, 2000). Assessing for problem solving components cuts across all domains and curricular areas providing data about the toddler as a learner, not just about learning of specific skills. Observation and assessment should be an ongoing process, not just a measure of a single point in time. Toddlers move back and forth between the components of problem solving. Observing at one point in time may reflect the toddler's temporary return to ineffective strategies in problem solving and not give a true picture of the toddler's knowledge and ability.

Implications for Teacher Educators

The implications discussed in the previous section address the teachers, both in-service and pre-service. In order for these implications to become part of classroom practice, another group of educators must also be addressed. This is the group of teacher educators who work with the pre-service and in-service teachers. In this section I discuss two implications for teacher educators.

Teacher educators will need professional development on toddlers' ability to engage in problem solving. I suggest this because many teacher educators underestimate what toddlers are capable of doing. The use of developmental checklists and early learning standards as goals often limit what is expected of toddlers. The findings from this study and the earlier studies (Langer, 1986; Rayna et al., 1989; Stambak et al., 1989) suggest that children are not only tenacious in their problem solving but they demonstrate a practical, or motor understanding of movement of objects (physics), classification, seriation, and number. Understanding what toddlers are capable of doing when provided with appropriate materials and opportunity to play should lead teacher educators to change how courses or workshops on toddler curriculum are presented to pre-service and in-service teachers.

A second implication is that teacher educators must structure field experiences in toddler classrooms to include the opportunity for students to observe and present the child-initiated activities that lead to problem solving. This would require careful selection of sites for field placements because not all teachers implement a curriculum that provides toddlers the chance to engage in child-initiated problem solving (Hegland et al., 2003; Leavitt, 1994). This type of field experience would also require the teacher educator to scaffold the students' understanding of this type of problem-solving activity. Most students, or pre-service teachers, have not experienced this type of curriculum and will need the opportunity to engage in their own form of problem solving and reflection in an environment that is safe and supportive.

Suggestions for Future Research

In this study I observed eight toddlers (18 through 24 months old) in a classroom setting as they engaged in child-initiated play with the research materials. The findings in the study are consistent with the literature and extend those findings to a classroom setting. The findings also suggest several directions for future research.

The sample used in this study represents a convenience sample of rural, typically-developing, middle-class children. Future research needs to include a wider number of subjects in the same age group (18 through 24 months old) and a wider diversity of population. This diversity should include a variety of settings (urban, rural, private child care, public day care, etc.), socio-economic class, abilities, and ethnicity.

Studies need to be designed to include other open-ended materials, especially materials that offer the opportunity for children to engage in problem solving related to causality. Much of the research has looked at spatial problem solving (Kamii et al., 2004; Langer, 1986; Miyakawa et al., 2005) but little has been done related to how children learn about causality. Studies involving materials that allow children to explore movement of objects and energy could lead to findings related to causality.

The focus of the current study was on how individual children acted on the objects in a classroom setting. Future research should look at how the peers in the classroom influence the actions of the individual. The findings of the current study indicate that children will choose to engage with open-ended materials and will stay engaged for long periods of time. The findings did not address how peers supported or disrupted that engagement. This type of future research may involve looking at data with a different theoretical framework; one that provides a lens for social interactions.

In addition to looking at peer influence future research should look at the teacher-child interactions. These interactions were not analyze in the current study, but field notes indicate that some interactions resulted in children stopping their problem solving while other interactions supported further problem solving.

Future research should also study the effects of the different socio-moral classroom atmospheres on toddlers' problem solving. Research with older children suggests that a classroom based on mutual respect is best for supporting children's construction of knowledge (DeVries & Zan, 1994). Do the same results hold true for toddler classrooms where teachers often have to be somewhat more coercive because of the age of the children and the need for safety?

A final suggestion for future research is to extend to younger ages. Studies using cylinders and spheres with younger children who are able to manipulate the materials could analyze actions to see if there are age differences in the type of actions or in the problem-solving process.

The current study is a starting point. Building on this, future research in toddler classrooms could provide data to guide the development of a toddler curriculum that meets the three criteria of having a strong theoretical base, aligns with what is known about toddlers and how they learn, and is practical in the toddler classroom. Such a curriculum would be a major step in addressing the need for high-quality learning experiences that are currently missing in most toddler classrooms. With continued research, evolving from the toddler studies, this same high quality could extend to infant classrooms.

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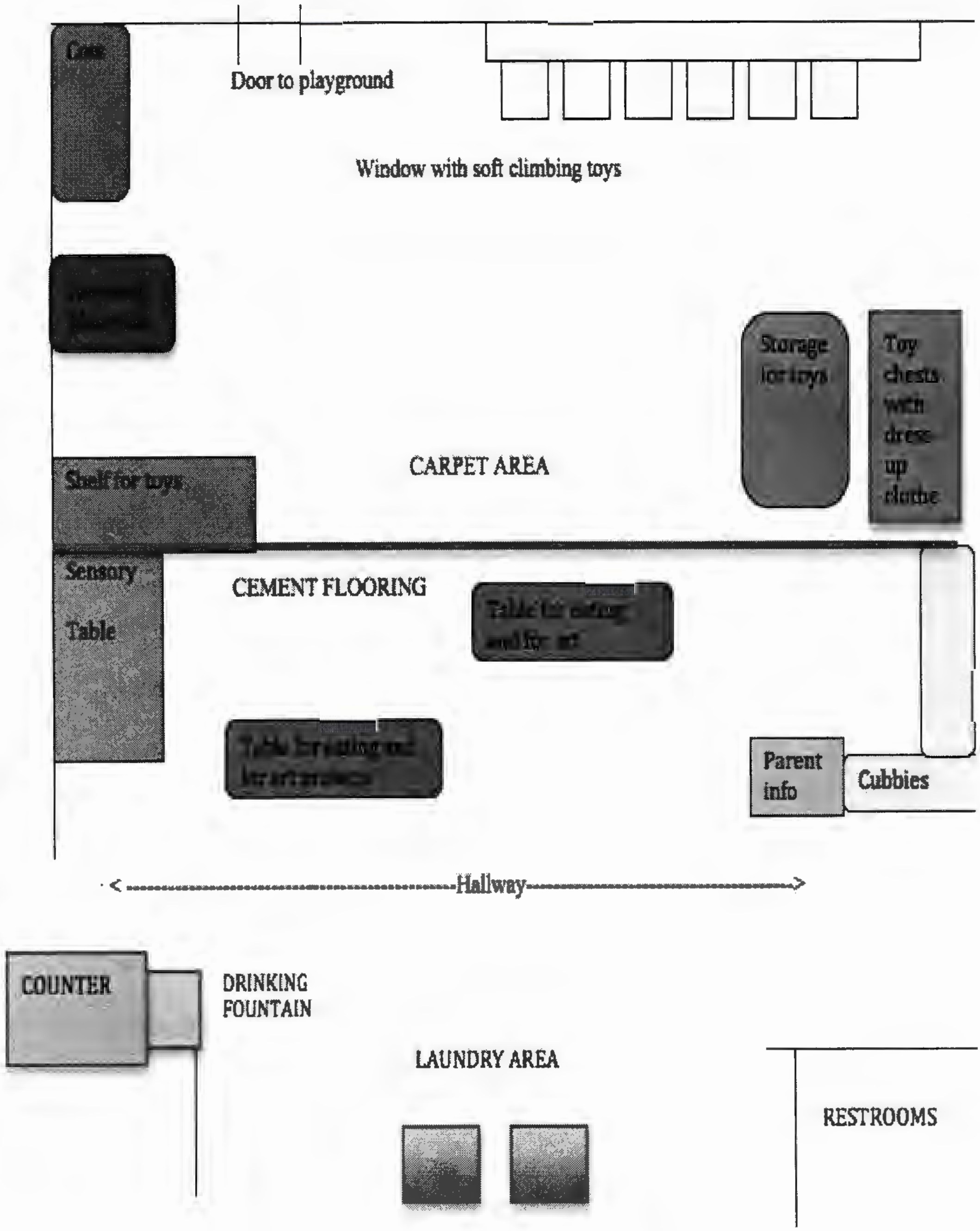
APPENDIX A

BABIES 2 CLASSROOM FLOOR PLAN



APPENDIX B:

BABIES 2 DAILY SCHEDULE

6:30 a.m.	Jenny and Stacy open Children begin arriving and are allowed to rest on cots or have books read to them
7:30 a.m.	Breakfast in the room
8:00 a.m.	Free choice/play time
9:00 a.m.	Snack in the room
9:30 a.m.	Activity time Jenny or Stacy have a small group activity while the other children have free choice. The group is rotated and children have a choice of going to the table or having free choice time. Story time
10:15	Outdoor play time, weather permitting (Bad weather—group game/activity)
11:00	Story time, dramatic play, group activity
11:30	Lunch in the room
12:15	Get cots out and children transition from lunch to nap
12:30	Nap time
2:00	Afternoon staff arrive
2:45	Snack time in the room
3:15	Story time and group time
3:30	Children start departing/free choice time

By 5:30 all children have departed.

APPENDIX C

CODING DIRECTIONS FOR SEQUENCES OF ENGAGEMENT

Thank you for agreeing to work on this! The purpose of this part of the data analysis is to determine what constitutes engagement with the materials. The best way to do this is to watch for "events". An event is a period of time that the child is acting on/with the materials. An event starts when the child first starts acting on/with any of the materials and ends when the child is no longer acting on/with the materials. Within an event a child may act on/with several different materials, but as long as they are engaged, it counts as one event.

I am giving each of you raw footage clips to code. We will all code the same clips and I will compare the results. From that I will determine if I have defined "engagement event" so clearly that we can agree on how many events took place for each child on a clip, how long those events lasted, and start and ending time for each event. You will be watching the clips multiple times (once for each child we are studying). Keep track of your hours on the form I am providing.

Directions:
An event starts when a child performs an action with the tubes, the balls, or the tubes and balls together. Examples of actions: hitting balls together, twirling balls in hands, hitting tubes on the floor, putting balls into the tubes, etc. (See attached for sample actions)

This action can also be the act of observing IF the child is looking at another child(ren) engaged with the tubes, balls, or tubes and balls together.

The event ends when

- The child is not in view (may have walked off camera or the camera moved),
- The child stops acting on/with the research materials (may still hold the materials but is not performing any actions or watching others),
- The child drops the materials and walks away, or
- The child is interrupted by another child or adult in the room and stops engaging with the materials.

At times you may see only part of the child (the camera angle only catches part of the child). If it is evident from the part you see that the child is still acting on/with the materials, count that as part of the event. If you cannot tell because not enough can be seen, do not count it even if you assume that the action is continuing.

Do not count it if the child is holding the research object(s) but is not performing any action on that object(s) or watching others engaged with the objects.

Engagement may involve the child changing materials during the time (starting by putting balls into the tubes but then walking away with only the balls and acting on the balls only and then returning to balls and tubes). Do not stop timing when the child changes materials unless the child stops acting on the materials.

When you watch the video, observe only one child at a time. Try not to react to, or be distracted by, what the child is doing or saying or by other activity on the video. Just focus on whether or not the child is action on/with the materials. Do not get pulled away by thinking about what is going on or analyzing what is happening. You may want to turn the volume down so you are not distracted by the actions/sounds of other children in the room.

Using the recording table:
Use one column per child. As a child starts an event, write the start time under the Start column. Also, in the Event column, write a brief word or two to describe the beginning of the event. For example, "hitting balls together". Continue timing the event until the child stops acting on/with any of the research materials. A child may start with one action on some of the materials (hitting balls together) and then move into acting on/with other materials. An event ends only when the child stops acting on/with any of the materials in any way or when the child is out of the camera's view. Do not change the label that you listed at the start of the event.

When the event ends, record the time in the Stop column. If the event ended because the camera moved and the child was no longer in view or the child walked out of view of the camera, put a checkmark next to the time the event ended: 00:23:40 √

For the next event, move to the next line of the chart. Events may happen quickly. Often there are only a few seconds between events. I have found it useful to stop the video when I see the start of an event, record the label for the event and the start time, and then restart the video. I stop it again at the end so I can record the time.

If a child demonstrates more engagement events than what you have room for on one page, continue onto a second page using the same column as on the first page (i.e. first column, middle column or last column).
Actions a child may perform: (This is not an exhaustive list. You may observe other actions)

With balls:
Hitting balls together
Mouthing
Throwing

Kicking
Rolling
Squeezing
Putting into containers (of any kind---toy trucks, drawers, other toys)
Carrying
Spinning

With tubes:
Rolling
Inserting one into another
Blowing through
Talking into
Looking through the end
Looking through sideways
Stacking
Lining up end to end
Swinging
Putting arm into
Hitting on floor
Inserting objects into tube

With tubes and balls:
Reaching into tube to get ball or other object
Putting ball into a tube
Putting ball on tube opening
Filling tube with balls
Rolling ball at tube opening
Rolling ball through more than one tube

APPENDIX D

CODING DIRECTIONS FOR INDIVIDUAL ACTIONS

Guidelines:

- You will be coding only the actions the target child performs on the research materials (cylinders and spheres).

- Code only the child's actions with the research materials, not with other materials in the classroom. Actions, with coding abbreviations, are listed below.

- Code all actions in sequence as they happen. If the child performs an action more than once in sequence, code it each time.

  Example: The child has been holding 2 spheres. He/she then inserts one s sphere into a cylinder, and quickly inserts the next sphere into the cylinder. You would code both actions of inserting the sphere into the cylinder.

- Do not code what the adults and other children are doing, even if the target child is interacting with them.

- Do not code an action if you do not see the entire action. At times a child's back may be to the camera, other people moving in front of the camera block your view of the child's actions, or the child moves out of camera range.

CODES

Cylinders

wc Cylinder with white rim

bc Cylinder with blue rim

rc Cylinder with red rim

ycc Cylinder with one open end and one yellow removable cap

Spheres

ss Small sphere

ms Medium sphere

ls Large sphere

Positions for cylinders

V Vertical

H Horizontal

I Inclined

- IR Slopes to the right as the viewer looks at it
- IL Slopes to the left at the viewer looks at it
- IF Slopes so lower end is facing viewer
- IB Slopes so lower end is away from viewer

Actions

Hd Holds: Keeps object in grasp; supports object so it won't fall;
Keeps cylinder or sphere in hand
Keeps cylinder or sphere in arms
Keeps cylinder or sphere cradled between arms and body
Places cylinder or sphere on body part (mouth, head, neck, shoulder, etc.)
Keeps hand on cylinder or sphere placed somewhere other than on body (floor, table, or other surface)

In Inserts: Put an object, arm, or hand into another object
Puts a sphere into a cylinder but does not release it
Puts hand/arm into cylinder
Puts one cylinder into another cylinder

L Lifts: Uses hand(s) to move object from a lower position to a higher position
Raises sphere to a higher position/place
Raises cylinder to a higher position; cylinder maintains same relative incline or position

Lk Looks: Eyes are focused for at least 2 seconds on an object or on actions of other people engaged with the research materials; Head movement/eyes follow movement of an object
Looking at materials and/or the actions of others engaged with the research materials
Tracks the movement of a research object

P Pushes: Hand or foot makes contact with an object causing the object to move
Uses hand to move a cylinder or sphere
Uses foot to move cylinder or sphere
Uses on object to move another object while maintaining contact between the two objects

Rel Releases: Lets go of an object by withdrawing support of hand or other body part that had been holding the object
Opens hand and lets go of object
Drops sphere into a vertical cylinder
Removes hand that has been supporting an object
Gives the cylinder or sphere to another person
Drops object that has been held

Sk Shakes: Moves object up and down or side to side with short, quick movements
Moves the cylinders or spheres quickly up and down or side to side
Swinging cylinders or spheres

Str Strikes Holds an object in hands and bangs or hits object against another object, body part, or on a surface (floor, table, etc.)
Hitting two spheres together
Hitting two cylinders together
Hitting the cylinder with the sphere
Hitting the sphere or cylinder on the shelf, table, or other furniture
Hitting or tapping any part of an object on the floor.
Hitting or tapping cylinder or sphere on any body part

Th Throws: Propel from the hand with a sudden forward, downward or upward motion
Throw sphere away from body (forward, up or down)
Throw cylinder away from body

Tp Tips: Raises or lowers one end of a cylinder at a time

Moving cylinder so one end is elevated
Moving cylinder so ends are flipped in opposite direction
Moving cylinder ends up and down so ends alternate being elevated
Raising or lowering one end of the cylinder to change the incline;

Unc Uncodable: The action cannot clearly be seen by the coder OR the action is not included in the codable actions.
Child's back is to the camera
Another person blocks the view
Child is temporarily out of camera range
Camera angle makes it difficult to see the child's action

Directions:

1. You will be doing a modified time sampling. The coding sheet is set up for 10 second intervals.

2. Stop the DVD every 10 seconds and code in the appropriate box the action the child is performing at that time. Restart the video and continue coding until the next 10 second interval.

3. When coding, write the action, colon, and the object acted on. Start a new line for each new action:

   P:ss (Pushes small sphere)
   Th: ss (Throws small sphere)
   Hd: ms (Holds medium sphere)

4. Coding contents and positions:

   a. If a cylinder is the object acted on, you will write the code for the cylinder, a dash and then the position.

   Hd: bc-V (Holds: blue cylinder vertical)

   b. If the cylinder is at a slant, you will code the direction of the slant. This will be coded from the viewer's point of view not the child's. You will indicate the direction by stating the lower end of the cylinder (where the sphere would roll out)

   Tp: wc-IR (Tips: white cylinder so it slants to the right)

   c. When the child Inserts an object into another object, indicate that by using the word "into" after the object being inserted. :

   In:ss into RC (Inserts small sphere into red cylinder)

d. If the cylinder contains spheres or other cylinders, that will be coded as follows. Write the action, colon, object, back slash and the objects in the cylinder, dash, position

Hd: rc/3s-H (Holds: red cylinder with 3 spheres in a horizontal position)

5. If, you cannot see the action (child's back is to the camera, another child is in the way, etc.), mark it as uncodable.

7. If two actions occur at the same time, code one action and then leave 5 spaces and code concurring action on the same line:
   L; wc-IL   In: ss into wc-IL

8. You may add words to clarify. For example , for Strikes note what object was hit against
   Str:ss on wc
   Str:wc/s on floor