2003

An investigation of the concept of balance in children ages 6–9: Logic and protologic identifiable in making mobiles

Seon Chun
University of Northern Iowa

AN INVESTIGATION OF THE CONCEPT OF BALANCE IN CHILDREN AGES 6-9:

LOGIC AND PROTOLOGIC IDENTIFIABLE IN MAKING MOBILES

A Dissertation

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Doctor of Education

Approved:

Rheta DeVries

Dr. Rheta DeVries, Chair

Gregory P. Stefanich

Dr. Gregory Stefanich, Committee Member

Rebecca Edmiaston

Dr. Rebecca Edmiaston, Committee Member

Carolyn Hildebrandt

Dr. Carolyn Hildebrandt, Committee Member

Dr. Betty Zan, Committee Member

Seon Chun

University of Northern Iowa

June 2003

UMI Number: 3094679

This dissertation

is dedicated to

all early childhood educators

who have passion for children

ACKNOWLEDGEMENTS

When I came to America, I received a small wooden display saying "Count your blessings" as a gift. I did not know what it really meant at that moment but during my life in America, so many people and incidents have often made me think of the phrase.

I am blessed to have a wonderful advisor, Dr. Rheta DeVries. She took multiple roles – advisor, mentor, teacher, editor, therapist, role-model of a true researcher, and English teacher – and always made time for me. It was a privilege to study under her. Thank you for accepting me as your student and sharing your expertise.

I am blessed to have a great dissertation committee - Dr. Gregory Stefanich, who kept reminding me that I am an educator; Dr. Rebecca Edmiaston, who did not forget to give me encouragement; Dr. Carolyn Hildebrandt, who shared her sharp insight about Piaget's theory; and Dr. Betty Zan, who willingly spent extra time to read the paper. No one could have had as wonderful a committee than I had. Thank you all for your support and guidance.

I am blessed to have a caring family and an endless list of friends. Most of all, I had my dear sister Weon, Dr. Kyung-Woo Lee, Judy Walsten, Dr. Linda Fitzgerald and Gail Hadley who persistently showed their love and prayed for me. Thank you to all other friends who were there for me.

I am blessed to have had supportive teachers and children who participated in this study. Without their help, this work could not have been done. Thank you for your enthusiasm.

Above all, I would like to thank God for allowing me all the blessings and being with me all the time.

TABLE OF CONTENTS

LIST OF TABLES

PAGE

LIST OF FIGURES

PAGE

AN INVESTIGATION OF THE CONCEPT OF BALANCE IN CHILDREN AGES 6-9:

LOGIC AND PROTOLOGIC IDENTIFIABLE IN MAKING MOBILES

An Abstract of a Dissertation

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Doctor of Education

Approved:

Rheta DeVries

Dr. Rheta DeVries, Chair

John W. Somervill

Dr. John W. Somervill
Dean of the Graduate College

Seon Chun

University of Northern Iowa

June 2003

ABSTRACT

This research was conducted to explore children's construction of protologic (foreshadowing of operations) in the context of experience with balance mobiles in a constructivist setting and to explore the usefulness of making mobiles in promoting children's development of the concept of balance.

The statement of the problem is (a) Can constructivist principles of cognitive development be used to understand children's progress in the course of educational activities involving balance? If so, how? What does the progressive construction of notions about balance look like in children's behaviors?; and (b) Does children's understanding of balance improve after experimenting with making mobiles?

The participants in this study were 10 first grade children and 12 third grade children from a public elementary laboratory school located in Cedar Falls, Iowa. The pretest and posttest used a primary balance scale and a beam balance. Making mobiles was used as the intervention. The research of Piaget, Kamii, and Parrat-Dayan (1974/1980) and Inhelder and Piaget (1955/1958) were used as the basic framework for the pretest and posttest.

All interviews and the dialogues during the tests and making mobiles were video-recorded and transcribed for analysis. Evidence of compensation and reversibility, coherence, coordination, and contradiction were assessed in children's reasoning during intervention activities using operational definitions developed by Jean Piaget.

Before the intervention, all children had an idea that weight impacts balance, 13 out of 22 children had the idea that distance from the fulcrum impacts balance, and 6 out

of 22 children considered weight and distance at the same time. After the intervention, all children maintained the idea that weight is related to balance but more children, 16 out of 22, had the idea that distance is related to balance; and 6 children among the 16 children considered weight and distance at the same time. Through the three intervention activities, more children showed consistently their belief that the higher side needs more weight to making bars balance and the understanding of the idea that distance is related to make bars balance. Nine children experienced a "Eureka" moment, that is, they had a sudden insight about how to make bars of mobile balance or connected their prior experience to the current situation.

CHAPTER I

INTRODUCTION

The purposes of this study are to explore (a) children's construction of protologic (foreshadowing of operations) in the context of experience with making balanced mobiles and (b) the usefulness of making mobiles in promoting children's development of the concept of balance.

Protologic refers to the continuity of logic between the sensory-motor period and the logic of concrete operations. In their book, Sinclair, Stambak, Lezine, Rayna, and Verba (1989) stated that protologic "links between concrete logic, intuitive logic, and sensory otor intelligence" (p. 7) and it precedes concrete logic. Sinclair et al. used the word, protologic, in many different ways such as foreshadowing (p. 7), unidirectional logic (p. 7), prelogical behaviors (p. 19), prefiguring (p. 26), presage (p. 41), rudimentary action (p. 58), and precausality (p. 179).

Many science educators have suggested, following Piaget, that if teachers want children to understand science better and develop their intelligence, they should include many classroom activities in which children can manipulate and experiment with objects (Chaillé & Britain, 1997; Duckworth, 1995; Juraschek & Grady, 1981; Kamii & DeVries, 1978/1993; Lind, 1998). According to Piaget (1929/1971), cognitive development progresses with gradual interiorization of action, making possible thought without overt action. Because thought processes of preschool children are closely linked to physical action, activities to promote the development of thought, such as concepts of physics, must appeal to children's interest in figuring out how to do something in physically

(DeVries & Kohlberg, 1990; Kamii & DeVries, 1978/1993). According to DeVries, Zan, Hildebrandt, Edmiaston, and Sales (2002), children in constructivist classrooms explore physical-knowledge through art activities as well as physical-knowledge activities. Making mobiles is a physical-knowledge activity that meets the criteria for good physical-knowledge activities, established by Kamii and DeVries (1978/1993). In addition, making mobiles provides an interesting opportunity to combine artwork with science (Gega & Peters, 1998). However, although many science concepts are involved in making mobiles, the activity is usually conducted as part of the art curriculum, without adequate recognition of the science concepts.

A mobile is a combination of suspended bars with two-dimensional or three-dimensional attached hanging objects. When children make mobiles, they need to think carefully about relationships among variables such as size, shape and mass of figures, and the best placement to hang figures on bars to make the bars level. Making mobiles can promote development of fine motor skills and cooperation (Robinson, 1982).

As the review of literature shows, making mobiles has not been studied systematically in relation to the development of children's conceptual understanding. This research contributes to an understanding of how teachers can facilitate children's acquisition of the concept of balance and foster the development of intelligence.

Statement of Problem

1. How can constructivist principles of cognitive development be used to understand children's progress in the course of educational activities involving balance?

If so, how? What does the progressive construction of notions about balance look like in children's behaviors?

2. Does children's understanding of balance improve after experimenting with making mobiles?

Limitation

This research is limited by the fact that the small samples of first- and third-grade children from a laboratory school limit generalization of findings of this study.

CHAPTER II

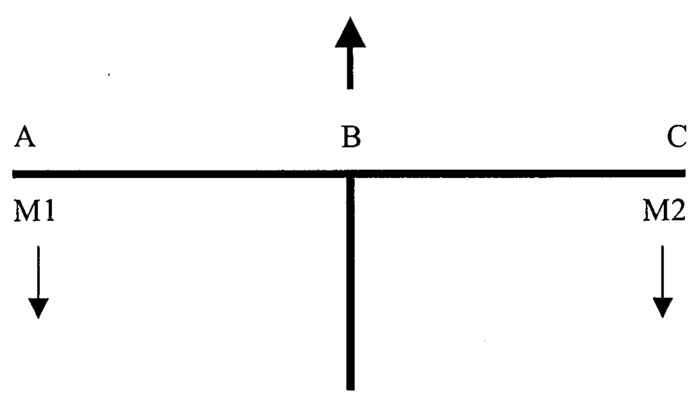
REVIEW OF LITERATURE

In considering the literature relevant to this study of making mobiles in fostering children's conceptions of balance, it is important to call attention to the scientific explanation of balance, basic research on children's conceptions of balance, applied research in classrooms, and existing curricula relating to balance and mobiles. These topics are discussed below.

The Scientific Explanation of Balance Phenomena

A primary balance (see Figure 1) is a bar acted on by forces in such a way as to make it rotate about its fulcrum (B) (Nelson & Winans, 1952).

Figure 1. The mechanics of mass and distance in a primary balance.



AC is a lever with the fulcrum at B and the mass acting at A and C. B is the center, and A and C are the ends of the bar equidistant from the fulcrum. Two pans are attached to A and C. When an object (M1) is placed in pan A, M1 will force down A, raising the lever at its lighter end C and will rotate C. If the distance from the fulcrum is not equal, the mass M1 can be moved back and forth between A and B according to the mass of the object M2 to maintain balance. The quantitative rule coordinating mass (M1 and M2) and distances is:

$$AB \times M1 = BC \times M2$$

When B is the center of the bar, distance AB equals distance BC. If the bar is balanced, M1 equals M2.

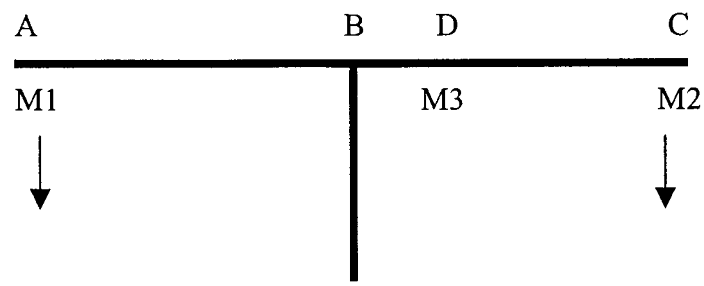
When B is the center of the bar, as it is mentioned above, we can ignore the mass of the bar itself. In this case, three forces act on the bar: two downward forces (the mass of M1 and M2) and one upward force (the support force of the central pivot, B) (Bloomfield, 2001). The most common force acting upon an object is its mass (White, Manning, & Weber, 1955). There exists a point such that the entire mass may be considered as concentrated at that point. The point is called the center of gravity, the point at which all the mass seems to be centered. The mass of the system is evenly distributed around the point.

Extending the discussion about Figure 1, in making mobiles, children might use objects with different mass. If M1 < M2, another object (M3) can be added (see Figure 2). The quantitative rule coordinating mass (M1, M2, and M3) and distances is:

$$AB \times M1 = BC \times M2 + BD \times M3$$

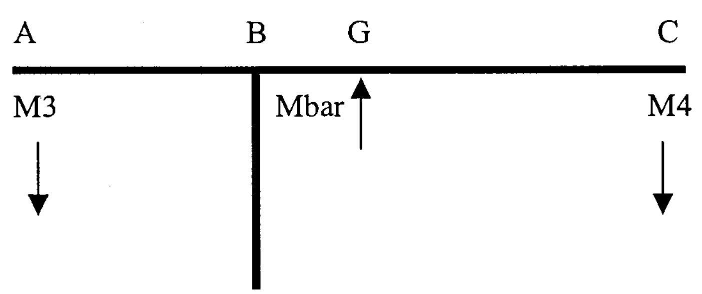
If the sum of the products of mass and distance are equal on each arm of the scale, the scale will be balanced.

Figure 2. The mechanics of mass and distance on an equal arm balance.



While making mobiles, children face cases in which the fulcrum (B) and the center of gravity (G) of the bar are not in the same location. Actions children can take to make the bar balance are related to minimizing the distance between the fulcrum and the center of gravity so that they both finally become in same location (see Figure 3).

Figure 3. The mechanics of forces on an unequal arm balance.



To make that happen, children can use just two objects, M3 and M4, where M3 is heavier than M4 because the mass of bar (Mbar) and distance between fulcrum (B) and the center of gravity of the bar (Gbar) need to be counted. The quantitative rule coordinating mass (M3 and M4) and distances is:

$$AB \times M3 = BGbar \times Mbar + BC \times M4$$

Once the bar is balanced, the fulcrum B becomes the center of gravity of the system.

When a bar balances, mass produces equal but oppositely directed torques about the pivot. Torque can be defined as moment of force; product of a force and a distance. Its unit is a force unit times a distance unit. In other words, as stated by Shultz, Mareschal, and Schmidt (1994), "the torque on each side of the fulcrum is the product of mass and distance for that side" (p. 59). The torque equation is:

$$\sum_T = ML \text{ (M = Mass; L = Distance)}$$

One science curriculum, Full Option Science System (1995), considers balance as an everyday word used to describe a state of equilibrium. Its writers believe that first and second graders know when something is in balance, because it does not fall over. A physicist would say that a state of equilibrium is reached when both the net force and the net torque acting on a body or system are zero. If there is a strong force pushing one way that is balanced by an equally strong force pushing in the opposite direction and also a torque in one direction and an equal torque in the other direction, the net force and net torque are zero, and a state of equilibrium is achieved. If a force is applied to a stable or balanced body or system, the net imbalance in force might cause the body to change position. If the system recovers and returns to its starting position, the system is stable. Mobiles always return to their balanced positions.

Bloomfield's (2001) explanation of how a lever works exemplifies the seesaw. A seesaw works best when two children weigh the same or similarly because riders match evenly. The even match makes the two arms of the beam balance each other, and the balance makes riders rock back and forth easily. In the case when a child is not heavy enough to raise torque, the seesaw does not make a seesaw movement. In this case, another light child could get on in order to balance the one heavy child or the heavy child could move closer to the seesaw's pivot point. Young children learn to do this long before they understand the technicalities of torque, force, and balance (Bloomfield).

Balance Studies of Piaget and His Colleagues

Inhelder and Piaget (1955/1958) studied how children interact with a balance scale and how they construct the concept of balance regarding equilibrium. They used two balance scales: one was a conventional balance with holes along the cross bar and the other one had no holes. Each had a basket on each side that could be moved along the cross bar. Children could vary distance and weight with the two balance scales.

In their open-ended structured interviews, Inhelder and Piaget (1955/1958) asked questions or made suggestions while children interacted freely with the balance scale. In their study, Inhelder and Piaget distinguished between concrete and formal operations in children's thinking about the balance scale task. They found that children's performance on the balance scale task reflects an underlying developmental thinking process. They described three stages with six substages in knowledge about the balance scale. These stages are:

Stage I-A: Failure to distinguish between the subject's action and the external process (3- to 5-year-olds). Children do not have any idea of equality or coordination between distance and weight. Some children try to make the beam balance by establishing symmetry of weight without considering distance. Moreover, although children use symmetry, it is at the level of trial-and-error, not at an operational level.

Stage I-B: Integration of intuitions in the direction of the compensation of weights (5- to 7- or 8-year-olds). Children are able to understand compensation of weight and make some unsystematic discoveries about the role of distance. In other words, children sometimes understand if one side of the balance scale is heavier, the other side is lighter. According to this understanding, children put weights on both sides to make the beam balance. Some children notice that distance affects balancing but do not have systematic correspondences of the type "further from the fulcrum equals heavier."

Substage II-A: Concrete operations performed on weight and distance but without systematic coordination between them (7- or 8- to 10-year-olds). Children are able to function with concrete operations regarding weight and distance, but they are not able to coordinate systematically weight and distance. In other words, children make symmetric coordination between weights and distances using their intuition, and the coordination is more like a random trial-and-error level of action.

Substage II-B: Inverse correspondence of weights and distances (10- to 12-year-olds). Children are able to make inverse correspondences of weights and distances, with unequal weights and distances resolved by qualitative relationships. In other words, children may understand that a light weight at a longer distance from the fulcrum can balance a heavier weight at a shorter distance from the fulcrum. They may also begin to quantify some of the relationships between weights and distances. However, children are not able to generalize the relationships yet.

Substage III-A (appears at 12 years old or later). Children start to succeed in putting the law of balance into practice, but they are rarely able to explain it. For instance, children in this stage are able to move hanging objects into or out from the center to make a bar balance when the hanging objects are different weight. In addition, children are able to predict which side of a bar would go down when two objects with the same weight are placed different distances from the fulcrum.

Substage III-B (appears at 12 years old or later). Children are able to explain the law of balance through reasoning that shows an understanding of compensation of weight and distance, and reciprocity.

Inhelder and Piaget (1955/1958) concluded that understanding of the law of balance develops with the onset of the formal operational concept of proportionality. Children do not acquire understanding of the concept of proportionality until Stage III. In other words, children in Stage III have some sense that the combination of a small weight and longer distance from the fulcrum equals a bigger weight and a shorter distance. Inhelder and Piaget used the following formula to describe proportionality:

$$W/W' = L'/L \qquad \text{(p. 173)}$$

W/W' is the two unequal weights and L'/L is the distance from an axis at which W and W' are placed. Inhelder and Piaget perceived Stage II as foreshadowing of the understanding of proportionality. That means children in Stage II show some understanding of the relationship between weight and distance.

In light of the research by Inhelder and Piaget (1955/1958), children aged 6-year-olds and 8-year-olds were selected for this study. The goal was to include children whose understanding of the principles of balance was not completed in order to study protologic prior to operational understanding. Moreover, because of the uniqueness of the materials, making mobiles requires children to have already developed certain levels of understanding of the relation between weight and distance. Therefore, children who are in the lower-preoperational stage are not appropriate for this study.

Piaget (1974/1980) conducted research with Kamii and Parrat-Dayan with a balance scale to examine the role of contradiction in the development of logical thought. They identified four stages.

Level 1A (4- to 5-year-olds). Children at this level usually think that the two pans (A and B) at the two extremities of the beam will both go down when weights are placed in both. Children think of the reactions of pans A and B as independent of each other. This reflects a lack of coordination in thought of the two arms of the balance. Their thinking process is incoherent, due to logical contradictions. For example, when one pan rises or descends, children think the other will make the same movement; when cubes are to be put in the pans at the same time, children think the pans will both go down at the same time despite the fact that they can see that the beam is one piece of wood. Another example Piaget et al. (1974/1980) described is that when they asked a 4-year-11-month-old-child what would happen if a cube is dropped in one pan, he answered that "It [A] will swing to and fro [left to right] like that" (p. 101). In the pilot study, the researcher of the current study observed a 6 year-7-months-old-child who answered similarly. The child answered that the blue cup, a pan on one side of a bar, would swing up and over to the opposite side if a cube was put in one side of the pan while the other side of the pan was empty.

Level 1B (5.5- to 7-year-olds). Children in this age range think the object on one side can act upon the object on the other side, but still only in a unidirectional way. They lack reversibility, which indicates incomplete compensation. For example, the children at Level 1B think one pan will fall more than the other rises, or they will both go down a little bit (when one cube is put on each side), or a cup on one side will move first. A 6-year-7-month-old-child in the pilot study (between Level 1A and Level 1B) responded that one cup would swing (1A), when one cups falls; the other cup would rise by the same amount (1B); two cups would go down at the same time when one cube is put in both sides (1A); and one would move first when one cube is put in each side (1B). She also showed numerical symmetry, putting equal numbers of cubes on each side to make the bar level.

Level 2A (7- to 9-year-olds). In this age range children understand the reason for physical balance when using equal weights but they show hesitation with their unstable logico-mathematical schema. For instance, when children at this level are asked what would happen if one cube is put in each side, answers are: *the arms would move at the* *same time, the cups would move to the same height, they may just go down a little bit, and they won't go down because there (one side of the bar) and there (the other side of the bar) are the same.* A third grader, 7 years and 6 months old, in the pilot study of the current research seemed to be at this level. She understood how to balance but showed a little hesitation in her action of balancing the bar and made a mistake in leveling the bar.

Level 2B (9- to11-year-olds). No difficulty and no hesitation or confusion are shown. The symmetry and cohesion of the different parts of the scale is understood. They also understand a given weight causes the same result no matter where it is put. In other words, they can apply the same logic to another apparatus.

In short, the developmental study of Piaget et al. (1974/1980) shows that contradictions are created by a lack of compensation between actions and/or inferences. When a child has trouble in predicting and comprehending successive events, a disequilibrium begins. However, no numerical data on the results of their study was provided. We do not know how many children at various ages were categorized at each stage. However, Piaget et al. did label the stages with typical ages.

In this study, the researcher referred to the study of Inhelder and Piaget (1955/1958) and Piaget et al. (1974/1980) to determine which age subjects to include to design the pretest and posttest protocol, and to code data.

Applied Research on Balance

Following the study of Inhelder and Piaget (1955/1958), many other researchers (Bart, Frey, & Baxter, 1979; Juraschek & Grady, 1981; Kliman, 1987; Maher & O'Brien, 1980; Miller & Bart, 1986; Siegler, 1976; Webb & Daurio, 1975; Weybright, 1972) have used *the Equilibrium in the Balance* as the same or adapted task format to identify their subjects' stages of cognitive development. Among these studies, Siegler and Kliman conducted theirs with young, normal – not gifted – children.

In conducting research on a balance scale with 120 females (mean age 6 years to 17 years), Siegler (1976) developed four possible rules used to solve balance problems based on research by Inhelder and Piaget (1955/1958), Lee (1971), and his pilot work. The rules reflect the status of children's knowledge about the balance scale and children follow the rules when they predict the stability or instability of configurations of actual weights on the balance scale. The rules are:

Rule I. Use only weight to determine whether the scale will balance or not.

Rule II. Use mainly weight to determine whether the scale will balance or not, but consider distance to solve simple problems.

Rule III. Use both weight and distance to determine whether the scale will balance or not in more complicated problems.

Rule IV. Use the law of balance to determine whether the scale will balance or not.

Siegler (1976) used a controlled interview setting. He presented children with given configurations of weights on a balance scale where the pans were supported by blocks, so that the pans would not respond to weighting. Siegler asked children to predict which side of the scale would fall when the blocks are removed. Children did not have a chance to interact with the balance scale to answer either before or after the task and therefore did not test their predictions. The six distinct problems Siegler used were:

1. Balance problems: Equal number of same objects placed at equal distances from the fulcrum.

2. Weight problems: Different numbers of identical objects placed at equal distances from the fulcrum.

3. Distance problems: Equal number of identical objects placed at different distances from the fulcrum.

4. Conflict-weight problems: A greater number of identical objects (a greater mass) placed close to the fulcrum (shorter distance) on one side but a smaller number of identical objects (a lighter mass) placed farther from the fulcrum (longer distance) on the other side. The side with greater weight would go down.

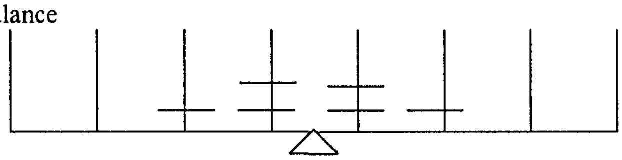
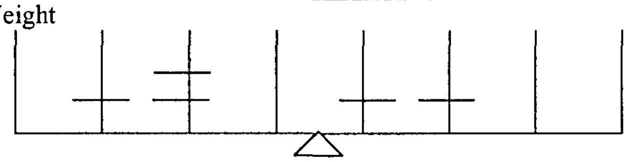
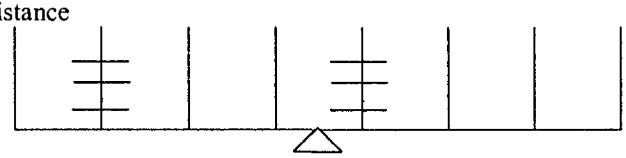
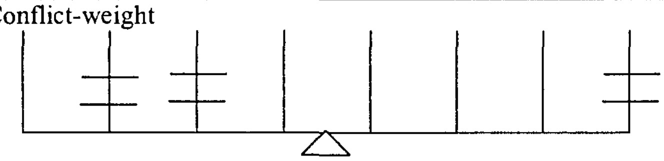
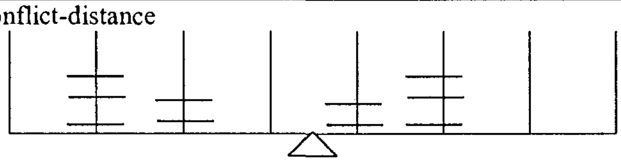
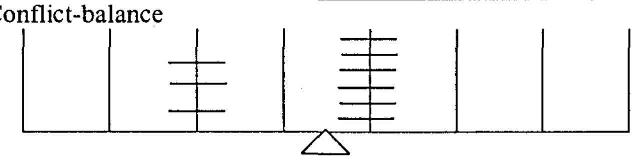
5. Conflict-distance: A smaller number of same objects (a lighter mass) placed farther from the fulcrum (greater distance) on one side but a greater number of same objects placed closer to the fulcrum (shorter distance) on the other side. The side with objects at a greater distance would go down.

6. Conflict-balance problem: A smaller number of same objects (a lighter mass) placed farther from the fulcrum (longer distance) on one side but a greater number of identical objects (a greater mass) placed closer to the fulcrum (shorter distance) on the other side. The bar would stay balanced.

Siegler (1976) predicted how children using the four rules would respond to the six problems through a table (see Table 1). Table 1 shows that, for example, children who use Rule I would predict correctly (100%) on problems of balance, weight, and conflict-weight and predict incorrectly on the other three problem types; and children who use Rule IV would solve all types of problems.

Table 1

Predictions for Percentage of Correct Answers and Error Patterns on Posttest for Children Using Different Rules (Predicted Success and Fail)

Problem type	Rules			
	I (%)	II (%)	III (%)	IV (%)
Balance 	100	100	100	100
Weight 	100	100	100	100
Distance 	0	100	100	100
Conflict-weight 	100	100	33	100
Conflict-distance 	0	0	33	100
Conflict-balance 	0	0	33	100

**Note: Adapted from Siegler (1976), p. 486.*

An important limitation of Siegler's work (1976) is that, in contrast with the current study, Siegler did not allow children to interact with the balance scale and did not consider reactions and comments of children. Thus he analyzed children's knowledge about the balance scale solely by considering children's predictions alone, not by considering actions and verbalizations. Although it is true that some children have limitations in verbalizing their thoughts, listening to what they say provides concrete evidence of how they think. In addition, children's logic can be deduced through observing actions and reactions of children with materials.

Kliman (1987) examined how 6- to 12-year-old children learned about the balance scale through a combination of free exploration and direct questioning. Special-case and context-specific knowledge were her research focus. She viewed learning as a continuous process. Her goal was to find out how children learn more about the balance scale through making connections to prior knowledge. She found that children made more of what she called *local* observations. Local observations consider only one variable or one phenomenon. For example, children make the scale balance using just weight or whichever side is up or down based on their recent experience. After local observations, children made general and context-independent observations such as *distance matters*. In her study, she was also concerned with mathematical knowledge connected with the balance scale. She found that experience with a balance scale helped children make connections between informal mathematical knowledge and the formal arithmetic facts they are asked to memorize in school. This finding supports the effectiveness of hands-on learning in mathematics along with many other curricula and gives good insights into how classroom teachers can effectively convey mathematics lessons to children.

Although research by Inhelder and Piaget (1955/1958), Piaget et al. (1976/1980), Siegler (1976), and Kliman (1987) has played an important role in the scholarly field, it lacks practical classroom application. The current study responds to this lack by attempting to explain how teachers can facilitate children's concept of balance through making mobiles. Research such as this is one of the ways to bridge between constructivist theory of knowledge and classroom practice.

Educational Curricula

One of the goals of this study is to explore the idea of whether we can observe reasoning development in the context of making mobiles and if so, what this might imply for classroom teachers. That intention is closely related to curriculum, especially science curriculum in early childhood education. This section examines the current status of science curriculum in early childhood education and reviews literature and studies related to making mobiles from the perspective of both art and the application of scientific reasoning of logic.

Science Curriculum in Early Childhood Education

Many educational organizations have placed a strong emphasis on the importance of science education in early education; including the National Research Council that produced the National Science Education Standards (1996), and the American Association for the Advancement of Science that produced Benchmarks for Science Literacy in 1993. The basic positions of these organizations are that all children are able to learn science, and all children have a right to the opportunity to become scientifically literate. From this perspective, in order to provide that opportunity, educators, especially early educators, should introduce children to the essential experiences of science through hands-on activities in which young children can explore and inquire (Bredderman, 1983; Field, Bernal, & Goertz, 2001; Juraschek & Grady, 1981). The study of Inhelder and Piaget (1955/1958) provides a theoretical foundation for the importance of providing hands-on activities. In their study, Inhelder and Piaget found that most young children are at the preoperational and concrete operational stages in interacting with the balance scale. These findings lead to the view that classroom science activities should involve objects that children can manipulate, explore, and experiment with to increase their understanding and intellectual development.

However, a number of researchers suggest that in most early childhood classrooms, science, particularly physical science, is not given equal importance with other areas of the curriculum (Bloomfield, 2001; Duckworth, Easley, Hawkins, & Henriques, 1990; Gega & Peters, 1998; Sprung, 1996). Moreover, when it is taught, the focus is often on content inappropriate for the developmental level of young children (Kamii & DeVries, 1978/1993; Trumbull, 1990). For example, Kamii and DeVries suggest four criteria in selecting physical-knowledge activities involving the movement of objects:

1. The child must be able to produce the movement by his or her own action. The core of physical-knowledge activities is that children make actions on objects and

they observe how the objects react. Considering this, activities that do not allow children to produce the movement of objects are meaningless.

2. The child must be able to vary his or her action. Physical-knowledge activities provide an opportunity for children to test and observe many possible outcomes of their actions on objects by varying their actions.

3. The reaction of the object must be observable. If children cannot see the reactions of the objects, they cannot make correspondences between their action and the result. It does not allow children to reason about what happened and why. When children cannot observe reactions, they might think the reactions of objects are done by magic.

4. The reaction of the object must be immediate. Considering children's limited attention span, to keep their interest and to help them engage and think about the physical phenomena, immediate reaction is necessary. (pp. 8-9).

Based on a synthesis of elementary science curricula reforms over the past three decades, Bredderman (1983) claimed that the activity-process-based approaches in teaching science bring more positive results than traditional science methods in a wide range of student outcome areas at all grade levels. The activity-process-based approaches congruent with hands-on, process-oriented, activity-centered science inquiry are intrinsically constructivist. Constructivist education encourages children at all levels to move away from rote learning of right answers and puts them into an inquiry-based process so that children construct knowledge through experience, research, and work cooperatively with both peers and adults. While there may ultimately be a right answer, children's answer might be sometimes wrong and it is more understandable for children to arrive at a right answer through a process of exploration, discovery, and invention than through memorizing and repeating by rote (Kamii & DeVries, 1978/1993). The approach of this study in making mobiles is to allow children to experiment with materials and their ideas. In the process, children are intensively engaged in activity, and their involvement induces them to construct their own knowledge.

Mobiles in Art

Mobiles in art have a short history. They are a relatively new art form. According to Lynch (1967), "a mobile is created for the sake of movement and it is the particular way in which it moves that captures our attention and intrigues us" (p. 7). The first form of mobile was made by the Russian constructivist artist, Naum Gabo in 1920. Marcel Duchamp used the word *mobile* first at the Paris Exhibition in 1932 (Brand, 2003; New Encyclopædia Britannica, 2002). The first mobile in the style with which most of us are familiar was created in the early 1930s by Alexander Calder (1898-1976). He is one of America's most important artists and most famous for his kinetic sculpture mobiles. Calder called mobiles four-dimensional drawings. Calder gave this art form its general direction and specific style. Since Calder made the first wind mobile in 1932 (Solomon, 1964), he developed various forms of mobiles such as hanging mobiles, wall mobiles, standing mobiles, motorized mobiles and table mobiles, using different materials and shapes. In all, he made more than 16,000 mobiles by the 1970s (Harrison, 2002).

As an art form, mobiles are related to sculpture, painting, drawing, and design. Aspects of this three-dimensional art form include harmony and contrast in color, texture, shapes and form, spatial relationships, and weight and size. In a conversation with Lipman (1976), Calder said that he started to make mobiles because "(I) felt that art was too static to reflect our world of movement" (p. 263). In 1946, philosopher Jean-Paul Sartre wrote of Calder's mobiles in the preface of the Galerie Louis Carré catalogue for an exhibition in Paris (Calder Foundation, 2002). It was translated into English for the Curt Valentin exhibition held December 9-27, 1947, at the Buchholz Gallery in New York.

> A mobile, one might say, is a little private celebration, an object defined by its movement and having no other existence. It is a flower that fades when it ceases to move, a pure play of movement in the sense that we speak of a pure play of light....when everything goes right a mobile is a piece of poetry that dances with the joy of life and surprises.... There is more of the unpredictable about them than in any other human creation.... It is a little jazz tune, evanescent as the sky or the morning: if you miss it, you have lost it forever...they are nevertheless at once lyrical inventions, technical combinations of an almost mathematical quality and sensitivity symbols of Nature. (Sartre, 1946, "The Mobiles of Calder" by Jean-Paul Sartre, ¶ 2, 3, 7)

Making mobiles has been utilized in classrooms as an art activity and/or a science activity. For instance, Levitt (2002) provided her second grade children an opportunity to apply what they learned about balance through making mobiles. She provided a variety of weighing instruments and questions pertaining to math and problem-solving. After the experience with making mobiles, the children of her classroom stated:

"Mobiles are like shapes in a circus."

"I think it was frustrating but it was still fun."

"I learned that if one side is down, to make it balance you have to move the fulcrum or the beam."

"I learned that if you put the same weight on each side it will balance."

After making mobiles, they hung the mobiles from the ceiling of their classroom.

Physical-Knowledge Approach

Kamii and DeVries (1978/1993) introduced physical-knowledge activities in their book, *Physical-Knowledge Activities in Preschool Education: Implications of Piaget's Theory*. Kamii and DeVries based the rationale for physical-knowledge activities on Piaget's theory that values the role of action in the development of intelligence both in a general sense and in specific knowledge of the physical world. With a foundation of experiences in physical-knowledge activities, children find logico-mathematical relationships in phenomena of the world and, foremost, construct logico-mathematical knowledge, which "consists of relationships which the subject creates and introduces into or among objects" (p. 16). The reasoning children use can be discussed in terms of the dynamics of disequilibration and equilibration. Equilibration is an action process that leads from a state near equilibrium to a qualitatively different state at equilibrium by way of multiple disequilibria and reequilibrations. Equilibration is a constructive process to build logico-mathematical relationships by coordinating various factors that involve physiological maturation and interacting with the physical and social environment. Considering that the goal of all children's constructing knowledge process – regulation, negation, assimilation, accommodation, compensation, coordination, equilibration, etc. – is to build logico-mathematical relationships, the importance of physical-knowledge activities becomes greater. For instance, Kwak (1995) studied how a 5-year-old child developed his logico-mathematical knowledge through water activities. The child varied his actions on cups with holes and tubes, and observed the dynamics of water movement and learned about characteristics of water. That experience stimulated him to make relations between his actions and the results of his actions, which are logico-mathematical relationships. In short, children construct their logico-mathematical knowledge through experiences of physical-knowledge activities.

Kamii and DeVries (1978/1993) conceptualized two types of physical-knowledge activities: (a) activities involving the movement of objects such as physics, especially mechanics; and (b) activities involving changes in objects such as chemistry. Making mobiles is included in the former category because (a) the main scientific concept of mobiles is balance, one of the phenomena of physics; (b) mobiles utilize the movement of bars and hanging objects; and (c) children use an action of putting objects on bars to make bars balance.

Making mobiles meets the criteria for good physical-knowledge activities suggested by Kamii and DeVries (1978/1993), based on the constructivist rationale, the following ways:

1. The child must be able to produce the movement by his or her own action. In making mobiles, children choose which objects they will hang on bars and where they will hang the objects.

2. The child must be able to vary his or her action. In making mobiles, children move hanging or resting objects toward or away from the fulcrum to make bars balance,

based on their judgment of relationships between weight and distance from fulcrum. They also can vary the weight and size of the objects.

3. The reaction of the object must be observable. The child can easily observe the reaction of bars to the actions of hanging objects. The bars react – they either balance or tilt.

4. The reaction of the object must be immediate. The reaction of bars occurs immediately whenever children add or move hanging or resting objects on bars.

DeVries (2002) established principles of teaching in physical-knowledge activities extending the research of Kamii and DeVries (1978/1993):

1. Provide materials that invite children's interest and experimentation. DeVries suggests to include questions or problems children could figure out through experimentation when teachers provide familiar materials.

2. Ask questions related to four ways of engaging with objects: (a) acting on objects to see how they react, (b) acting on objects to produce a desired effect, (c) becoming aware of how one produced a desired effect, and (d) explaining causes.

3. Understand and assess children's reasoning by observing their actions.

4. Encourage children to notice regularities and construct logico-mathematical relationships.

5. Support children's ideas, even those that are wrong. Piaget often showed his interest in children's wrong answers because they are evidence of how children's logic develops. In other words, to construct correct ideas, children test their incorrect ideas.

6. Model and suggest new possibilities. Children sometimes do not have an idea of how to use the materials and how to extend their ideas further. Teacher's questions or modeling might provoke children's thinking.

7. "Back off" if a child does not respond to an intervention. Any intervention should meet children's developmental level. If it is beyond children's developmental level, they could get discouraged and frustrated rather than challenged.

8. Create a forum in which children can discuss their ideas and share their discoveries with others. Peer-learning and peer-teaching is sometimes more effective than teacher directed teaching.

Although Kamii and DeVries (1978/1993) did not deal with balance or mobiles in their book, the fundamental idea about physical-knowledge activities is embedded in this study. Furthermore, their principles of teaching were integrated into conducting present study.

Elementary Science Study

The Elementary Science Study (ESS, 1965) program is considered one of the major activity-centered science programs for elementary school. Sponsored primarily by the National Science Foundation, over a hundred scientists and educators participated in the program and produced ESS equipment, films, and printed materials. No specific theory of how children acquire knowledge was used in developing the materials (Rogers & Voelker, 1970). However, two fundamentally important aspects of ESS materials reflect Piaget's ideas on intellectual development: (a) using physical materials, and (b) children's engagement in pursuing their own ideas. Authors of ESS believe that children learn more when they do what they want to do with materials instead of what someone else wants them to do. Therefore, it is very important that children manipulate materials in the early phase of a unit or project so that they can learn different things at different rates. Furthermore, authors of ESS communicate some firm ideas about how the ESS materials should be used. Most of all, children use materials themselves, individually or in small groups, raise questions, answer them in their own way, and come up with their own conclusions. Another ESS principle is that teachers should create situations where children talk to each other. According to ESS, the materials are related to learning science concepts and developing intellectual skills such as intuitive and analytical thinking. Thus, the cognitive domain is served well. ESS is consistent with Kamii and DeVries' (1978/1993) physical-knowledge approach.

The program consists of 56 independent units across the elementary grades. Life science, physical science, spatial relations, and logic are included in the units. There are three kinds of units: (a) units designed to be used by an entire class at the same time, (b) units consisting of only a teacher's guide which suggests less structured, more open-ended activities and requires more teacher initiative, and (c) units designed for individual or small group work. ESS includes making mobiles in the Balance unit for a kindergarten through fourth grade activity in physical sciences. A teacher's guide and a pupil kit are the basic instructional materials for the activity. The ESS authors believe that through the mobile activities, students engage in problem solving and develop understanding of natural phenomena.

The approach of ESS is interdisciplinary learning. Thus hands-on experiences such as graphing, weighing, and measuring are a major part of the activities. Followed by presentation of challenging events, students participate in various open-ended explorations, engaging in many projects related with their life and world. For the exploration, many materials are provided so that students can find meanings for them. The main student assessment method is the informal formative assessment by teachers, classroom observers, and administrators. The assessors look carefully at how children respond to ESS materials during their developmental process.

ESS materials have been used in many ways and in many different places. The Republic of Korea and the province of British Columbia have adapted ESS materials in their elementary school curricula; the Peace Corps has used ESS in their training program, and later adapted the materials for use in places such as Ethiopia, the Philippines, and Colombia; some of the units are developed as the African Primary Science Program; and ESS materials are used for pre-service teacher training and in-service workshops for elementary teachers. ESS was used in about ten percent of the classrooms in the United States in 1972 (Griffith & Morrison, 1972) and would be used by over three million students by 1985 (Stefanich et al., 1985). One recently adapted research of ESS can be found in Chen, Isberg, and Krechevsky (1998). Chen et al. described a two-tiered mobile making project adapted from Elementary Science Study (1976) for enhancing visual-spatial abilities of elementary aged children. Their stated objectives for the activity were to make simple mobiles and to observe variables that affect mobile balance. They also described the core components of the activity as

"Understanding spatial relationships, fine motor skills, and trial-and-error strategy" (p. 32). However, these ESS materials are now out of print and difficult to find.

ESS was not originally designed for students with disabilities. However, Stefanich et al. (1985) applied ESS to orthopedically disabled students in inclusion settings for the following reasons: (a) the flexibility of the ESS materials within the program provides teachers and researchers with "an ideal format for the inclusion of orthopedically handicapped students" (p. 5), (b) the materials are made with non-toxic ingredients and firm (sturdy) materials for children's safety, (c) their easy handling design is suitable for orthopedically disabled students whose fine motor control is limited, and (d) most of all, ESS offers "many opportunities for varied grouping patterns and shared decision-making between handicapped and non-handicapped students" (p. 5).

According to research by Bredderman (1983), students using ESS showed higher academic achievement, high interest in science, and improvement in their skills compared to students in traditional, textbook-based classrooms. Based on his meta-analysis of ESS studies, Bredderman claims that the overall effects of the activity-based programs on all outcome areas combined were clearly positive, and concludes that more active adaptations of ESS into the curriculum are desirable.

Although ESS introduced mobiles as a science activity, it does not say how teachers should intervene and/or facilitate children's development of the concept of balance.

Full Option Science System

Faculty associated with the Lawrence Hall of Science, University of California at Berkeley (1995), developed an elementary school science program called Full Option Science System (FOSS) supported by the National Science Foundation. Based on an understanding of how children think and learn, the FOSS program includes many hands-on inquiry activities and interdisciplinary projects. The activities and projects are open-ended tasks, so there is a good balance between student discovery learning and teacher directed learning. The authors of the FOSS program believe that in applying FOSS activities into a classroom, it is very important to build an atmosphere that inspires curiosity in students, encourages and respects the curiosity, and provides physical, intellectual, and emotional support. Those environments help students seek their own answers through hands-on experiences. The FOSS program materials are designed for children in different developmental levels. For instance, Field, Bernal, and Goertz (2001) conducted three FOSS activities in a fifth grade gifted and talented class in the Lower Rio Grande Valley in Texas. The Balance and Motion Module is included in the physical science materials for Grades 1-2 of the FOSS program, and making mobiles is introduced in that module. Authors of FOSS believe that making mobiles provides children experience with the concepts of balance, counterbalance, and stability. However, the FOSS program differs from the Kamii and DeVries's (1978/1993) approach in that it focuses on scientific truths, not development of logic. In other words, the focus of the FOSS program is on the acquisition of scientific facts rather than the examination of children's reasoning processes as emphasized by Kamii and DeVries.

Clinical Interview

Piaget found the method of standardized tests was not appropriate to study how children think and the reasoning behind their answers and behavior. Thus, he developed and implemented his own way to investigate children's reasoning – engaging children in conversation after providing some questions developed to explore children's minds. This is the beginning of "the main inspiration for current clinical interview methods" (Ginsburg, 1997, p. x).

Piaget often used open-ended questions in order not to impose an adult's opinion on children's responses. The clinical interview has also been called the *critical exploratory method*, presumably to reflect both its experimental, hypothesis-testing nature and its flexibility. Kamii and Peper (1969) described the differences between the psychometric method and the exploratory method. The former method requires an examiner to follow fixed procedures without any deviation. In contrast, in the latter method an examiner follows the child's thinking path in a natural and conversational way with an outline and a hypothesis in mind. The clinical interview, according to Bingham, Moore, and Gustad, (1959), is "a conversation directed to a definite purpose other than satisfaction in the conversation itself" (p. 3). The clinical interview is used to explore, to discover, to specify cognitive processes, and to test hypotheses.

The main distinguishing characteristic of clinical interviews is that the interview itself is seen by the interviewer as a dynamic experience in hypothesis generation and testing. This aspect causes some misunderstanding in utilizing clinical interview methods. In other words, some researchers understand them as free-form conversations with a child. Although it is true that clinical interview methods allow an interviewer to have flexibility, the interviewer must have clearly defined questions and hypotheses in mind and test the hypotheses using the questions (Emeric, 1987; Ginsburg, 1997). Inhelder (1989), one of Piaget's collaborators, suggests that throughout the interview, "the experimenter has to formulate hypotheses about the cognitive bases of the child's reactions…and then devise ways of immediately checking these hypotheses in the experimental situation" (p. 215).

Clinical interviews provide rich data and uncover the thoughts and concepts underlying the child's verbalization. The interviewer displays an attitude of respect toward the child by conveying through word and deed that he or she is interested in the child's thinking. This characteristic makes clinical interview methods a primary research methodology for constructivists.

Other researchers also support the use of the clinical interview. Ginsburg (1997) agreed with Piaget on the inappropriateness of using traditional standardized methods to find out what children know. Instead, he supported using clinical interview methods. He stated some theoretical and ethical reasons for the value of using clinical interview methods to enter the child's mind; its constructivist rationale and its distinctive approach to "fairness" (p. xii). He highly valued clinical interviews in promoting children's interest and understanding of their own thinking. Ginsburg lists a contemporary rationale for the clinical interview as follows:

1. Acceptance of constructivist theory requires that clinical interview methods be used.

2. The clinical interview offers the possibility of dealing with the problem of subjective equivalence. Each child often gives a different answer even though he/she gets the same questions. This is because he/she perceives the question in his/her own way, using his/her unique knowledge and logic. The clinical interview provides opportunities to explain each child's own interpretation of a question.

3. The clinical interview helps us examine the fluid nature of thinking. The flexibility of the clinical interview makes it possible to explore children's continuously changing thinking process and development.

4. The clinical interview aids in the investigation of learning potential.

5. The clinical interview is useful for understanding thinking in its personal context.

6. The clinical interview allows us to deal with a specific individual in a group setting.

7. The clinical interview embodies a special kind of methodological fairness, especially appropriate in a multicultural society.

The review of literature has revealed that little of the research in developmental psychology on the balance has influenced education. This study focused on educational aspects of the concept of balance and its application to an educational activity.

Research Questions

The purpose of this study was to explore children's construction of protologic in the context of experience with mobiles. The study addressed the following questions:

1. What behaviors showed children's understanding of concept of balance in making mobiles?

2. How can constructivist principles be used to understand children's experimentation in making mobiles related to balance?

3. Do children show progress from pretest to posttest in their concept of balance after experiences making mobiles?

CHAPTER III

METHODOLOGY

The activity of making mobiles was designed to approximate a classroom setting in which the teacher/experimenter has less control over the children's experimentation than in situations such as Inhelder and Piaget's (1955/1958) or Siegler (1976) where they limit the scope of experimentation.

Participants

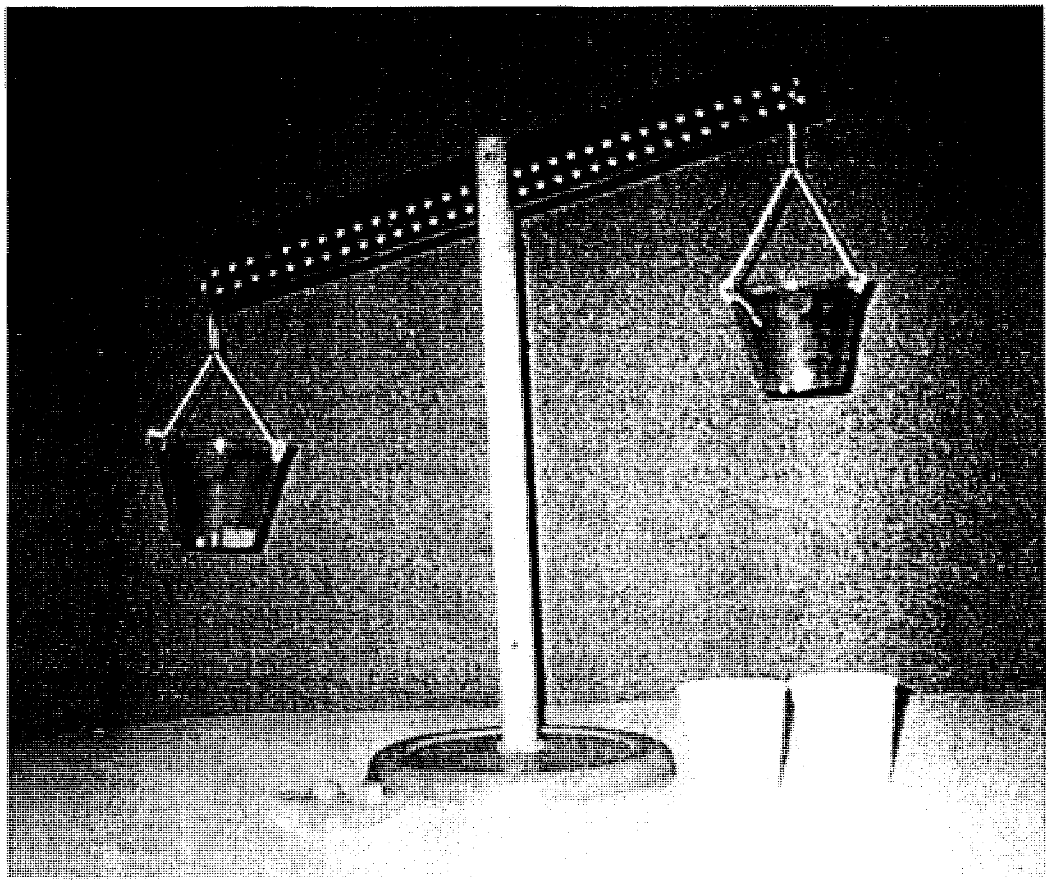
The participants in this study were 10 first-grade children and 12 third-grade children. The first grade group consisted of five males and five females. Ages ranged from 6 years and 2 months to 7 years and 1 month with a mean age of 6 years 6 months. The third grade group consisted of three males and nine females. Ages ranged from 8 years and 3 months to 9 years and 2 months with a mean age of 8 years and 5 months. All participants attended a public elementary laboratory school located in Cedar Falls, Iowa. The participants were children whose parents signed a consent form for the research (see Appendix A for the consent form for parent/guardian). The children themselves also signed a consent form for the research (see Appendix A for the consent form for children). Because their participation is completely voluntary and derived from their interest in the research topic, the children had a chance to refuse. Their parents were told that they might discontinue their child's participation at any time, with no penalty or loss. Subjects' participation was reviewed by the Committee for the Protection of Human Subjects at the University of Northern Iowa.

Materials

Pretest and Posttest

The apparatuses used in the pretest and posttest were two balances: a primary balance and a beam balance. The primary wooden balance scale (see Figure 4) had a 16.5 inch cross bar with 33 holes. This scale was used with the first set of questions to determine the children's knowledge of the concept of balance. Equal lengths of string (approximately 2 in.) were attached to two clear plastic cups and attached onto the bar with a wire hook.

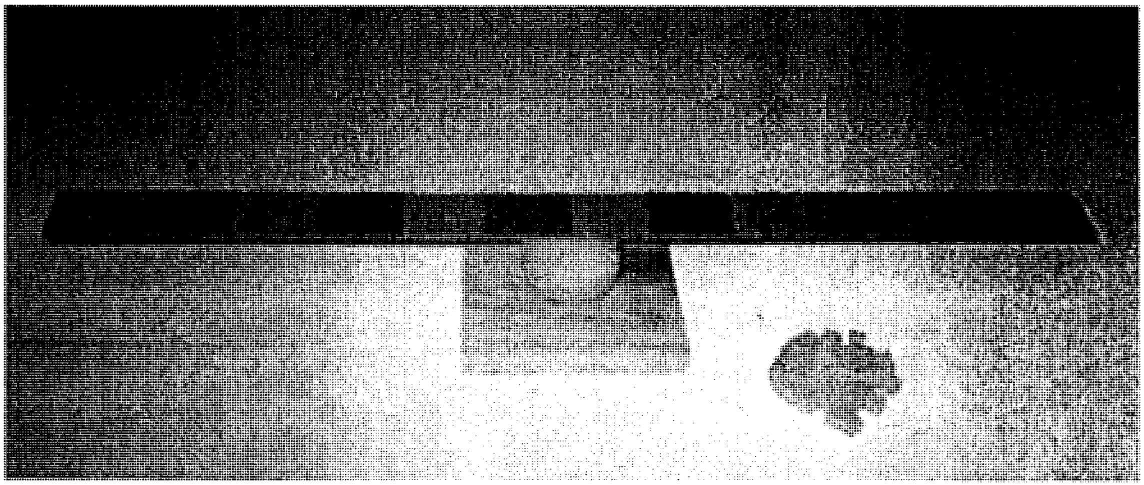
Figure 4. Apparatus for the pretest and posttest: A primary balance, two plastic cups with cereal, and 40 hollow plastic cubes.



Materials included two clear plastic cups (2.5 in. in diameter across the top, 2 in. in diameter across the bottom, and 2.5 in. in height), a balance stand (16 in. high) with a support pin for the fulcrum, two wire spring hooks, 40 hollow plastic cubes (3/8 in. side) that were identical in color, size, shape, and weight to keep variables to a minimum. Corn-flake cereal and sugar-coated corn-flake cereal were used to find out children's balance concepts where mass and volume varied. For clarity in reference to the two cups, a red sticker was attached to one cup, and a blue sticker was attached to the other cup.

A second balance, a beam balance, was used to determine if the child was able to apply the balance concept to a new situation or not. The beam was a wooden bar 24.5 inch long and 1.75 inch wide (see Figure 5). It was put on top of a tennis ball, serving as a fulcrum, that was put in a round indentation in a 5 in. X 5 in. wooden square board, serving as a support. Colored stripes at 2-inch intervals were added to the surface of the beam for convenience in coding.

Figure 5. Apparatus for the pretest and posttest: A beam balance.



Intervention Activities

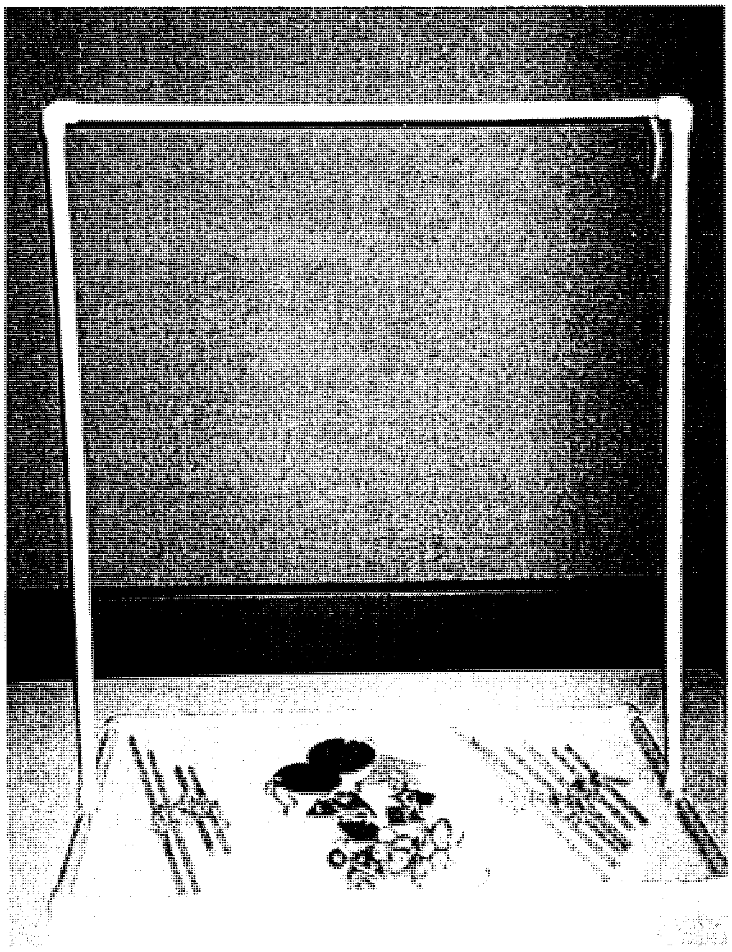
Criteria for mobile-making materials were: (a) accessibility (classroom teachers can prepare materials easily); (b) low cost (classroom teachers can obtain materials easily); and (c) attractiveness (to motivate children's interest).

Figure 6 shows materials chosen for making mobiles. They include:

- A 28 in. high stand with a 24 in. crossbar made with dowels (7/16 in. in diameter) and plastic connectors for hanging mobiles.
- Dowels of various lengths (7.5 in., 12.5 in., and 15 in.), each with an eye-screw in different places - 7.5 in. (2.5 in. – 5 in.), 12.5 in. (6 in. – 6.5 in.), and 15 in. (6 in. – 9 in.)
- Two-dimensional hanging objects with basic shapes – two circles (diameter 3 in.), two triangles (side 3 in.), and five squares (side 1.5 in.) made of felt.
- Three-dimensional hanging objects (approximately 1 in. long and 10/16 in. wide) such as miniature apples, pears, and watermelons.

To maximize children's possibilities for easily attaching and detaching elements, a piece of yarn (approximately 2 in.) was attached to the dowels and hanging objects in advance. In addition, to increase friction between the dowels and yarn, the dowels were sprayed with textured paint. This reduced the difficulty created yarn sliding and made it more likely that the yarn stayed where the child placed it.

Figure 6. Apparatus for the intervention activities: Making mobiles.



Procedures

The research procedure consisted of three parts – pretest, intervention activities, and posttest. The procedure of the pretest was repeated in the posttest.

Pretest and Posttest

Each child met with the teacher/experimenter in a quiet place in his/her school outside of the classroom. Each child was invited in the following way: *I brought some* *things I want to show you, and it is your turn now.* The procedure of the pretest and posttest were basically followed according to the prescribed protocol. Follow-up questions allowed flexibility, depending on children's responses.

The pretest and posttest clinical interview procedure was adapted from Piaget et al. (1974/1980), derived to investigate subjects' concepts of balance. The subjects were asked two sets of interview questions. The first set of interview questions was for the primary balance. Samples of questions are: *If I put one cube in the red cup, what do you think would happen to the red cup? Could you show me with your hand where it will go? Why do you think so? What would happen to the blue cup (empty)? (After putting corn-flake cereal in a cup) Can you make it balance with sugar-coated corn-flake cereal?* etc. After certain questions, the teacher/experimenter and children conducted actions together. The teacher/experimenter let go of the balance and children were allowed to see the result.

The second set of interview questions was for the beam balance. The interview started with the balanced beam and followed a consistent procedure: *If I put one cube on this right side, what do you think would happen to the beam? Could you show me with your hand how far it will go down/ up? What makes that happen? What would happen to the left side? (after putting a cube on right side of the beam) Can you make it balance with/without cubes?* etc.

Each interview lasted approximately 15 to 20 minutes. The full interview protocols for the pretest and posttest can be found in the Appendices B and C. All pretest and posttest interviews were video-recorded and coded for data analysis.

Intervention Activities

The subjects participated in three sessions of making mobiles. In each session, children freely explored materials and built mobiles. At the beginning of Intervention I, the teacher/experimenter asked children to explain a little more about their mobiles after they were done. Thus, at the end of each session, when children were finished making mobiles, they had the opportunity to share information about their mobile such as how they built it and why it worked or did not work.

Two children were invited to participate in making mobiles at the same time. The teacher/experimenter asked the first-grade teacher and the third-grade teacher, in advance to pair up subjects who worked well together.

During the weeks of September and October, children participated in three mobile making sessions in a room outside the classroom. They were given their own identical sets of mobile making materials. During the first session, children made mobiles with six bars varying in length (two 7.5 in. dowels, two 12.5 in. dowels, and two 15 in. dowels) with eye-screws in the middle and two-dimensional hanging felt objects with basic shapes – two circles, two equilateral triangles, and five squares of felt.

At the second session, children made mobiles with five bars varying in length (two 7.5 in. dowels, two 12.5 in. dowels, and one 15 in. dowel) with the eye-screw off center and the two-dimensional hanging objects with the basic felt shapes described above for Intervention I. In addition, halves of three-dimensional hanging objects such as miniature apples, pears, and watermelons were provided to respond to the children's request of more things to hang.

During the last session, children made mobiles with four bars varying in length (two 7.5 in. dowels, one 12.5 in. dowel, and one 15 in. dowel) with the eye-screw off center and two-dimensional hanging objects and the three-dimensional hanging objects such as miniature apples, pears, and watermelons.

Before asking the children to make mobiles, the teacher/experimenter showed them four pictures of mobiles built by Calder. The pictures used were: *Cone d'ebene (1933), Little wooden mobile (1934), Mobile, wood, metal, cord (1936?)*, and *Constellation mobile (1943).* The basic structure – straight bars and hanging objects – of the mobiles in the pictures was the same as the ones the subjects were encouraged to build. The teacher/experimenter invited children to participate by saying: *I brought some things for you. (Show pictures of mobiles), Have you ever seen anything like this one before? This is called a "mobile." These mobiles were built by Alexander Calder who is an American artist. You are going to make mobiles today. You have exactly the same set of materials, but you can trade them with each other. You can also help each other, and I'm here to help you and give answers to any questions you may have.*

As described in chapter II, clinical interview methods were used for conducting intervention activities. Therefore, no fixed interview questions were used but some general types of questions and comments were regularly used. Protocols for the intervention activities can be found in Appendix D.

Children freely explored the mobile-making materials, and the experimenter sometimes asked questions such as *What do we need to do first to make a mobile? How can you make this bar level? What makes it tilt? If I want to hang this shape in here* *(one end of a bar), what do I need to do to make it level?* etc. If children succeeded in making a balanced single tier, they were encouraged to add one more dowel to make a mobile with two tiers using questions like *Can you add one more stick and make it level? Or Can you make a mobile using more than one bar?*

The questions and procedures for the intervention varied depending on children's reactions. With flexibility in interventions, the experimenter varied the level of interventions and direct questioning. In Intervention I, the level of intervention was low. There were a couple of reasons for this strategy. First, considering the reality of most classroom situations which there is one teacher per classroom, it is impossible for the teachers to interact intensively with a few children who are in one activity area. Teachers need to have contact with all children in their classroom. The researcher tried to simulate a real classroom experience of the children. Second, assuming the materials for intervention activities were new to the subjects, the researcher assumed children might need some time to get used to how the materials work first, and they could have a chance to demonstrate their logic with the materials. Based on this rationale, after introducing mobiles with pictures, the teacher/experimenter mostly observed how children responded to the materials, asked a few questions, and helped if they asked.

In Intervention II, the level of intervention was increased. The first reason was that the apparatus for the intervention was new and challenging to the children. Thus, many children needed help, encouragement, and guidance. The teacher/experimenter asked more challenging questions, such as *Is there any other way you can make it level instead of adding or taking out shapes?* The second reason for increased intervention came from the observation of children's behavior in Intervention I. Many children added additional bars only on the eye-screw, which was the fulcrum of the uppermost bar. That allowed children to build just a one-tier mobile. The researcher thought some of these children had the capability to build more complicated mobiles, so the teacher/experimenter asked children to attach additional bars someplace other than the eye-screw or the hook.

In Intervention III, the level of intervention was the highest for the following reasons: (a) to guide children to concentrate on making bars balance, (b) to encourage them to demonstrate their maximum capability in making mobiles, and (c) to get direct verbal explanations from the children for coding. Thus, the teacher/experimenter gave children some directions by asking them not to put more than one of any object on the hook; not to hang bars right beside the eye-screw, which would be the fulcrum; to make one bar level first and then add more bars; to think about what would happen before they act; and to try to make all bars level. Besides giving the directions, the teacher/experimenter asked many questions, for instance, *Why did you put the circle on this side and not on here? What made it fall down? If I move this bar in this way (to the center or to the end), what do you think would happen? If I move this, will any thing happen to this bar (lower level bar or upper level bar)? Why? Why not? What made that happen?* etc. Children's responses to these direct questions would help the researcher understand how and why children reacted to the mobiles and how much they had constructed their knowledge about balance. Moreover, getting direct verbal explanations from the children was helpful to determine whether a child has a practical level of knowledge and/or a conceptual level of knowledge. Piaget (1937/1954) and Kamii and DeVries (1978/1993) concluded that exploring physical knowledge activities helps children develop their conceptions of causality. Piaget also discussed how children's understanding of physical phenomena proceeds from the practical (knowing how) to the conceptual (knowing why). When children explain their thoughts, their answers should reflect their developmental levels in reasoning. Being able to explain their thoughts means they know why. Knowing why, the reason, means they have the concept.

Coding

Pretest and Posttest

Coding of the pretest and posttest interviews was based on stages identified by Piaget et al. (1974/1980) and the study of Inhelder and Piaget (1955/1958) as documented in chapter II.

Two coding tables were designed for the pretest and posttest. One coding table (see Appendix E) was developed based on the definition of stages in development of the balance concept provided by Piaget et al. (1974/1980). The columns of the table were filled out while watching the video tapes of children's performances in pretest and posttest. Besides the table, important notes were added and transcribed. Based on the coded data, children's developmental stages were determined (see Appendix F for the coding table).

Intervention Activities

To assess children's conceptual processes during the intervention activities, the researcher developed a coding table (see Appendix G), focusing on children's behaviors, answers, and patterns of their actions. Based on the coding table, the raw data was mined for evidence of logic or protologic: compensation and reversibility, coherence, and coordination. They were assessed according to operational definitions based on Piaget's theory of operations, as follows:

1. Compensation: Action opposed to and tending to cancel or equalize some effect. For example, when a bar tilted, the child made it level by adding something to the higher side of the bar, or taking something off from the lower side of the bar, or moving hanging objects along the bar, etc.

Reversibility is another necessary factor for building operational reasoning and is closely related to compensation. According to Inhelder and Piaget (1955/1958), reversibility is "the permanent possibility of returning to the starting point of the operation in question" (p. 272) and one of its forms is the ability "return to the starting point by compensating a difference" (p. 272). It can be defined as the ability to carry out an action in two opposite directions, while being conscious of the fact that it is the same action; and the ability to know that something can be returned to its former state. For example, when building mobiles, some children put the same size of shapes or same length of bars on the opposite side of a bar at the same time and at the same distance from the fulcrum. Children compensated the movement of the bar at once and could anticipate what would happen if the shapes or bars were taken off.

2. Coherence: This term refers to a lack of coherence in logic as a whole that is characteristic of operational logic. Young children do not show consistent reactions to the objects if they do not have coherence of their logical system. For example, when

making a tilted primary balance straight, a child adds objects to the end that is up (lighter end), but sometimes the child adds objects to the end that is down. The child does not show consistency in reacting to a tilted bar. This means the child does not have a firm understanding of all variables and is not able to anticipate and predict how the bar would react.

3. Coordination: This means considering and/or using variables together. This involves constructing new relationships that go beyond what can be observed by putting and/or using variables together. For instance, when the experimenter asked a seven-year-old girl to make an unequal arm balance, she succeeded for putting more cubes on the shorter side of the beam. Her actions suggest that she is coordinating two relationships: the relationship between mass and action of the balance (given equal arm lengths, the heavier side will go down) and the relationship between mass and distance (given equal mass, the longer arm will go down).

4. Contradiction: There are two kinds of contradiction. One is where a child's expectation is not borne out by what the objects do (external contradiction). For instance, a six-year-old child was asked what would happen if a cube was dropped into each pan of a scale at the same time. The child answered both pans would go down at the same time. When she found that it did not happen, she felt an external contradiction that Piaget calls negation in action. The second kind of contradiction, an internal contradiction, occurs totally within the mind of the knower. This is related to conceptualized negation.

Videotapes of the intervention activities were transcribed using a kind of figural shorthand to describe each child's actions. An example of figurative coding of children's actions and verbalizations is shown in Appendix H.

Data Analysis

Tapes that showed children's unique thought were transcribed. In the transcription, any evidence of children's reasoning related to the law of balance and the logic/protologic was marked with highlighter for further analysis. The coding form shown in Appendices E and G was completed using information provided by the videotapes.

For the pretest and posttest, two steps were taken for coding. First, while watching each video, the coder marked all of each child's answers on a coding table (see Appendix E) containing all the questions the teacher/experimenter asked the children in the pretest and posttest. Thus, the completed coding table contains all the answers of the children. Next, based on the answers in the coding table for the primary balance and beam balance, another coding table (see Appendix F) with the characteristics of the stages in Piaget et al. (1974/1980) was filled out for each child in order to identify the stage of individual students. Some children showed characteristics of three different stages at the same time. In that case, characteristics of only the two lowest stages were considered in assigning children's stages. The other responses were ignored because showing a characteristic of a lower stage means the child has not fully developed his/her logic to move to the next stage. Moreover, a child cannot develop to the next stage with characteristics of the former stage (Inhelder & Piaget, 1955/1958). However, the researcher considered the transitional stage of a child, so two levels were combined to identify the stage of some children.

For the intervention, three steps were taken for coding. While watching video, the researcher transcribed using words and figural forms indicating what length of a bar a child used; when the child put the hanging objects, which felt pieces or miniature fruit shapes the child choose and where to put them on bars; how the bar react to the compensatory action; and which way – closer to or away from the fulcrum – the child moved the hanging objects. Beside the child's process of making mobiles, the child's critical behaviors, such as puzzlement, Eureka moments, frustrated behavior, answers, cooperation, and some dialogue between the child and the teacher/experimenter, of the child were indicated. Based on the transcription, the researcher made some analytical notes of the child's performance such as how many tiers the child built, whether the actions were consistent or not, compensatory actions, and other characteristics related to the concept of balance in making mobiles. At the last step, the researcher made analytical notes for each child's key behaviors in the three the intervention sessions such as if the child show compensatory actions or not, how he/she did the, if they were consistent or not, if coordination actions were shown or not, if the child showed cooperative behaviors, frustration, Eureka moments, moments of reflection, how the mobiles the child built looked like, and any other important behaviors.

For intervention activities, some children did not say much and were not expressive. Their paralinguistic cues such as facial expression, private talk, gestures, pauses, and puzzlements were observed, recorded, and coded as well as verbalizations.

CHAPTER IV

RESULTS

The data were analyzed in three parts: (a) stages of development in predictions of movement of a balance in the pretest and posttest, (b) responses related to objects' weight and distance from the fulcrum in the pretest and posttest, and (c) children's reasoning during intervention activities.

Children's Stages in Predicting Movement of a Balance: Pretest and Posttest

Children's stages of development were identified in prediction of movement of a balance in tasks with a balance scale based on the research by Piaget et al. (1974/1980). The main characteristics used in identifying stages are drawn from the study of Piaget et al. (see Table 2). These stages were assigned based on children's responses to the questions asking for predictions about whether and how a primary balance would move if objects are placed in a hanging cup from a primary balance or on a beam balance.

Table 2

Criteria Used in Identifying Stages

Stage	Characteristics
1A	Both cups go down at the same time
	Each cup at a time moves – lack of coordination
1B	Putting an object in one cup does not act upon the cup on the other side of the balance (that is, in a unidirectional way)
	One cup will fall more than the other rises
	Cups will both go down a little bit
	One cup will move first
	Numeric symmetry
2A	Hesitation
	The arms will move at the same time
	The cups will move to the same height
	The cups may just go down a little bit
2B	No hesitation, no confusion, and no difficulty

Data analysis indicted that some children showed certain characteristics, for instance, of both Stage 1A and Stage 1B at the same time. For example, Adam (9;2) answered that both cups would go down and one cup would move first (characteristics of Stage 1A) when one cube was put in the cup of one side. At the same time, he also showed numeric symmetry in balancing (a characteristic of Stage 1B). The researcher interpreted this finding as an indication the children are in a transitional stage. C. Kamii (personal communication January 22, 2003), one of the authors of the study with Piaget, agreed with this interpretation. Thus, Stage 1A/1B and Stage 1B/2A were added to the developmental stages. However, Stage 2A/2B was not added because there is clear distinction between 2A and 2B.

Based on the characteristics shown in Table 2, the subjects' stages of development in the primary balance prediction in pretest and posttest were identified. Table 3 shows the results.

Table 3

Frequencies and Percentages of First- and Third-Grade Subjects' Stages in the Development of Balance Scale Predictions

Grade		Stage						
		1A F (%)	1A/1B F (%)	1B F (%)	1B/2A F (%)	2A F (%)	2B F (%)	Total F (%)
1	Pretest	1 (10)	3 (30)	3 (30)	2 (20)	1 (10)		10 (100)
	Posttest			3 (30)	5 (50)	1 (10)	1 (10)	10 (100)
3	Pretest		2 (17)			3 (25)	7 (58)	12 (100)
	Posttest				4 (33)	1 (8)	7 (58)	12 (100)

The first graders are distributed across a range from Stage 1A to Stage 2A in the pretest and from Stage 1B to Stage 2B in the posttest. The third graders are distributed across a range from Stage 1A/1B to Stage 2B in the pretest and from Stage 1B/2A to Stage 2B in the posttest. The result of this study was a little bit inconsistent with the findings of Piaget et al. (1974/1980). They did not provide quantitative data in their study, but they stated that most children of 7 to 10 years are in Stage 2A, and most children of 9 to 11 years are in Stage 2B. In contrast, in the current study, only one first-grader was at 2A and one first-grader was at 2B in posttest. Seven third graders (58 %) were at 2B in both the pretest and posttest.

Table 4 shows the distribution of the frequencies of first- and third-grade individual subjects' stages in pretest and posttest.

Table 4

Frequencies of First- and Third-Grade Subjects' Stages in the Development of Balance Scale Predictions in Pretest and Posttest

Grade		Posttest					
	Pretest	1A	1A/1B	1B	1B/2A	2A	2B
1	1A			1			
	1A/1B			2	1		
	1B				3		
	1B/2A				1	1	
	2A						1
	2B						
3	1A						
	1A/1B				2		
	1B						
	1B/2A						
	2A				1	1	1
	2B				1		6

Table 5 shows how many children progressed, made no change, and regressed from pretest to posttest.

Table 5

Frequencies and Percentages of First- and Third-Grade Subjects Who Progressed, Made No Change, and Regressed from the Pretest to Posttest in Balance Scale Prediction

Grade	Progressed F (%)	No Change F (%)	Regressed F (%)
1	9 (90)	1 (10)	
3	2 (17)	8 (67)	2 (17)

Almost all first graders demonstrated more advanced levels of balance concepts in the posttest than the pretest. The third graders' distribution is puzzling. As shown in Tables 3 and 4, although most subjects scored at the same level or higher in the posttest, 1 third grader at Stage 2A moved down to Stage 1B/2A on the posttest and 1 third grader at Stage 2B moved down to Stage 1B/2A. This might be because their concept of balance is not operationally firm, so their reaction is inconsistent. Seven third graders were already at the highest stage on the pretest, and 6 children remained at this level on the posttest.

The interview in this study was not limited to the equal-arm pan balance used by Piaget et al. (1974/1980). In order to further explore children's reasoning about the balance, additional situations were designed, as described in chapter III, inspired by Inhelder and Piaget's research (1955/1958) and Kliman's (1987) using a balance scale, with variations of weight and distance from a fulcrum. Seven third graders in the current study reached the ceiling on the task of Piaget et al. They were able to answer all the questions of pretest and posttest without hesitation with correct predications. The research by Piaget et al. focused on the variable of weight but not distance from the fulcrum whereas Inhelder and Piaget studied both variables of weight and distance. The problems posed by Inhelder and Piaget were therefore more difficult than those posed by Piaget et al. It seemed appropriate to consider how the 7 third graders at the highest stage in the Piaget et al. interview appeared in relation to the stages presented by Inhelder and Piaget. In this study, 5 children out of the 7 scored in Inhelder and Piaget's Stage II-a. They showed the same concrete operations in weight and distance (from the fulcrum) but exhibited a lack of systematic and consistent coordination of weight and distance. For instance, in the situation of unequal arm balance (see Figure 9, p. 63), one child moved the blue cup that was hung on the shorter side of the bar closer to the fulcrum a little bit. Then she moved the red cup that was hung on the opposite side closer to the fulcrum. She adjusted the distance from the fulcrum by trial-and-error. One child out of 7 scored in Stage II-b of Inhelder and Piaget's study. The child was able to achieve balance with unequal weights and/or with unequal distance situations. However, she could not generalize the relation between weights and distance to all different situations. One child was in Stage III-a. Considering the fact that Inhelder and Piaget said that Substage III-a appears in 12-year-old or older children, this result is extraordinary. Although the current research did not focus on the concept of proportionality, as Inhelder and Piaget did, using number and distance, children of this study did not have a chance to demonstrate their reasoning on distance and weight using number. However, the child in Stage III-a could apply the law of balance, as described in chapter II in practice although he could not explain exactly how he did it and why it worked. None of the children were in Stage III-b, the highest level, where children do not have any problem explaining the law of balance and applying it. The children's answers to questions related to distance from the fulcrum (for instance, putting two cubes in the red cup and putting one cube in the blue cup) were analyzed to make this distinction. The results of each question are discussed in the next section.

Pretest and Posttest Questions Related to Weight and Distance from a Fulcrum

Five categories of questions were presented to assess the subjects' understanding of the relationship between objects' weight and distance from the fulcrum (see Appendices B and C for interview protocol). Two categories of questions (discussed below) with the primary balance and one category of questions with the beam balance were not asked in the pretest session because they are related directly to the intervention activities and thus might have influenced the intervention results.

In one additional situation, two different kinds of cereal in identical cups were shown to children and the children agreed they held the same amount of cereal. Then, children were asked what would happen when sugar-coated cereal is poured in a cup on one arm of the balance and the same amount of plain corn-flake cereal is poured in a cup hanging from the other arm of the balance. This question was asked to examine the subjects' reasoning about mass and volume – in other words, how children perceived the weights of hanging cups with the same volume but different mass. This is an advanced question to assess the subjects' level of reasoning in light of considering two variables at the same time. Table 6 shows how children responded to this question.

Table 6

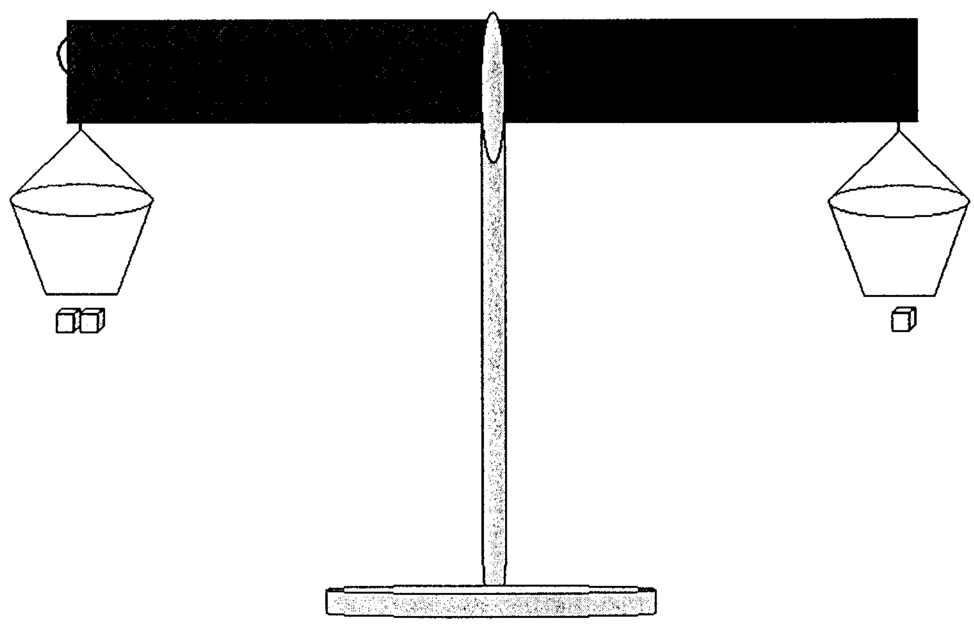
Frequencies and Percentages of First- and Third-Grade Subjects' Predictions in the Pretest and Posttest about Sugar-coated Cereal Vs. Plain Cereal (Same Volume but Different Mass)

Answers	Grade			
	1		3	
	Pre F (%)	Post F (%)	Pre F (%)	Post F (%)
Sugar-coated cereal will go down			**2 (17)**	**3 (25)**
It would be balanced	8 (80)	8 (80)	6 (50)	5 (42)
One would be heavier than the other	2 (20)	1 (10)	2 (17)	3 (25)
Don't know		1 (10)	2 (17)	
Did not ask				1 (8)

Most first graders (80% in both pretest and posttest) and almost half of third graders (50% in pretest and 42% in posttest) believe that if two cups have the same amount, they will weigh the same. Two third graders (17%) in the pretest and three (25%) in the posttest answered correctly that the sugar-coated cereal would weigh more. Five children responded their weight is different because their size is different (sugar-coated one is thicker and bigger, according to their explanation). Some children confused volume with number. Two children responded they needed to count the pieces of cereal to see if they are the same amount or not.

The next questions were: if two cubes are put into the red cup, and one cube is put into the blue cup (see Figure 7), what would happen? After children predicted the answer to the question, they saw the result. Then they were asked if there is any way to make the bar level without putting in or taking out cubes from the red cup and/or the blue cup. This question was asked just on the posttest.

Figure 7. Two cubes in one cup and one cube in the other cup.



This question focuses on children's numeric asymmetry to see their reasoning about unequal weights at equal distances from the fulcrum. To make the bar balance without using more cubes, children need to move the cup with two cubes closer to the fulcrum. Or they can change the fulcrum by moving the bar to the side of the cup with one cube. Table 7 shows children's reasoning on this question.

Table 7

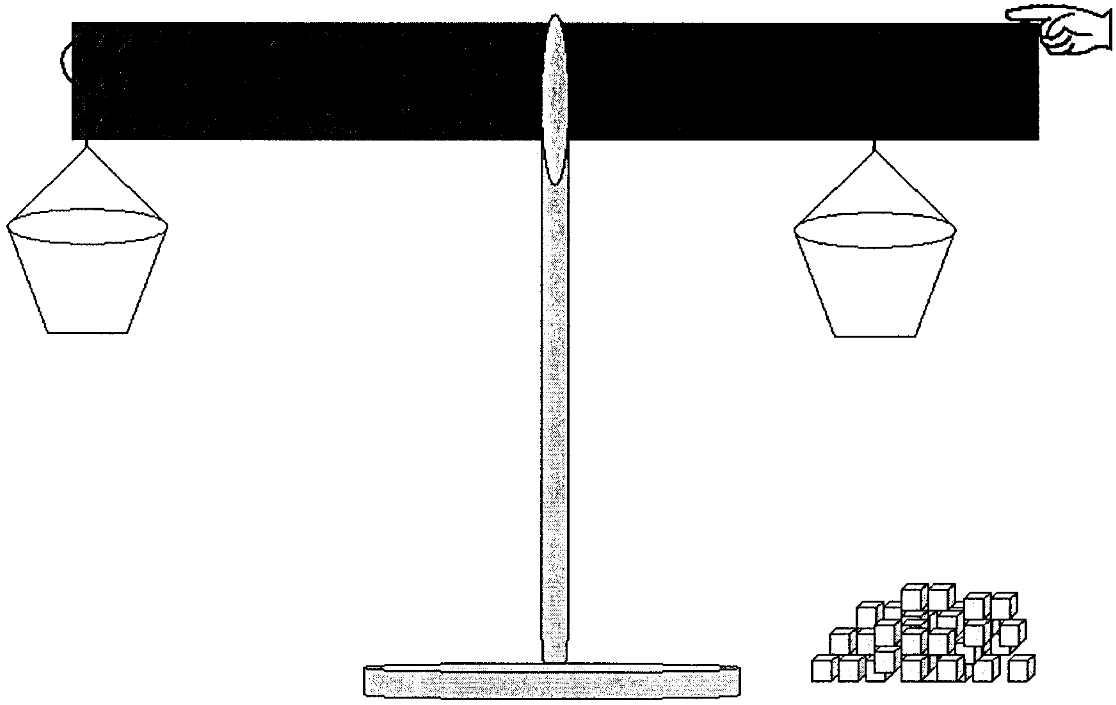
Frequencies and Percentages of First- and Third-Grade Subjects' Predictions in the Posttest about Movement of the Balance: Unequal Weight at Equal Distance

	Grade	
	1	3
Questions and Answers	F (%)	F (%)
What will happen?		
Two cubes will go down because heavier	**8 (80)**	**12 (100)**
Stay same	1 (10)	
Did not ask	1 (10)	
Can you make it level without using more cubes?		
Yes (makes it level)	1 (10)	3 (25)
No (does not make it level)	8 (80)	8 (67)
Did not ask	1 (10)	1 (8)

Eight first graders and all third graders predicted correctly that the cup with two cubes would go down when a different number of cubes are put in each cup. This is not surprising because most subjects showed the numeric symmetry concept in the pretest. However, for the second question, most subjects (80% of first graders, 67% of third graders) answered that it is impossible to make the bar level without using more or lesser cubes because one cup has two cubes and the other cup has one. They did not think about the possibility of moving the cups to make the bar level. However, it could be that children did not think they were allowed to move the cups along the bar or change the fulcrum. Two third graders tried to make the bar level even though they predicted they could not make it level without using more or lesser cubes. Judith (8;7) moved the blue cup, the cup with one cube, closer to the middle, which is the wrong direction. The other child, Jordan (9;0) moved the bar to change the fulcrum to the side of the cup with two cubes, which is the wrong direction.

The next question used the equal-arm-balanced situation and was only asked on the posttest. One cup was moved to the sixth hole of one side of the bar (see Figure 8).

Figure 8. Equal weight and unequal distance.



The interviewer held the bar level and asked children what would happen if the bar were let go. After the children predicted what would happen, the teacher/experimenter let go of the bar and children saw the left side go down. Then they were asked if there was any way to make the bar level using cubes and without using cubes. Table 8 shows the responses of children on this question.

Table 8

Frequencies and Percentages of First- and Third-Grade Subjects' Predictions in the Posttest about the Effect of Cups at Unequal Distance from the Fulcrum

	Grade	
	1	3
Questions and Answers	F (%)	F (%)
What will happen?		
Left will go down	**2 (20)**	**4 (33)**
R will go down	8 (80)	8 (67)
Can you make it level?		
Using cubes		
Yes, I can (Succeeded in making it level)	8 (80)	5 (42)
No, I cannot		
Did not ask	2 (20)	7 (58)
Without using cubes		
Yes, I can (Succeeded in making it level)	6 (60)	10 (83)
No, I cannot	2 (20)	
Did not ask	2 (20)	2 (17)

This is to test children's reasoning about equal weight in a situation of unequal distance of cups from the fulcrum. To answer the first question, children must consider distribution of weights in a balance system. In other words, children should know that if cups are equal in weight, the relative weight of the right side of the bar would decrease the closer the right cup is to the fulcrum. Eight children (80%) in first grade and 8 children (67%) in third grade predicted that the right side of the bar would go down, which is a wrong answer. The reasons given were:

- Weight:
    - "This part (the bar to the right side of the cups) sticks out." (Alex P., 6;2)
    - "The right side has more weight." (Justice, 6;3)
    - "The bar left behind (to the right of the cups) is heavier so it will make it go down." (Montana, 8;3)
    - "It (the left side cup) has less weight at right here (in the end of the left side)...." (Jensen, 8;9)
- Distance from the fulcrum:
    - "It (the left side cup) is farther (from the middle, fulcrum)." (Brian, 6;10)
    - "It (the right side cup) is closer to the middle and heavier." (Ryan, 7;1)
    - "When we make mobiles, if we put in the end, it goes up." (Juliann, 8;5)
- Different placement:
    - "It (the right side cup) is put in a different place." (Danielle, 6;7)
    - "It (the right side cup) is moved." (Blake, 6;11)
    - "You moved it (the right side cup) in: the weight will pull down (the left side cup)." (Leon, 8;4)

- No specific reason:
    - "Don't know." (Annaman, 6;4)

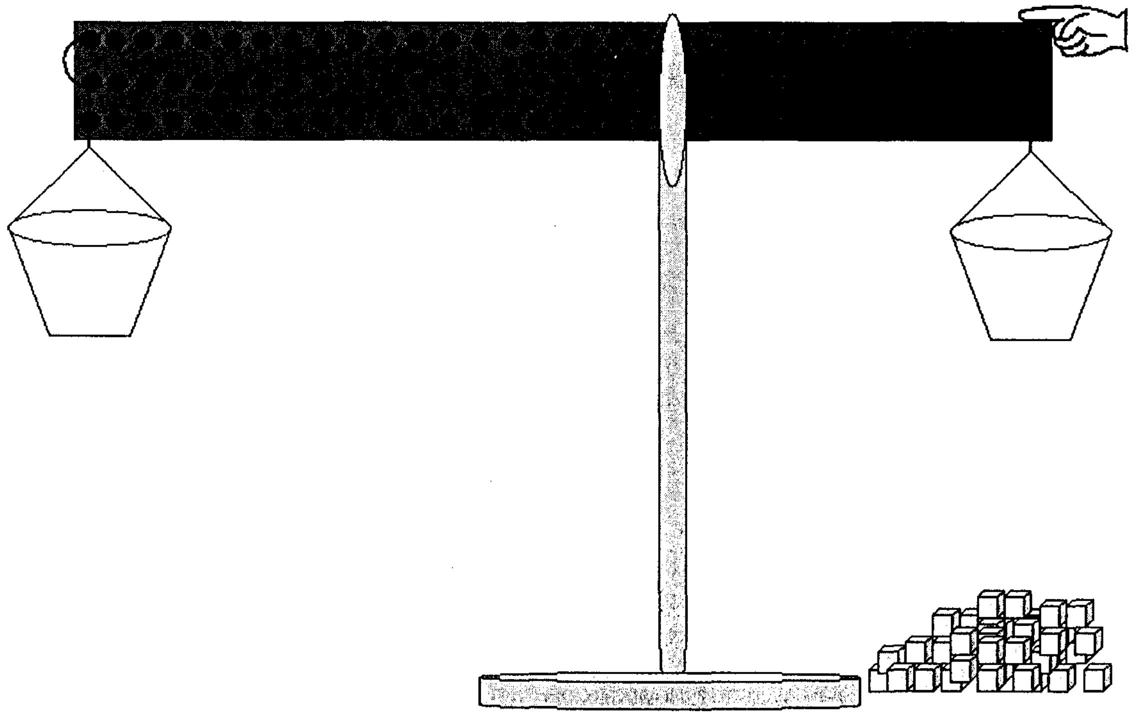
Two (20%) first and 4 (33%) third graders predicted that the left side of the bar would go down, which is the correct answer. The reasons given were:

- Weight:
    - "The right side is smaller (from the middle, fulcrum) than used to be, so it will go up. The right side is shorter." (Amelia, 7;0)
    - "The edge (left side) is heavier." (Janae, 8;5)
    - "The left side has more weight than the right side." (Judith, 8;7)
    - "Closer to the end, it gets heavier." (Josse, 9;0)
- Distance from the fulcrum:
    - "The left side is on the end so it will go down." (Nick, 6;9)
    - (She was wrong at first. After she saw what happened) "I forgot. Whatever in the end will go down." (Allison, 8;4)
    - "The left side might go down because usually outside goes down more." (Jaren, 8;6)

Although most children could not predict correctly how the bar would react to the change in placement of the cup, many children (6 first graders and 10 third graders) were able to make the bar level without using more cubes. All those children simply moved the cup to the middle or end to make it level. Children thus succeeded in making the bar level at the practical level but not at the conceptual level (as matched by prediction).

Another situation was presented where the bar was an unequal arm balance (see in Figure 9).

Figure 9. Unequal arm balance.



While holding the bar, the teacher/experimenter asked children what would happen if the bar were let go. Children saw the result and were asked if they could make the bar level using cubes and without using cubes. Children were probed as to why they predicted as they did. Table 9 shows the results.

Table 9

Frequencies and Percentages of First- and Third-Grade Subjects' Predictions and Actions in the Pretest and Posttest about the Unequal-Arm Balance

	Grade			
	1		3	
Questions and Answers	Pre F (%)	Post F (%)	Pre F (%)	Post F (%)
What will happen?				
Left will go down	**5 (50)**	**6 (60)**	**9 (75)**	**8 (66)**
R will go down	3 (30)	4 (40)	2 (17)	4 (33)
One side might go down	1 (10)			
Was not sure	1 (10)		1 (8)	
Can you make it level?				
Using cubes				
Yes (make it level)	9 (90)	9 (90)	11 (92)	10 (83)
No (cannot make level)	1 (10)	1 (10)		
Did not ask			1 (8)	2 (17)
Without using cubes				
Yes (makes it level)		5 (50)	7 (58)	9 (75)
No (cannot make level)	4 (40)	5 (50)		3 (25)
Don't know	1 (10)		1 (8)	
Did not ask	5 (50)		4 (33)	

Many children were able to reason without difficulty that the longer side of the bar would go down in both pretest (half the first graders and 75% of third graders) and posttest (60% of the first graders and 66% of third graders). That might be because the children could see the physical clue that one side of the bar is longer than the other side. Therefore, they reasoned that: one is longer → longer is more → more is heavier.

Half of the first graders (50%) and over half of the third graders (75%) were able to make the bar balance without using cubes in the posttest. This shows the children's practical reasoning of compensation putting a bar back to the middle makes the bar level.

To further check children's concept of balance, the researcher provided a beam balance and asked questions. Some of questions were the same as ones that were asked with the primary balance, and some of them were new for this situation. Table 10 shows the results of children's responses on the questions with the beam balance.

At first, children were asked what would happen if one cube (then two cubes) were put on one side of the beam and how far it would go down or up. Most first graders (89%) and all third graders were able to answer correctly in posttest. Table 10 shows two ways first graders proposed making the beam level: taking cubes off and adding a cube. Taking cubes off reverses the action, and adding cubes to make the same number of cubes both sides cancels the reaction of the beam.

Table 10

Frequencies and Percentages of First- and Third-Grade Subjects' Predictions in the Pretest and Posttest to Questions and Answers about a Beam Balance

Questions and Answers	Grade 1 Pre F (%)	Grade 1 Post F (%)	Grade 3 Pre F (%)	Grade 3 Post F (%)
Put cubes on one side of the beam				
What would happen?				
The side with a cube(s) will go down	**10 (100)**	**9 (90)**	**12 (100)**	**12 (100)**
Both will go down		1 (11)		
The way children make it level				
Take cubes off	3 (30)	3 (30)		
Add cubes to make number equal	6 (60)	5 (50)	12 (100)	5 (42)
Add by trial - error	1 (10)	1 (10)		
Did not ask		1 (10)		7 (58)
Can you make it level when I put three cubes on one side and two cubes on the other side?				
Yes, I can (makes it level)	--	5 (50)	--	7 (58)
No, I cannot (does not make it level)	--	4 (40)	--	4 (33)
Did not ask	--	1 (10)	--	1 (8)
Move the fulcrum to the right, no cube				
What would happen?				
Left side will go down	**9 (90)**	**9 (90)**	**12 (100)**	**12 (100)**
Right side will go down		1 (10)		
It will be level	1 (10)			
Can you make it level?				
Using cubes (makes it level)				
Yes (makes it level)	9 (90)	10 (100)	12 (100)	12 (100)
No, I'm not sure	1 (10)			
Without using cubes				
Yes (makes it level)	8 (80)	7 (70)	10 (83)	10 (83)
No, I can't (does not make it level)	2 (20)	1 (10)		
Did not ask		2 (20)	2 (17)	2 (17)
Makes relation to the primary balance		1	3	1

The next question was asked only in the posttest with the beam balance: Can you make the beam level with three cubes on one side and two cubes on the other side (of the beam with both ends of the beam equidistant from the fulcrum)?

In this numeric asymmetry situation, children were challenged to consider the possibility of changing the distribution of the cubes or moving the fulcrum to make the beam level. Five first graders and 7 third graders were able to make the bar level by putting three cubes on one side and two cubes on the other side of the beam. Some of them put three cubes on one side and two cubes on the other side, then moved the bar to the side of the beam with two cubes so the side with two cubes gets longer (see Figure 10). This shows the children have an idea about the necessity for compensation of distance when there is unequal weight. Others kept the fulcrum and varied the placement of cubes like spreading the three cubes across one side of the beam and put two cubes on one spot together (Figure 11), or moving two cubes to the far end of the beam and putting a cube on the top of the fulcrum (see Figure 12). That also shows awareness of the necessity for compensatory relations among distances from the fulcrum and distribution of weights.

Figure 10. How some children moved the fulcrum when three cubes were on the shorter side of the beam, and two cubes were on the longer side.

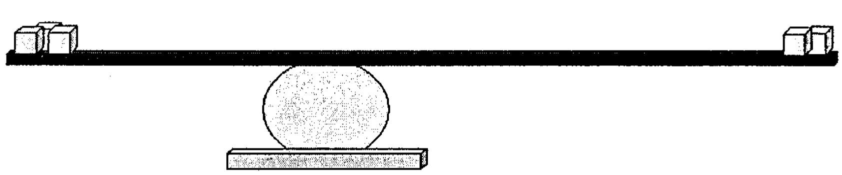


Figure 11. How some children kept the fulcrum and spread the three cubes out across one side.

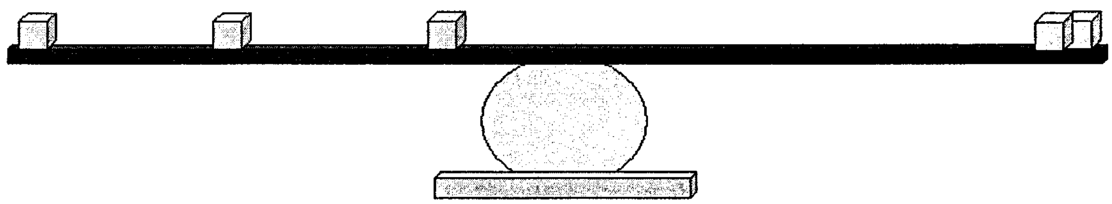
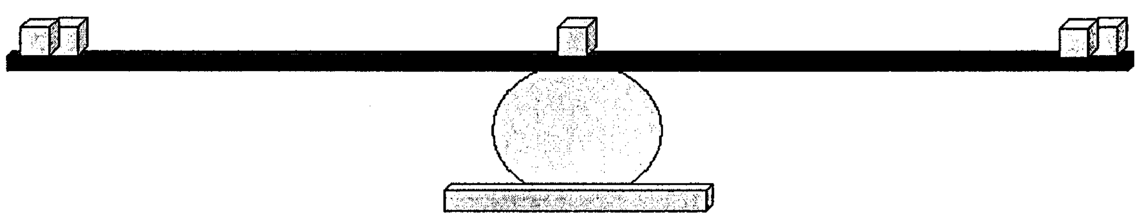
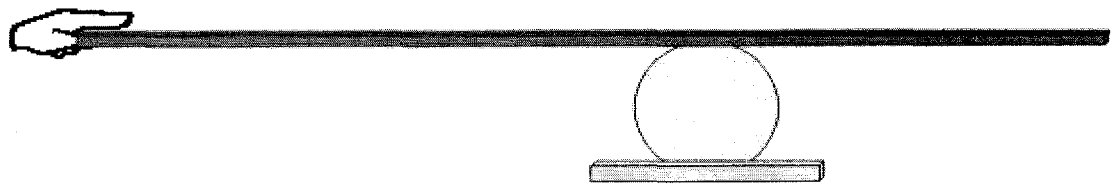


Figure 12. How some children kept the fulcrum and put one cube on the fulcrum, and two cubes at the end of each side.



Next, after moving the beam to the left side (moved the fulcrum of the beam, see Figure 13), the teacher/experimenter asked children what would happen if the bar were let go and why. After children predicted the possible result, the bar was let go so the children could see the actual result. They were then asked to make it level using the cubes and without using the cubes.

Figure 13. Unequal-Arm beam balance.



These questions were easy for almost all first graders (90%) and all third graders. Overall, children showed better performance on the questions with the beam balance than the primary balance. For instance, the question of making the beam level in putting three cubes on one side and two cubes on the other side is the same as that presented in the primary balance, shown in Figure 7, in light of balancing in a situation of unequal weight and equal distance. However, more children (5 first- and 7 third-graders), compared to the number of children in the primary balance situation (1 first- and 3 third-graders) gave the right answer to the questions. C. Kamii (personal communication, January 22, 2003) suggested that children perceive differently situations of *pulling down* (the primary balance) and *pressing down* (the beam balance). Another possible reason is that the number of variables children need to consider differ with each apparatus. The primary balance apparatus included the bar, the stand as a fulcrum, and two hanging cups. On the other hand, the beam balance apparatus has only a beam and the ball as a fulcrum. It has nothing equivalent to the two hanging cups of the primary balance. This means the primary balance contains one more variable than the beam balance, therefore, children need to coordinate more variables. In future research, it would be interesting to see how children would respond to this task with the primary balance without the cups (that is, by using weights on posts across the top of the bar). Another possible reason also could be that the beam balance resembles a see-saw, which many children have prior experience with, so they could make connection between them.

In sum, before the intervention all children had the idea that weight makes things go down; 13 (3 first graders and 10 third graders) children had the idea that longer/ farther from the middle, the weight is greater; and 6 (2 first graders and 4 third graders) children considered weight and distance at the same time to balance. After the intervention, all children had the idea that weight is related to balance; 16 children (6 first graders and 10 third graders) had the idea that distance is related to balance; and 6 children (2 first graders and 4 third graders) among the 16 children considered weight and distance at the same time to balance.

Intervention: Making Mobiles

Practices based on the following constructivist principles of teaching were implemented in the interventions: (a) the setting was social (that is, two children participated in making mobiles at the same time), (b) children were encouraged to cooperate with each other, (c) reference materials (pictures of various mobiles) that might facilitate children's performance were provided, (d) the teacher/experimenter asked provocative questions, (e) the teacher/experimenter offered help, (f) children's desire to end the activities was respected, and (g) children were allowed to freely explore the materials.

Three sessions of making mobiles were conducted in order to provide a constructivist activity related to balance. When asked whether they had ever seen mobiles before, all except four first graders answered that they had. However, just one child in the third grade had experience in making mobiles. The children who had seen mobiles were not familiar with the term "mobiles" and how they worked. Table 11 shows the length of each of the interventions in each grade.

Table 11

Range and Mean Length of Time for First- and Third-Grade Subjects Intervention

Grade	Intervention I		Intervention II		Intervention III	
	Range (Min:Sec)	Mean (Min:Sec)	Range (Min:Sec)	Mean (Min:Sec)	Range (Min:Sec)	Mean (Min:Sec)
1	10:58 ~ 23:32	17:07	12:29 ~ 19:38	16:30	10:35 ~ 20:17	16:58
3	11:42 ~ 20:19	15.53	10:17 ~ 27:43	19.82	16:02 ~ 27:39	20.31

The overall range is large in both first and third grade. However, the mean length of time the first graders engaged in the interventions was relatively stable through the interventions. In contrast, the third graders participated longer in Interventions II and III than Intervention I. Third graders engaged in Intervention II and III longer than the first graders.

The sequences of children's actions in the intervention activities were all transcribed using figural forms and abbreviated signs (see Appendix H for an example).

The Levels of Mobiles Children Built

Children's performance levels were assessed in terms of the number of tiers their mobiles contained. Table 12 shows results.

Table 12

Frequencies and Percentages of First- and Third-Grade Subjects Who Made One-, Two-, and Three-Tier Mobiles

	Grade					
	1			3		
Performance	I F (%)	II F (%)	III F (%)	I F (%)	II F (%)	III F (%)
Succeeded						
One tier	8 (80)	7 (70)	7 (70)	8 (67)	6 (50)	5 (42)
Two tier	2 (20)	1 (10)	1 (10)	4 (33)	5 (42)	6 (50)
Three tier			1 (10)			1 (8)
Failed		2 (20)	1 (10)		1(8)	

Children built mobiles having from one- to three-tiers (see Figure 14, Figure 15, and Figure 16 for examples). One-tier mobiles have one fulcrum. In other words, even though some mobiles have many levels, if the mobiles have one fulcrum, they are one-tier mobiles (see B of Figure 14).

Figure 14. Examples of one-tier mobiles.

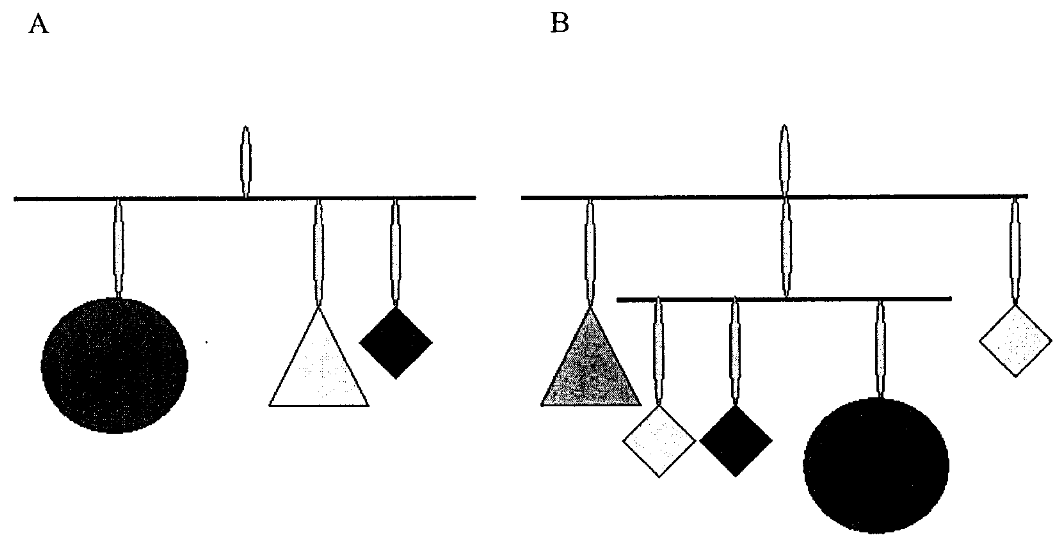


Figure 15. Examples of two-tier mobiles.

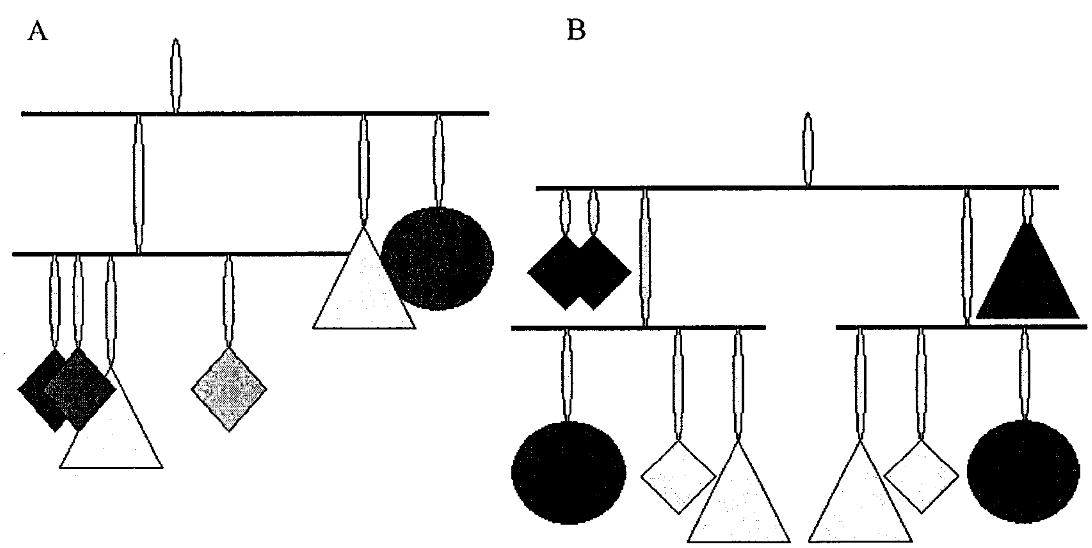
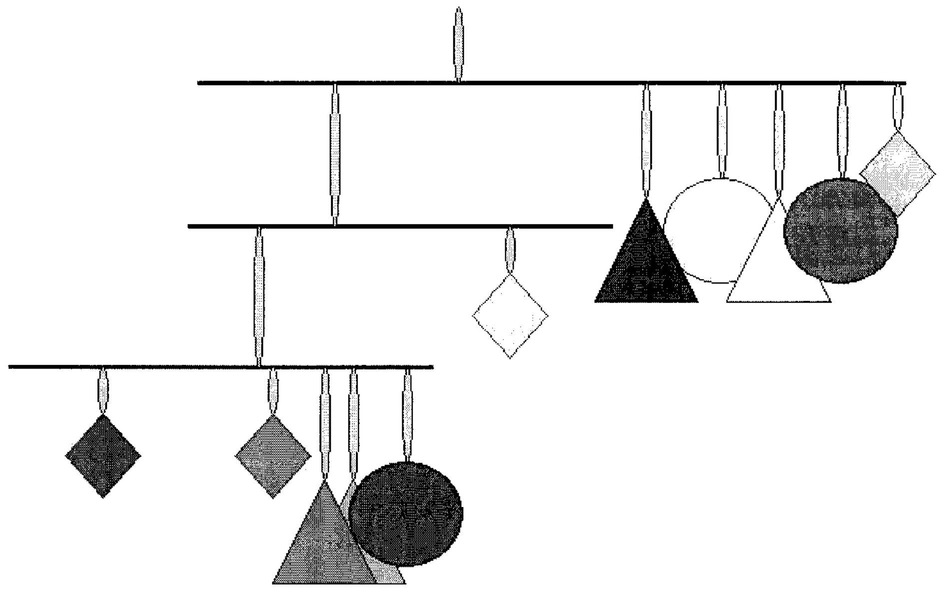


Figure 16. Example of a three-tier mobile.



All children from both grades succeeded in building balanced mobiles of at least one tier with many levels in Intervention I. In Intervention II, 80% of first graders built balanced mobiles with bars having eye-screws on an off-center position. This percentage increased to 90% in Intervention III. One child at each grade succeeded in building three-tier mobiles in Intervention III. More third graders were able to build mobiles with more than one-tier than were first graders. Table 13 shows achievement of individual first- and third-grade children in the pretest, interventions, and posttest.

Table 13

Number of Tiers Built by Individual First- and Third-Grade Subjects' in Three Interventions and Their Stages in the Pretest and Posttest

Grade	Name		Stage and Tiers				
			Pretest	Inter. I	Inter. II	Inter. III	Posttest
1	Amelia *	(7;0)	1A	1	1	1	1B
	Daniel *	(6;7)	1A	1	1	1	1B
	Blake *	(6;11)	1A/1B	1	FAILED	FAILED	1B
	Ryan *	(7;1)	1A/1B	2	1	3	1B
	Aja *	(6;6)	1B	1	1	1	1B/2A
	Justice *	(6;3)	1B	1	FAILED	1	1B/2A
	Nick *	(6;9)	1B	1	2	1	1B/2A
	Brian	(6;10)	1B/2A	1	1	1	1B/2A
	Annaman *	(6;4)	1B/2A	2	1	2	2A
	Alex P. *	(6;2)	2A	1	1	1	2B
3	Adams *	(9;2)	1A/1B	2	1	1	1B/2A
	Janae *	(8;5)	1A/1B	1	2	2	1B/2A
	Jensen	(8;9)	2A	1	FAILED	1	1B/2A
	Allison	(8;4)	2B	1	2	1	1B/2A
	Leon	(8;4)	2A	1	1	2	2A
	Jordan *	(9;0)	2A	2	1	2	2B
	Alex S.	(8;10)	2B	2	2	2	2B
	Jaren	(8;6)	2B	1	1	3	2B
	Josse	(9;0)	2B	1	1	2	2B
	Judith	(8;7)	2B	2	2	2	2B
	Juliann	(8;5)	2B	1	2	1	2B
	Montana	(8;3)	2B	1	1	1	2B

Note. * means children who made progress from pretest to posttest.

One first grader failed to build a mobile of even one-tier in Interventions II and III. He commented that "It is impossible" to build a mobile with the bars when eye-screws were off-center. Except for one child (10 %), all first graders performed at the same or better level in Intervention III than Intervention II. Except for two children (17%), all third graders performed at the same or better level in Intervention III than Intervention II. Some interesting findings were shown through interventions.

First, some children who were identified in higher stages in pretest showed low levels of performance in making mobiles. A first grader showed Stage 2A reasoning in the pretest and Stage 2B in the posttest. However, he could build only one-tier mobiles through the three interventions although he explained correctly how the bars would react and showed coherence in making bars level. He might simply have not been aware that gentle movement might help things stay on bars. However, one possible reason for his failure is his lack of fine-motor skill (Chen, Isberg, & Krechevsky, 1998; Robinson, 1982). When he put objects on bars, he almost dropped them carelessly. In contrast, Jaren (8;6) who succeeded in building a three-tier mobile in Interventions III was very gentle and skilled in dealing with materials.

One child in first grade failed to build mobiles in Interventions II and III. He hung felt pieces showing symmetric reasoning in shape, number, and color. It is not clear whether he did this for the physics aspect or the aesthetic aspect of the project. However, considering that more children showed symmetry in shape and number than in color, his symmetric reasoning in color might be closer to an aesthetic aspect rather than a scientific aspect. In the posttest, the child could explain why one side of the beam had many cubes and the other side had none; and he succeeded in making the beam level by putting three cubes on side and two cubes on the other side. His comment on that question was, "It's easy." He spread the three cubes on one side of the beam and put two cubes together on the other end of the beam. He certainly had the concept of distribution of weight. He might not able to apply his knowledge into a new setting. Similarly, one child in third grade was identified as Stage 2B in both the pretest and posttest. However, she showed frustrations through Interventions II and III and built a one-tier mobile in Intervention III. She could not apply her knowledge into this new situation.

Second, intervention from the teacher/experimenter helped children build mobiles. For instance, one first grader who failed to build mobiles in Intervention II was asked what would happen to the upper bar if the lower bar were moved closer or further from the fulcrum. The teacher/experimenter encouraged him to explore relationship between the distance from the fulcrum and the reaction of bars. Before he was asked the question, he moved objects by trial-and-error, and often appeared frustrated. After the intervention from the teacher/experimenter, he built a one-tier mobile. Another first grader succeeded in making one bar (A) level in Intervention III. He tried to hang one more bar but was not successful. He was not doing anything. The teacher/experimenter asked if he could add one more bar and make it level. Encouraged, he did make another bar level. He added one more bar (B) and added one more bar (C) on B. The mobile became three levels. However, he put B on the fulcrum of A, C on the fulcrum of B, so the mobile was not three tier but one tier. The teacher/experimenter asked him not to put bars right on the eye-screw, which is a fulcrum. He pushed the bars away from the fulcrum little bit, making the bars unlevel, and added hanging objects on the bars to make them level again. He put many hanging objects on C, so the longer side of B got higher. The teacher/experimenter reminded him B was not level. He coordinated the bars and built a three-tier mobile. If there had been no intervention, he would have stopped building the mobile after he succeeded in making a one-tier mobile.

Reasoning in Making Mobiles

Critical behaviors indicating children's reasoning were observed while children engaged in making mobiles. Based on the observed behaviors, children's conceptual processes were assessed during the intervention activities. A coding system focused on three aspects of the cognitive structure of balance – compensations and reversibility, coherence, and coordinations. In addition, attention to the structuring process included consideration of moments of perturbation or contradiction.

Compensation and reversibility. The key concept of balance is to understand the dynamic interactions of weight and distance from a fulcrum. In Intervention III, one advanced third grader experienced this by saying that there were two ways to make the higher side of a bar go down: one is adding shapes onto the high side and the other is moving hanging objects on the high side away from the fulcrum.

First, to make bars level, children could take actions of lowering the high side of the bar and/or raising the lower side of the bar. As noted in chapter III, canceling opposite actions to equalize or counterbalance the situation is called compensation. As discussed in chapter III, compensation is closely related to reversibility. Thus, all compensatory actions are related to the concept of reversibility and are important in assessment of cognitive structure or cognitive structuring. Three types of compensation actions were observed: adding, taking off, and switching. A fourth type of compensation - varying the distance from the fulcrum in order to change the weights - was observed and was discussed separately because varying distance is a big part of the concept of balance.

Adding actions means adding hanging objects or bars to a bar either on the same side or the opposite side. Taking-off action means eliminating objects already on a bar to make the bar level. Switching means to exchange positions of objects already on bars or to change objects already on with other new objects to adjust the total weight of a bar. Table 14 shows the frequencies of children's compensating actions.

Table 14

Frequencies of First- and Third-Grade Subjects' Actions Showing Children's Compensation Reasoning in Making Mobiles

	Grade					
	1			3		
Compensating actions to change weight	I F	II F	III F	I F	II F	III F
Adding objects	10	10	10	12	12	12
Taking off objects	1	1	1	2	4	
Switching objects	1	1	1	1	1	2

As Table 14 shows, the most common action of all (100%) first and third graders was adding hanging objects and/or bars to make bars level. This suggests that adding objects is the first reaction of most children when they see an unbalanced bar and want to make it level. Adding is easier than adjusting distance. This result is consistent with

Inhelder and Piaget's research (1955/1958) showing that children are able to understand compensation of weight in Stage I-b and they are able to function with concrete operations regarding distance in Stage II-a. Few first and third graders used taking off and switching objects to make bars level. The switching objects' actions are discussed further below with the concept of coordination.

The fourth type of compensation to make the bar level is varying the distance from the fulcrum of hanging objects and/or bars. Moving objects means relocating objects by pushing them toward and away from the fulcrum along the bar to adjust distance from the object to the fulcrum to make a bar level. Children's adjustment actions, including a simple action of pushing objects right beside the fulcrum, were observed. However, they did not think of adjusting distance from the fulcrum at first. Children get the distance concept in balancing later than the weight concept in balancing. Through the three intervention sessions, more than half of the children moved hanging objects and/or bars to make bars level. Children who showed compensation behavior repeatedly were asked to explain what would happen if an object were moved closer to or farther from the fulcrum. Table 15 presents data on the number of children who ever used changing placements of objects on bars. Most of the children adjusted the distance from the fulcrum.

Table 15

Frequencies and Percentages of First- and Third-Grade Subjects' Performance on Varying Distance from the Fulcrum in Making Mobiles

	Grade					
	1			3		
	I	II	III	I	II	III
Varying distance	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)
Show	5 (50)	5 (50)	8 (80)	9 (75)	8 (67)	11 (92)
Do not show	5 (50)	5 (50)	2 (20)	3 (25)	4 (33)	1 (8)

Half of first graders (50 %) and over half of third graders (75 %) attempted to adjust objects' distance from the fulcrum in Intervention I. When children showed consistent compensatory actions, the teacher/experimenter asked them what they were doing and why. Some first- and third-graders could explain how their actions affected the bars' movement. For instance, one third grader, Juliann (8;5, Stage 2B) said, "it makes it more balanced if I move the fruits.... If you put more weight...near the center, it will put less weight (on the shorter side) and this will go higher." This child has some understanding of the relation between distance and weight and can explain how distance and weight interact to affect balance.

When children added many hanging objects on bars without attempting to adjust the placement of objects in relation to the fulcrum, the teacher/experimenter asked them if there was any way to make a bar level without adding or taking off objects. The purpose of the question was to remind or to help children to think about the compensatory distance from the fulcrum.

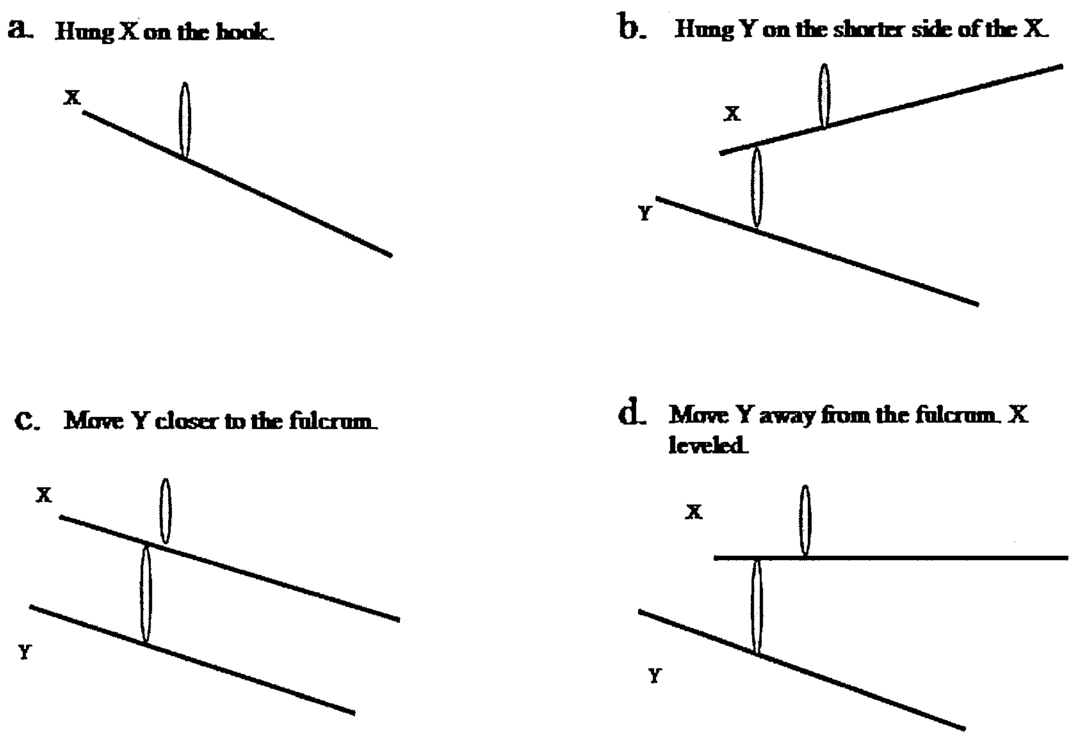
While no systematic findings appeared for the small number of children who were asked the question, results suggested that the question may have helped some children think about moving objects on the high side closer to or away from the fulcrum. Other children simply denied that anything could be done. These findings are rather surprising in light of the fact that Table 15 showed that most children did compensate for distance from the fulcrum while actually making mobiles. One speculation is that this may reflect a difference between practical and conceptual understanding. That is, children can succeed in moving objects closer to or away from the fulcrum without being conscious of the concept. However, Table 22 (discussed below) shows that only 5 third graders were consistent in their compensatory actions, and only 2 explained the physics law of balance (see Juliann, above).

The following example clearly shows how one third grader, Judith (8;7), reasoned according to the logic of the physics law of balance. The dialogue happened in Intervention III where eye screws were off-center.

> Judith hung X on the hook (see a of Figure 17). On the shorter side of the X, Judith put the Y bar on. The shorter side of X bar went down a bit (see b).
>
> Teacher/Experimenter: Is there any way you can make it level without adding any objects?
>
> Judith: (Nods and moves the Y bar closer to the fulcrum of the X bar.) (see c)
>
> Teacher/Experimenter: Does moving make it different?
>
> Judith: Yes, it (Y bar) will get heavier.
>
> Teacher/Experimenter: How about moving to outside? (away from the fulcrum)

Judith:	It (Y bar) will fall.
Teacher/Experimenter:	Why?
Judith:	Because so much weight in here (the shorter side of Xbar).

Figure 17. Example of a child's compensatory action: Adjusting distance from the fulcrum.



Coherence. In situations related to the concept of balance, children's coherence in reasoning can be discussed through how much their action in balancing is consistent. If a child consistently adds objects onto the high side of a bar and moves objects in the right direction along a bar, he or she can be said to have coherence in practical logic concerning balancing. Table 16 shows the frequencies and percentages of children's consistent actions in balancing bars. As shown in Table 18 and 21 (discussed later), children might compensate distance, for examples, in Intervention II but not in Intervention III.

Table 16

Frequencies and Percentages of First- and Third-Grade Subjects' Coherence in Making Mobiles

	Grade					
	1			3		
	I	II	III	I	II	III
Coherence actions	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)
Put things on the high side						
Consistent	2 (20)	4 (40)	6 (60)	12 (100)	10 (83)	11 (92)
Inconsistent	8 (80)	6 (60)	4 (40)		2 (17)	1 (8)
Changed distance from the fulcrum						
Consistent	1 (10)	1 (10)	5 (50)	3 (25)	3 (25)	5 (42)
Inconsistent	4 (40)	4 (40)	3 (30)	6 (50)	5 (42)	6 (50)
Never	5 (50)	5 (50)	2 (20)	3 (25)	4 (33)	1 (8)

In Intervention I, only two first graders demonstrated consistency in putting objects on the high end of a bar when it is not level, while all third graders did so. A reason that so many of the first graders did not demonstrate consistent actions of putting weights on higher side of bars might be because children concentrated on making symmetric arrangements. Moreover, the bars with centered eye screws can be balanced easily by actions of putting objects on each side. In contrast, bars in Interventions II and III require children to put things on the higher side. In Intervention II, 40 percent of first graders show consistency, and the number was slightly increased to 60 percent in Intervention III. Third graders showed stable consistency at or near the ceiling in putting things on the high side in all intervention sessions. Some children never compensated distance, especially in Intervention II where about half of both first and third graders never did so. These were not always the same children in each intervention. That might indicate their logic is not operational, thus, their behaviors showed their protologic.

Following is a dialogue with one third grader, Allison (8:4), who demonstrated coherence in her logic by reasoning consistently:

> Allison hung X bar on the hook. On the shorter (and higher) side of X bar, Allison put one circle. The higher side of X bar went down.
>
> Teacher/Experimenter: Why did you put the circle on this side (shorter side of X bar) not that side (longer side of X bar)?
>
> Allison: Because this side (shorter side of X bar) was up. If I put one here (longer side of X bar), it will go down even more.
>
> Allison applied her logic consistently without making errors.

<u>Coordination.</u> Children's reasoning about coordination could be seen when they were aware of simultaneous effects on bars of at least two tiers of the mobile they were building. Children who did not show coordination actions simply focused on making the bar they were working on level and were not aware of simultaneous movement of the other bars. Children performed coordination actions to make bars level in Interventions

II and III. Only 2 children demonstrated coordination reasoning in Intervention I because most children built only one-tier mobiles. Even some children who succeeded in building two-tier mobiles did not use coordination reasoning. Instead, for example, they used an ineffective strategy, numeric symmetry, to make a lower-level bar balance after an upper-level bar was balanced. Figure 18 is an example showing how a third-grade child coordinated between an upper-level bar (X) and a lower-level bar (Y) to make the bars (X and Y) level in Intervention III.

From putting objects on X, X became level (a). While putting shapes on the shorter end of Y (b), the higher side of X went down (c). The child realized it after she made Y level. Then she put more shapes on the right side of X to compensate. One two-tier mobile was built (d).

Another way some children coordinated the bars was putting shapes alternatively on the upper-level bar and the lower-level bar, keeping the two bars close to level all the time. One third grader who used this strategy explained her reasoning like this: "If you put too much weight on this (a lower-level bar), that one (an upper-level bar) will go down." Some children performed this coordination action by trial-and-error, which means they put hanging objects on the wrong side and/or they could not explain correctly how putting one object on one bar would affect the other bars. However, they *knew* they needed to do something to make both bars level. This is an example in which we can see their protologic.

Figure 18. Example of a child's coordination of tiers in a mobile during Intervention III.

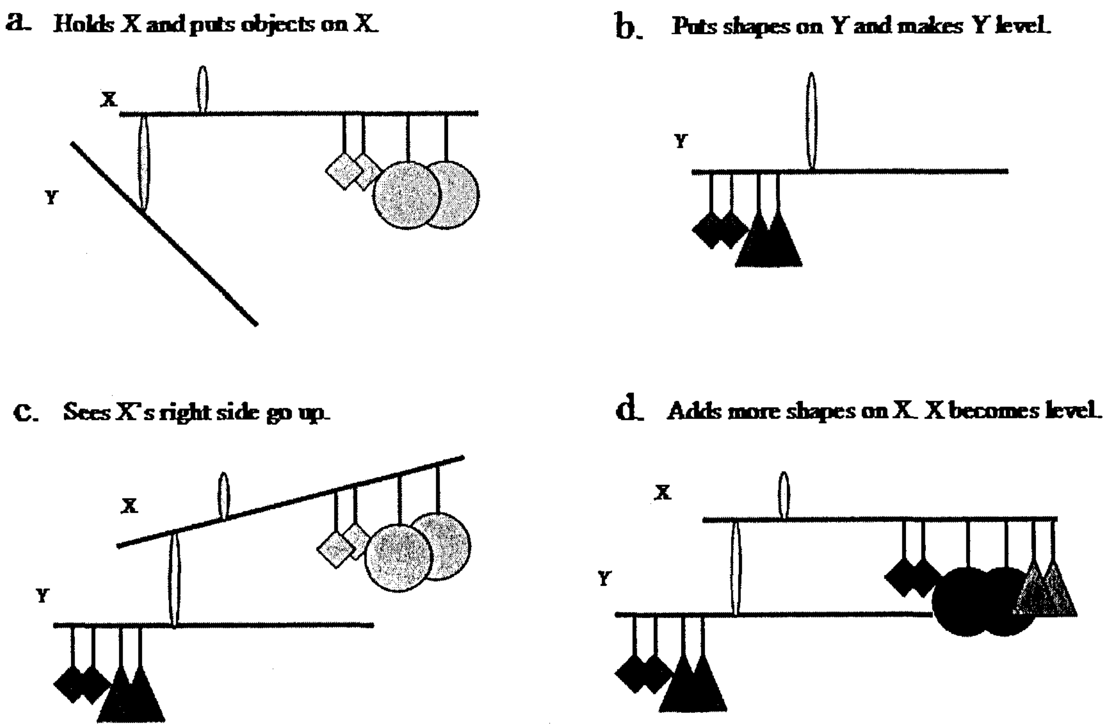


Table 17 shows the number of children who did and did not show coordination actions.

Table 17

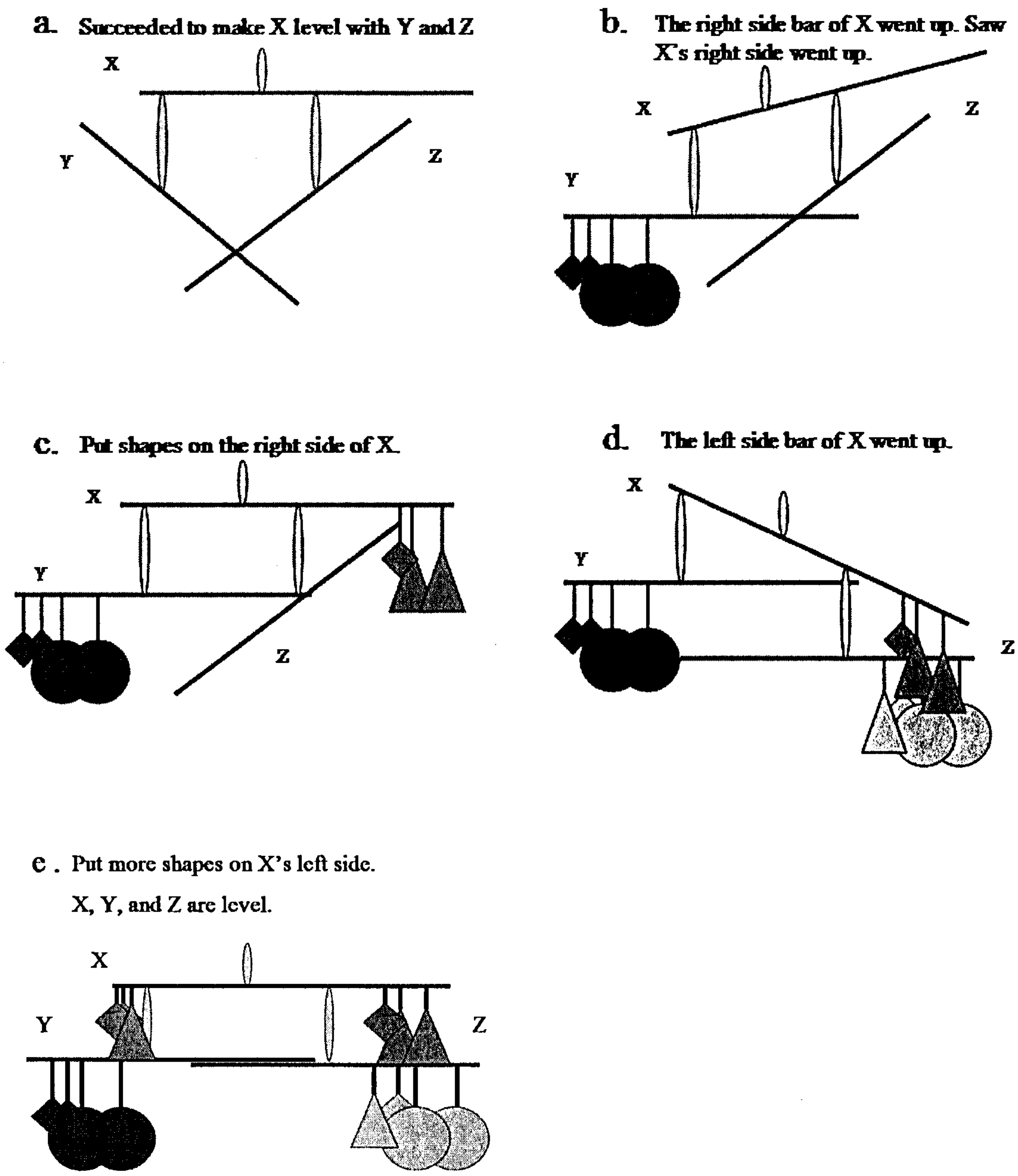
Frequencies and Percentages of First- and Third-Grade Subjects' Performance on Coordination between Upper-level Bar and Lower-level Bar in Making Mobiles

	Grade			
	1		3	
Performance on coordination	II F (%)	III F (%)	II F (%)	III F (%)
Coordinated	4 (40)	5 (50)	6 (50)	11(92)
Did not coordinate	6 (60)	5 (50)	6 (50)	1 (8)

About half of the first and third graders showed coordination between an upper level bar and a lower-level bar in Intervention II. However, almost all third graders demonstrated coordination actions in Intervention III while only half of first graders did.

Figure 19 shows a third-grade child working on level Y after succeeding in making X level with Y and Z (a). She started to put objects on Y. At one moment, she realized the right side bar of X went up (b), so she put shapes on it to make it go down. Then she finished making X and Y level (c). She started to put shapes on Z to make it level. This time X's left side went up (d), so she needed to put more shapes on X's left side (e). This example indicates the child could not work on three bars at the same time. In other words, the child was not aware that she could make X's right side bar go down by adding shapes on Z (lack of coordination of system). If the child had the ability, in (b), she could have put something on the right side of Z that made right sides of both X and Z go down at the same time.

Figure 19. Example of coordination reasoning focusing on only the bars a child has worked on.



In sum, Tables 18 - 23 show individual performances with regard to compensatory actions and the observed behaviors in adjusting distance from the fulcrum, consistency in both putting things on the higher side and adjusting distance from the fulcrum of each subject, and coordination among bars.

A "Yes" on compensation of distance (Table 18 and 21) indicates that the child always moved objects in the right direction along the bar. "T & E" indicates that a child compensated distance but not always in the right direction. "Yes" on consistency in compensation (Table 19 and 22) indicates that the child always put weights on the higher side and always moved objects in the right direction to balance a bar. "Yes" on coordination (Table 20 and 23) indicates that the child compensated an imbalance of one tier by modifying something on another.

Tables 18, 19, and 20 shows that during Intervention I, 2 first graders showed consistently the higher side needs more weight to make straight bars balance and 5 children had the idea that distance is related to making bars balance. In Intervention II, 4 first graders showed consistently the higher side needs more weight to make bars balance, 5 children had the idea that distance is related to making bars balance. Four children considered more than two bars at the same time to make a mobile. In Intervention III, 6 first graders showed consistently the higher side needs more weight to make straight bars balance and 8 children had the idea that distance is related to making bars balance. Five children considered more than two bars at the same time to make a mobile. Two children explained how the bars would react depending on their actions. Two children showed consistency in compensation in Intervention II but not in Intervention III and one child

Table 18

First Graders' Compensation of Distance from the Fulcrum

	Intervention I				Intervention II				Intervention III				Post-test
Name	No	T & E	Yes	Expl.	No	T & E	Yes	Expl.	No	T & E	Yes	Expl.	
Amelia	V					V					V		1B
Daniel		V			V				V				1B
Blake	V				V				V				1B
Ryan			V				V				V		1B
Aja		V			V					V			1B/2A
Justice	V				V					V			1B/2A
Nick		V				V		V		V		V	1B/2A
Brian	V					V					V		1B/2A
Annaman		V				V					V		2A
Alex P.	V				V						V	V	2B

Note. T & E = Trial and Error; Expl. = Explain

Table 19

First Graders' Consistency in Compensation

	Intervention I						Intervention II						Intervention III						
	Put on high side			Comp. of distance			Put on high side			Comp. of distance			Put on high side			Comp. of distance			Post-test
Name	N	Y	Ex.	N	Y	Ex.	N	Y	Ex.	N	Y	Ex.	N	Y	Ex.	N	Y	Ex.	
Amelia	V			V			V			V				V			V		1B
Daniel	V			V				V		V			V			V			1B
Blake	V			V			V				V	V	V			V			1B
Ryan		V	Y		V	Y		V		V				V	Y		V	Y	1B
Aja	V			V				V		V			V			V			1B/2A
Justice	V			V			V			V			V			V			1B/2A
Nick	V			V				V		V				V		V			1B/2A
Brian	V			V			V			V				V			V		1B/2A
Annaman	V			V			V			V				V			V		2A
Alex P.		V		V			V			V				V			V		2B

Note. Comp. of distance = Compensation of distance; N = No; Y = Yes; Ex. = Explain could coordinated among bars in Intervention II but not in Intervention III. These regressed results might indicate their logic is not fully developed.

Table 20

First Graders' Coordination among Bars as a Compensatory System

Name	Intervention II				Intervention III				
	No	Yes	Expl.	NA	No	Yes	Expl.	NA	
Amelia	V				V				1B
Daniel	V				V				1B
Blake				V				V	1B
Ryan		V				V	V		1B
Aja	V					V			1B/2A
Justice	V				V				1B/2A
Nick		V			V				1B/2A
Brian	V					V			1B/2A
Annaman		V				V			2A
Alex P.		V				V	V		2B

Note. Expl. = Explain

Tables 21, 22, and 23 shows that in Intervention I, all third graders showed consistently the higher side needs more weight to making straight bars balance and 9 children had the idea that distance is related to make straight bars balance. In Intervention II, 8 third graders showed consistently the higher side needs more weight to

Table 21

Third Graders' Compensation of Distance from the Fulcrum

	Intervention I				Intervention II				Intervention III				Post-test
Name	No	T & E	Yes	Expl.	No	T & E	Yes	Expl.	No	T & E	Yes	Expl.	
Adams		V			V					V			1B/2A
Janae	V				V					V			1B/2A
Jensen		V				V		V		V			1B/2A
Allison		V				V				V		V	1B/2A
Leon	V					V				V		V	2A
Jordan		V			V						V		2B
Alex S.		V		V			V				V		2B
Jaren			V			V					V		2B
Josse			V	V			V				V	V	2B
Judith			V				V	V			V	V	2B
Juliann		V				V		V		V		V	2B
Montana	V				V				V				2B

Note. T & E = Trial and Error; Expl. = Explain

Table 22

Third Graders' Consistency in Compensation

	Intervention I						Intervention II						Intervention III						
	Put on high side			Comp. of distance			Put on high side			Comp. of distance			Put on high side			Comp. of distance			Post-test
Name	N	Y	Ex.	N	Y	Ex.	N	Y	Ex.	N	Y	Ex.	N	Y	Ex.	N	Y	Ex.	
Adams		V		V			V			V			V			V			1B/2A
Janae		V		V			V			V				V		V			1B/2A
Jensen		V		V				V		V				V		V			1B/2A
Allison		V		V			V			V				V		V			1B/2A
Leon		V		V				V		V				V		V			2A
Jordan		V		V				V		V				V			V		2B
Alex S.		V		V				V			V			V			V		2B
Jaren		V			V		V			V				V			V		2B
Josse		V			V			V			V			V			V		2B
Judith		V			V			V			V			V			V		2B
Juliann		V		V				V		V				V		V			2B
Montana		V		V				V		V				V		V			2B

Note. Comp. of distance = Compensation of distance; N = No; Y = Yes; Ex. = Explain make straight bars balance and 8 children had the idea that distance is related to make straight bars balance. Six children considered more than two bars at the same time to make a mobile. After Intervention III, 11 third graders showed consistently the higher side needs more weight to make straight bars balance. Eleven children had the idea that distance is related to make straight bars balance, and 11 children considered more than two bars at the same time to make a mobile and 1 child explained how the bars would react depending on their actions.

Table 23

Third Graders Coordination among Bars as a Compensatory System

Name	Intervention II				Intervention III				Posttest
	No	Yes	Expl.	NA	No	Yes	Expl.	NA	
Adams				V		V			1B/2A
Janae				V	V				1B/2A
Jensen				V		V		V	1B/2A
Allison		V				V			1B/2A
Leon				V		V			2A
Jordan		V				V			2B
Alex S.		V				V			2B
Jaren		V				V			2B
Josse				V		V			2B
Judith		V				V			2B
Juliann		V				V			2B
Montana	V					V			2B

Note. Expl. = Explain

Contradiction. While making mobiles, a few children experienced contradiction caused by perturbation. That is, they exhibited signs of surprise at unexpected results or puzzlement at results that contradicted expectation.

Both first and third graders experienced perturbation through all three intervention sessions. Examples of children experiencing perturbations were:

- Intervention I
    - When his partner suggested putting a bar at the end of a higher side, Alex (6;3) replied, "At the end? That can't be possible!" His prediction was contradicted by the result. From trying, he found that it is possible.
    - Allison (8;4) tried to hang a small bar on the lower side of a tilted bar. The small bar fell off. She was surprised to see the bar fall. She did not expect the bar to fall.
    - Jensen (8;9) tried to hang a small bar on a leveled bar. The small bar fell down. "It was not level!" She expected the leveled bar to stay level.
- Intervention II
    - Referring a balanced bar, Nick (6;9) said "I put two on this side and I put (counts shapes and finds there are three shapes hanging.)..." He expected there were two. His symmetrical reasoning was perturbed.
    - Josse (9;0) tried to make a tilted bar level. "Maybe this circle (on the higher side) will work." (Tried) "It didn't work! (because it is not heavy enough)" His anticipation was perturbed and challenges him.
- Intervention III
    - When the teacher/experimenter asked, "What would happen if a bar (lower-level) were moved to inside?" Alex (6;3) answered, "It's gonna still stay the same, I think." (Tried and the upper level bar went up.) "Don't know what happened..." His anticipation and logic were perturbed.

- There was a Y bar hanging on the high side of an X bar. A child made the Y bar level with two apples and one pear. She thinks the X bar would be level if she put two apples and one pear on the higher side. It didn't work (Montana, 8;3). Her anticipation was challenged.
- A child made a bar with off-center eye-screw level. "This side has more side (longer side). So I put three fruits on (the longer side) and this side (shorter side) I put (counts)...three...." (Juliann, 8;5). She expected there were more than three. This case also shows a contradiction in symmetrical reasoning in number.

These perturbations made some of the children focus more on their actions. One child repeated the same error but realized quickly and corrected her action: "No, it didn't work before. So it should be this way!" However, some children who experienced perturbations did feel frustration because they could not figure out how to solve the problem. Thus, finally they just let it go.

Other Important Findings

Besides the main results described above, other significant children's behaviors were observed during interventions.

Cooperative behavior. Because of the cooperative setting, some children showed four types of cooperative behavior: collaboration, helping, trading, and paying attention. Through the sessions, 10 children built mobiles together, 7 children asked help from others, 7 children offered help to others, 6 children traded their materials, and 3 children gave their materials for the other's use. Sometimes they looked at what the other did and asked how he or she did something. Then, they imitated what the other did. "I'll do just like Alex did!" and "I just did what Aja did!" Peer-learning happened. Facilitating cooperation is one of the goals in constructivist education.

Frustrated behavior. Making mobiles seemed challenging for some children. Table 24 shows various types of frustration some children expressed during interventions.

Table 24

Frequencies of First- and Third-Grade Subjects' Expressed Frustration

	Grade					
	1			3		
	I	II	III	I	II	III
Expressed frustration	F	F	F	F	F	F
Sighing	1	2	1		2	2
Visiting restroom		1	1		1	
Wandering around			1		1	
Inappropriate use of bars		1	2		2	
"It's hard."		3			2	1
"It won't work."		2	1	2	6	

As Table 24 clearly shows, the most frustrations occurred in the second intervention session where fulcrum were off-center. Four children expressed more than one frustrated behaviors. An interesting finding is that 50 percent of the third graders commented that the bars with an eye-screw in the middle (center) would not be leveled in Intervention II. For example, 1 third grader said, "It won't work because the hooks are not in the middle (center)." Children who did not succeed in making mobiles tended to show their frustration. However, only three frustrated behaviors were shown from third graders in Intervention III. This might be that children became familiar with the materials.

Moment to think. While making mobiles, 8 children paused in their actions and looked at their mobiles with curious eyes. When they were asked if things were OK, they answered, "I'm thinking." This need for a moment to think happened more often in Intervention I and Intervention II than during Intervention III. Interventions I and II were new challenges to the children, and Intervention III was the same as Intervention II. Intervention II is interesting in light of unstable and regressed results. That might be because with the new situation, children had many variables to consider.

"Eureka" experience. While making mobiles, 9 children had a "Eureka" experience. That is, they realized something suddenly or connected their prior knowledge to current experience. For instance, Josse (9:0) succeeded to make one bar (X) level in Intervention III with one circle on the longer side and one circle and one square on the shorter side. He attempted to put a short bar (Y) on the longer side of X. Y fell off. The teacher/experimenter asked what would happen if one short bar (Z) was put in the middle of the longer side of X. He answered it (Z) would fall, which is the right prediction. Next, the teacher/experimenter asked what would happen if Z was put farther from the fulcrum of X on the longer side of X. He said it would be heavier. Then, the teacher/experimenter asked what would happen if Z was put closer from the fulcrum of X on the longer side of X. "Oh...I get it. I put it (Z) right here (closer to the fulcrum of X on the longer side of X). He had a Eureka moment and succeeded in building a two-tier mobile.

Learning during activity. Four children learned the answers from their previous mistakes. For instance, Jensen (8;9) failed to build a mobile in Intervention II. In Intervention III, one circle was hanging on the shorter side of a bar (X). The teacher/experimenter asked what would happen when the circle was moved closer to the fulcrum. She answered that the shorter side would go down. She was wrong. After trying it, she said "I was wrong!" She experienced contradiction. The teacher/experimenter asked if she could make X level now without using more hanging objects. "Sure, I just move it back!" She caught the changing placement and the effect quickly. After that, she showed more changing placement behavior although her behavior was not consistent and more like trial-and-error. At the end of the session, she was able to build a one-tier mobile and attempted a two-tier mobile.

Ryan (7;1) seemed to learn during the posttest. In questions with the beam balance, when one cube was put on the left side of the beam, he answered, "It (the left side) will go down." When asked what would happen to the right side, he answered, "Right side...will go down." After his answer, through experiment, he saw the right side went up. Next, he was asked what would happen if two cubes were put on the left side of the beam, he answered, "It (the left side) will go down even more." When asked what would happen to the right side, he answered, "Right side...go...up?" He observed what happened when one cube was put on and changed his mind, with same uncertainty.

Progress of Logical Reasoning in Making Mobiles

Because this study was conducted in a relatively short period of time (eight weeks), it is difficult to see the developmental progress in the logic of a child. However, even though only two grade levels with 22 children were the subjects of the research, various levels of children's logical reasoning in making mobiles were observed. Movement from lack of logic to logic was discussed as follow.

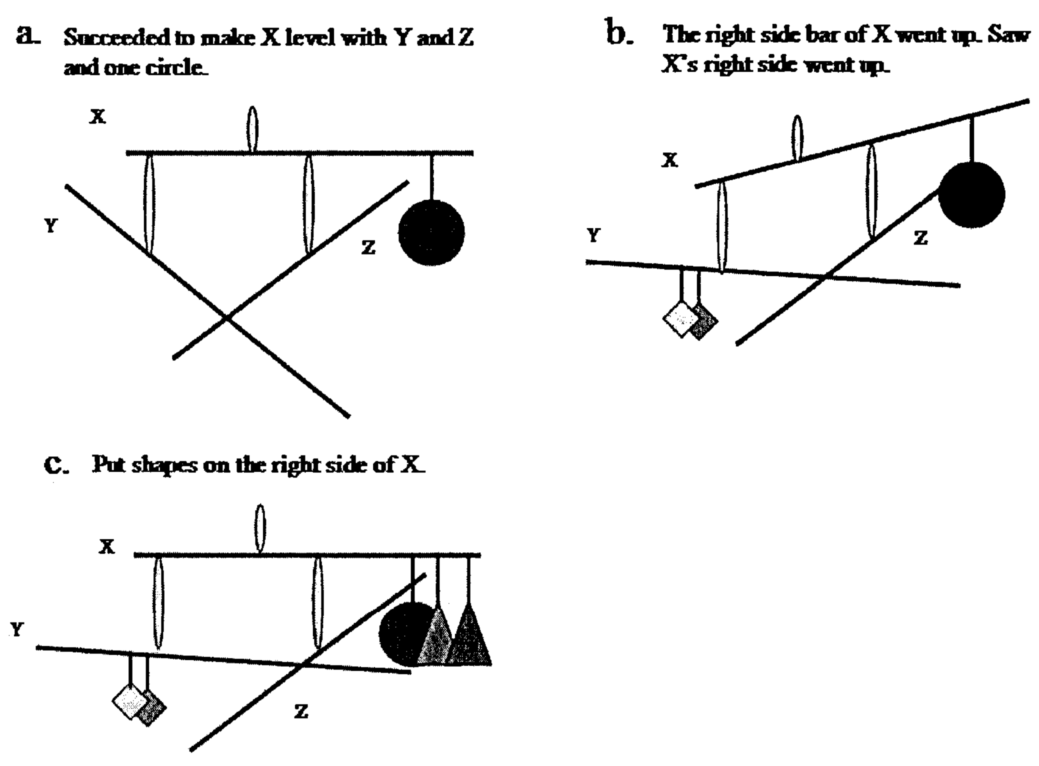
Lack of logic. Some children used symmetric reasoning as a method to achieve balance with off-center bars. For example, one first grader showed lack of logic behaviors in Interventions II and III. Blake (6;11) built a one-tier mobile with symmetry in number, color, and shape in Intervention I. He unsuccessfully applied symmetric reasoning in Interventions II and III. He put one circle and one square on the higher side of a bar, then put another circle and square on the lower side. The circle and square put on the lower side fell off. He repeated this action a few times and finally gave up trying to build a mobile.

Another behavior showing the lack of logic of children was to say off-center bars cannot be balanced. This comment also originated from children's symmetric reasoning. In the case of Blake, after he gave up building mobiles in Intervention II, the teacher/experimenter asked why he could not make mobiles. His answer was, "I can't make it level because one side tips over. It won't make it level." In other words, he thinks because the bars are not symmetric, they would not be leveled.

Protologic. Children of both grades showed protologic behaviors in Interventions II and III. One type of protologic behavior is related to adding. Sixteen children sometimes recognized that they needed to add weight to the higher side of a bar and did it. However, their action was not consistent all the time. In other words, they sometimes put objects on the lower side of a bar, which is not a compensatory action.

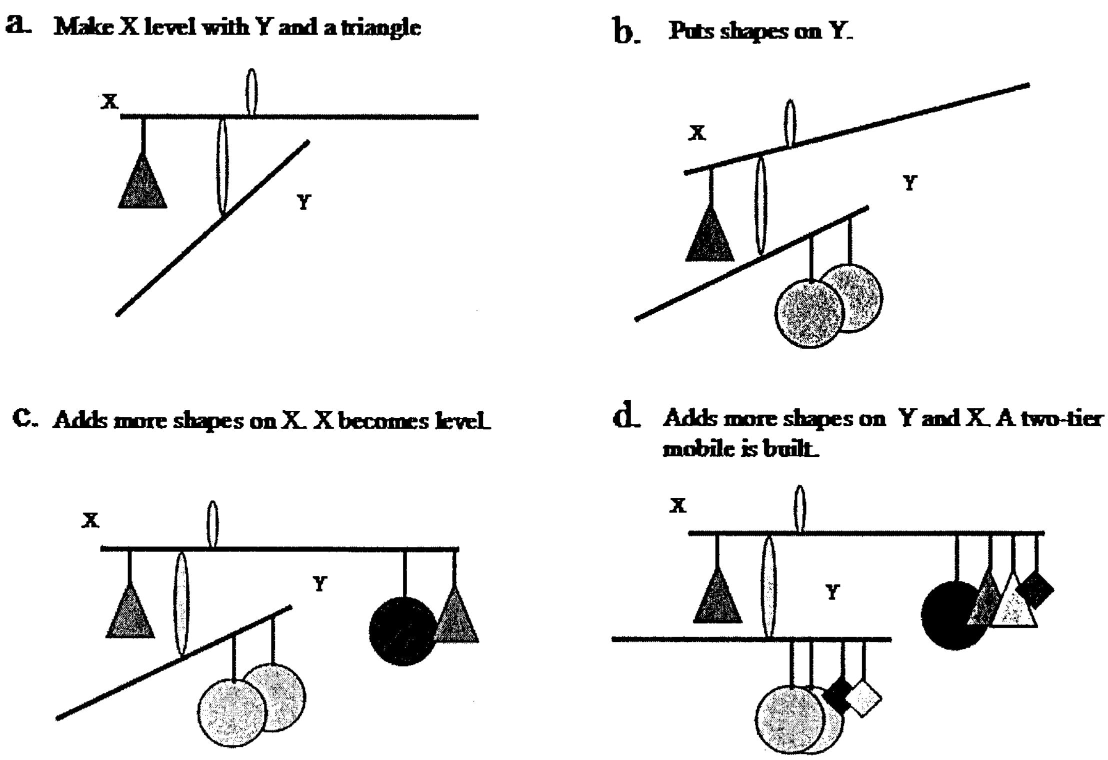
Nine children seemed to be acting based on what just happened, using information to modify their logic. They showed clear progress in organizing their logic through activities. For example, Leon (8;4) was working with three bars – one (X) was on the top, another (Y) was on the higher side of X, and the other (Z) was on the lower side of X (see Figure 20). Leon made X balance with Y, Z, and one circle. When he started to put objects on the higher side of Y, he saw X was tilted so the side with Z went up. He realized the effects of a second level on the first level. "Oh, I know how I can make it (X) level." He added some objects on the higher side of X. "See, I made it (X) level!"

Figure 20. Example of protologic I.



Another similar example was from Alex P. (6;2). He made X level by putting Y and a triangle on the higher (shorter) side of X (see Figure 21). Thus, he started to make Y level by putting shapes on the higher (shorter) side of Y. He realized the longer side of X went up. "Oh… this one (the longer side of X)…." He put more objects on the longer side of X. Y was not still level. "oh…now that side." He added more objects on the shorter side of Y. He repeated these actions and made a two-tier mobile.

Figure 21. Example of protologic II.



This example shows his action still focuses on leveling each bar but he realized that adding weights on the lower level bar makes the upper level bar tilt. However, he could not predict how his compensatory action affects the two bars at the same time. He started to recognize the reactions of the bars. Experience of making mobiles obviously intrigued him and led him to realize the relation between his action on one bar and the reaction of the other bars. In short, the examples of Leon and Alex P. shows protologic of coordination.

All the above incidents do not show operational reasoning of children but they do show prefiguring of logical concepts in children's reasoning. In other words, the children are in the process of structuring their logic toward complete coherent compensation and coordination of relationships related to mobiles.

Advanced logic. Incidents that showed children's advanced logic are: (a) some children recognized that weight should not be added to the lower side, (b) they did not add weight to a balanced bar, (c) they did not say the off-center bars cannot be balanced, (d) they never put weight on lower side alone, (e) they never put weight in symmetry when using off-center bars, (f) they anticipated balancing/ unbalancing effects – anticipatory schema, (g) they showed systems of compensations including coordination among bars, and (f) they moved hanging objects in the right direction for compensation.

CHAPTER V

SUMMARY, DISCUSSION AND CONCLUSION

The purposes of this study were to explore (a) how children build their protologic concepts of balance through experiences in making mobiles and (b) the usefulness of making mobiles in promoting children's development of the concept of balance. This study focused on examining the dynamics of children's reasoning process about balance in a constructivist activity, making mobiles.

Three research questions guided the study: (a) What behaviors showed children's understanding of the concept of balance in making mobiles? (b) How can constructivist principles be used to understand children's answers and behaviors related to balance? and (c) Do children show progress in their concept of balance after experiences making mobiles?

Ten first-grade children whose mean age is 6 years 6 months and 12 third-grade children whose mean age is 8 years and 5 months from a laboratory school in a mid-west city participated in this study.

Relation to Other Research

The findings of this study are consistent with the description of stages by Piaget et al. (1974/1980). The stages identified by Piaget et al. were used to define children's reasoning on the conception of balance using a pretest-posttest methodology. Analysis of their research and the present research indicate similarity in light of the description of reasoning on questions about the balance scale. In other words, the children of this study responded similarly to the descriptions contained in the literature in answering pretest and posttest questions. Moreover, both research investigations concluded that disequilibrium leads to children's cognitive developmental progress. However, 2 first graders in this study demonstrated a little more advanced level of performance than would be expected based on the ages for stages given by Piaget et al.

Generally, the findings of this study are also consistent with stages identified by Inhelder and Piaget (1955/1958). However, 1 first- and 1 third-grade children of this study demonstrated a little more advanced level of performance. Unlike Inhelder and Piaget who stated that children cannot make inverse correspondences of weights and distances until ages 10 to 12, 2 children of this study successfully demonstrated achieving balance with unequal weights and/or with unequal distance situations. However, this might be because an artifact of the procedure in the present study which did not quantify weight and distance related to the concept of proportionality in questions like Inhelder and Piaget did.

Children's Progress in the Concept of Balance

This research suggests that children's developmental levels in their concept of balance progressed after three interventions of making mobiles. At the beginning of the study, all children had the idea that weight is related to balance, and 13 children also had the concept of distance related to balance.

Through making mobiles, children showed active reasoning in the form of both prelogical and logical behavior, of compensation and reversibility, coherence, and coordination. Adding, taking off, switching, and moving objects to make bars level were the compensatory behaviors, and all children showed their compensation reasoning through adding objects. Compensation reflects at least the protologic of reversibility. In other words, children showed compensation actions, such as adding and moving objects, indicating they either knew that counteractions would cancel the result of their actions or in the case of protologic, that their thinking is moving in that direction. It means that they consider the reversibility of their actions. The logic of coherence could be found in 10 children whose actions of adjusting the placement of hanging objects or bars always went in the right direction to make the bar level. Coherence was also found in 17 children who put objects on the higher side of the bars in Intervention III. Finally, 16 children showed their logic of coordination by compensating the distribution of weights in a larger total system of tiers in Intervention III. That is, their purposeful physical coordination of two- or three-tier bars (indicating forethought, rather than trial-and-error manipulations) reflected their coordination of the whole system of balance.

The children showed a great amount of interest as they actively engaged in making mobiles. Making mobiles was truly a new experience to the children in the sense of applying their reasoning about balance to the new, concrete materials, and children demonstrated their reasoning in various ways. Children might have been motivated by their genuine engagement in the problems posed by the making mobiles. In a real sense, children engaged in a dialogue with the mobiles as they hypothesized and experimented. Some children who demonstrated higher levels of performance in building mobiles than might be expected of children at the ages studied. Making mobiles provided children opportunities to reflect on what they had done and what they needed to do to make a mobile with all bars level. This finding indicates that children engage more and learn more in well planned, interesting, and challenging situations.

One interesting finding was that, during interventions some children could perform actions reflecting the physics law of balance. For instance, in Intervention III, 5 third graders considered distance and weight at the same time when they made bars level. However, when they were asked questions about their reasoning, just 2 children could explain the law. Inhelder and Piaget referred to the former case as "intuitive regulations rather than operations" (p. xii). In other words, children make bars level by trial-and-error based on their intuition. They cannot explain their reasoning because they do not have the concrete operations.

In contrast, 3 third graders in Intervention III could explain what happened, but they sometimes compensated a situation in the wrong direction. This might be because children learned the concept of balance on the basis of experience but the logical structures were not fully developed. Thus, they could not apply their knowledge in practice. Children might be able to verbalize what they know after seeing the result of experimentation, but not be able to anticipate what they need to do in a real situation until they construct firm logical structures. Making mobiles was a situation in which children could exercise their knowledge of the concept of balance; thus, it helped children build the logical structure in the concept of balance.

In short, although the intervention activities were limited and there was no comparison group, this study suggests that making mobiles may be an activity that can promote children's levels of development in the concept of balance.

After the intervention, more children considered distance from the fulcrum when they encountered questions related to balance. This could be a simple effect of pretest on posttest. Children might remember the reactions they saw of the primary- and beam-balance from the pretest. However, it could also be due to the intervention activities and the teacher/experimenter's questions.

Educational Implications

This researcher found two extreme cases in terms of performance of children from two first graders. One first grader built a three-tier mobile in Intervention III, which is much beyond average performance for his age. At the same time, one first grader failed to build a mobile in Interventions II and III. What do these findings tell us?

Usefulness of Making Mobiles for Promoting Children's Knowledge and Development

Findings suggest that experiences of making mobiles do contribute to children's progress in knowledge about the concept of balance. The study also suggests that children's development of reasoning is advanced through experiences of disequilibrium that challenge their thinking about how balance works. Ten children demonstrated signs of frustration in manipulating the materials in Intervention II. However, most children showed interest in the activities despite some frustration. It is certainly worth it to provide the activity in the classroom.

Many studies (Brown, Camperell, Dapper, Longmire, McEwen, Majors, et al., 1986; Clark & Premo, 1982; Donnellan & Roberts, 1985; Field, Bernal, & Goertz, 2001; Fleer, Hardy, Baran, & Malcolm, 1996; Heffernan, 1997; IDRA Newsletter, 1998; Juraschek & Grady, 1981; Russell, 1996; Shymansky, Kyle, & Alport, 1982) have shown that science through hands-on activities is effective in facilitating children's development, especially children of a young age. In this study, children's verbal, facial, and other bodily reactions that expressed surprise and puzzlement indicated experiences of contradiction to their anticipations during making mobiles. Those reactions show that, as Piaget might say, making mobiles *perturbed* their logic. According to Piaget, perturbations initiate activation of the dynamics of disequilibration and equilibration that induce children's cognitive development. Piaget stated that children regulate their mental structures when they experience disequlibrium, and this regulation process leads children's cognitive development. Thus, experience of disequlibrium is critical in children's development. One might only "what causes disequilibrium?" This researcher believes that new, mentally challenging experiences, as long as they are not too much in advance of the current developmental level of a child, do stimulate children's thinking. Vernon (1976) stated in his study of Piaget and education that, "the greater the variety of stimulation and practice, the better established a structure becomes, and the more transferable to other similar situations; this is the essence of the accommodation process" (p. 33). In short, the activity of making mobiles was a new and mentally challenging experience to most of the subjects.

These observations are harmonious with DeVries's definition of constructivist education that promotes learning and development. That is, making mobiles appeals to children's spontaneous interests and desires to experiment and presents problems children want to figure out.

Children had opportunities to experiment and observe how bars with a fulcrum react when they put weights on them. Although the teacher/experimenter made no reference to the balance scales during the interventions, 3 children mentioned making mobiles in their posttest. They certainly made a relation between the balance scale and the activity of making mobiles.

In addition, because the mobiles requires carefully coordinated motor movements, children needed to be careful in manipulating them using their fine-motor skills. Thus, in some ways, children had chances to exercise and develop their fine-motor skills through making mobiles.

The mobiles built with the materials provided the children an opportunity to witness a concrete example of the physics concept of balance. In other words, the children needed to put objects on the shorter (higher) side of the bars to make mobiles with bars that are all horizontal. After building a mobile, some children might notice that the shorter side of a bar had more hanging objects than the other side. This experience had the potential to make children think about the relationship between number, distance, and weight.

Timing in Introducing Mobile Making

The findings of the research indicate 11 children progressed and 11 children did not progress after interventions. Assuming making mobiles facilitates children's development, the answer to the question, why some changed and some did not, could be related to the right timing to introduce the activity.

The findings show that this activity can be introduced to first graders as well as third graders. Considering that all first graders progressed in a balance task after the interventions, it is clear that working with balance is an appropriate activity to first graders. Considering the pretest-posttest data, although more than half of third graders maintained the same stage, all third graders were challenged to the questions implying the concept of distance and weight in pretest and posttest. In addition, making mobiles was a hard task for a few first-grade children and not an easy task to any children of both grades. However, most children took the activity as a challenge and coped well. Therefore, making mobiles is an appropriate activity to both first and third grade. Moreover, 4 children picked up things very quickly and applied their experiences to make the connection that they could utilize to solve other problems. These were children who brought their prior knowledge and experiences into a new situation. Having experiences is important, even though something appears not to have any effect at that moment. Later children might remember the experiences and make connections. Although they might not know or realize the physics law of balance while working on making mobiles, but they certainly considered the two variables – distance and weight – involved in the law. Considering the benefits some first graders received, making mobiles is appropriate to be introduced in regular first- and third-grade classrooms.

<u>General Efficacy of a Constructivist Socio-moral Atmosphere</u>

One of the goals of the intervention activities was to try to provide constructivist experiences for children. To achieve the goal, the setting was deliberately designed and implemented through pairing up children who play well together, utilizing clinical interview methods, and providing referencing materials. Children were encouraged to cooperate with each other and, as a result, 18 children showed cooperative behaviors such as peer-teaching and helping.

Much research (Au, Horton, & Ryba, 1987; Koulourianos & Marienau, 2001; Molina, 1997; Shin & Spodek, 1991) has shown that the quality of a teacher's intervention is critical in children's development. Moreover, teachers play important roles in motivating children in many ways. However, many classroom teachers with a large number of children in their classes experience difficulty engaging with all children's activities. Given the importance of teacher intervention, classroom teachers need support in providing appropriate interventions, and administrators need to support teachers in accomplishing this.

The role of the teacher/experimenter was influential in children's performance as encourager, facilitator, provider, and teacher. Besides providing materials, the teacher/experimenter posed direct questions that inspired children to think actively and to become aware of the physical reactions of the materials. In addition, the teacher/experimenter facilitated their experimentation, respected their ideas and feelings, and encouraged positive behaviors in relation with their peers. Most of all, the teacher/experimenter provided a socio-moral atmosphere where children felt safe to try their ideas and experiment freely. A safe and respectful atmosphere promotes children's development, according to DeVries and Zan (1994).

Recommendations for Further Research

This study is pioneering work and, thus, was necessarily exploratory. The researcher found many possible research topics to extend and deepen this study.

First, this study was conducted with 22 subjects but findings were not discussed intensively for each individual child's reasoning progress in mobile making. More intensive case studies in which children can be observed more frequently over a longer period of time would be helpful in investigating children's reasoning process about balance.

Second, this study was limited to a small number of first and third graders. Further study is needed at higher and lower grades to see the full developmental stages of children's reasoning about balance. In addition, further study is needed with a larger number of subjects for generalization.

Third, the participants were from a middle socio-economic background and came from one laboratory elementary school in Iowa. This study might be replicated with first and third graders from upper and lower socio-economic backgrounds.

Fourth, one type of material was provided for interventions. Research with diverse materials for making mobiles would be helpful to see whether it is important to provide materials that control the variable of weight in more elaborate ways.

Fifth, there was one teacher/experimenter with two subjects in each intervention session. That fact led to greater interaction between the interviewer and one of the subjects. However, a study with one teacher/experimenter and one subject would allow for more concentrated focus on each individual without neglecting any of the children.

And having one teacher for a whole classroom will also change the amount of time each child receives in normal classroom setting.

Finally, in aspects of research design, adding a control group is necessary in order to make generalizations about the effectiveness of making mobiles as an activity to promote children's concept of balance.

Conclusion

Why do some children add one more object to the side of a bar when it is already down? What are they thinking? Is there anything early childhood educators can help with? Once they solve the problem, is there anything that could facilitate their development?

At the end of the discussion of their study, Piaget et al. (1974/1980) stated two questions: "...how does the subject react to the initial disequilibrium, and by what processes does the subject achieve equilibration?" (p.114). Piaget did a great amount of research to answer the questions and provided us deep insights. This research was an attempt to test his findings and insights in a new setting. The findings of this research show that making mobiles caused children's disequilibrium. Making mobiles perturbed young children's logic; young children responded to the challenge and tried to solve the problems by regulating actions such as compensation and coordination; some children reached equilibrium, and others did not. Thus, making mobiles is a good physical-knowledge activity that teachers can implement in their classroom to promote the development of logico-mathematical knowledge/reasoning.

The findings of this study coincide well with a major tenet of Kamii and DeVries (1978/1993) which is that physical-knowledge activities promote logico-mathematical thinking. Kamii and DeVries claim that experience with physical-knowledge activities leads children to build logico-mathematical knowledge. The concept of balance cannot be acquired solely through physical experience or logico-mathematical experience. It has to be constructed through an active process. Physical-knowledge and logico-mathematical knowledge are closely related in life and are almost inseparable, especially with cognitive development of young children. Thus, through experimenting with bars and hanging objects, children have the chance to build logico-mathematical structures. For instance, a child may predict that a bar will be balanced if he or she puts identical objects on both sides of the bar but at unequal distances from the fulcrum. In contradiction to expectation, it does not balance because the child did not consider the distance from the fulcrum. This is a negation of the action. The process of resolving contradiction or the negation of his or her action is constructing logico-mathematical relationships. This is the major rationale for physical-knowledge activities, according to Kamii and DeVries.

The researcher agrees that this activity of making mobiles might be too hard for some young children, especially those who are not in upper concrete developmental stages, because it requires children to consider two variables at the same time. Thus, they might get discouraged and the activity might be meaningless for them. However, some young children can get benefits from this activity. Some educators (Deutsch, 1962; Intercultural Development Research Association, 1996; Linn, Lewis, Tsuchida, Songer, 2000; Mann, 1972; Price, 1982; Zigler, 1986) have claimed that too often students are expected to learn advanced content regardless of their developmental level, so many children fail to meet the standard and, consequently, are not successful in schooling. Thus, do we need to lower our standards so no child is left out? In contrast, some educators (American Federation of Teachers, 1999; Ford, 1997; Hawley, 1998; Jackson, 1998; Katz & McClellan, 1991; Koulourianos & Marienau, 2001; Rasmussen & Lund, 2002; Schliefer, 1995) believe that children are more capable than we think; they often surprise us by doing things we do not think they are capable of doing. If we do not want to leave any child out, we certainly need to consider the advanced children. The researcher is advocating the value of introducing advanced activities, although it should not be too advanced, for typical children who have some potential capability we do not recognize. Much research (Beaton, Martin, Mullis, Gonzalez, Smith, & Kelly, 1996; Ekstrom, Goertz, Rock, 1988; Goertz, 1989; Linn, Lewis, Tsuchida, & Songer, 2000; National Center for Education Statistics, 1984b; National Commission on Excellence in Education, 1983) shows American students are behind in mathematics and science compared to students of other countries. Where can we find the reasons? Does this mean American children are less capable than children of other countries? Considering the level of performance they showed in making mobiles, the researcher believes that some children could be able to understand and perform at advanced levels of understanding if they were exposed to more advanced concepts at an earlier age.

Walk into any classroom and look at each child. We see all children are very unique and so precious. Could we neglect any one of them for the benefit of the majority? No, we could not and should not. We, educators, need to remember that each individual learns at his/her own rate with a different developmental range. Nobody knows when is the best time for a child to be taught and intrigued. Then, going back to the initial question, is there anything we can do to help children learn? One of things the researcher can think of based on the findings of this study is that we, educators, should constantly provide children various levels of activities and an atmosphere that children can freely unfold and apply their ideas.

REFERENCES

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

American Federation of Teachers. (1999). *Building on the best, learning from what works: Five promising remedial reading intervention programs*. Washington, DC. (ERIC Documentation Reproduction Service No. ED445315)

Au, W. K., Horton, J., & Ryba, K. (1987). Logo, teacher intervention and the development of thinking skills. *Computing Teacher, 15*(3), 12-16.

Bart, W. M., Frey, S., & Baxter, J. (1979). Generalizability of the ordering among five formal reasoning tasks by an ordering-theoretic method. *Child Study Journal, 9*, 251-259.

Beaton, A. E., Martin, M. O., Mullis, I. V. S., Gonzalez, E. J., Smith, T. A., & Kelly, D. L. (1996). *Science achievement in the middle school years: IEA's Third International Mathematics and Science Study (TIMSS).* Chestnut Hill, MA: Center for the Study of Testing, Evaluation, and Educational Policy, Boston College.

Bingham, W. V. D., Moore, B. V., & Gustad, J. W. (1959). *How to interview* (4^{th} ed.). New York: Harper and Brothers.

Bloomfield, L. (2001). *How things work: The physics of everyday life* (2^{nd} ed.). New York: Wiley.

Brand, M. (2003). *About kinetic mobiles*. Retrieved February 20, 2003, from http://xenia.media.mit.edu/~brand/mobiles.html

Bredderman, T. (1983). Effects of activity-based elementary science on student outcomes: A quantitative synthesis. *Review of Educational Research, 53*, 499-518.

Brown, I., Camperell, K., Dapper, J. W., Longmire, M. L., McEwen, M., Majors, N. S., et al. (1986). *Staff development project science: Grade K-6.* (ERIC Documentation Reproduction Service No. ED285726)

Calder Foundation. (2000). *"The Mobiles of Calder" by Jean-Paul Sartre.* Retrieved August 8, 2002, from http://www.calder.org/SETS/life/texts_sets/life_sartre46_set.html

Chaillé, C., & Britain, L. (1997). *The young child as scientist: A constructivist approach to early childhood science education* (2nd ed.). New York: Longman.

Chen, J., Isberg, E., & Krechevsky, M. (Eds.) (1998). *Project spectrum: Early learning activities. Project Zero Frameworks for early childhood education, Vol. 2.* New York: Teachers College Press.

Clark, R. C., & Premo, J. L. (1982). What research says. *Science and Children, 19*(7), 46-47.

Deutsch, M. (1962). *Early social transition and the dropout problem.* (ERIC Documentation Reproduction Service No. ED001877)

DeVries, R. (2002). Physical-knowledge activities. In R. DeVries, B. Zan, C. Hildebrandt, R. Edmiaston, & C. Sales, *Developing constructivist early childhood curriculum: Practical principles and activities* (pp. 69-76). New York: Teachers College Press

DeVries, R., & Kohlberg, L. (1990). *Constructivist early education: Overview and comparison with other programs.* Washington, DC: National Association for the Education of Young Children.

DeVries, R., & Zan, B. (1994). *Moral classrooms, moral children: Creating a constructivist atmosphere in early education.* New York: Teachers College Press.

DeVries, R., Zan, B., Hildebrandt, C., Edmiaston, R., & Sales, C. (2002). *Developing constructivist early childhood curriculum: Practical principles and activities.* New York: Teachers College Press

Donnellan, K. M., & Roberts, G. J. (1985). What research says: Activity based elementary science: A double bonus. *Science and Children, 22*(4), 119-121.

Duckworth, E. (1995). *The having of wonderful ideas: Other essays on teaching and learning* (2nd ed.). New York: Teachers College Press.

Duckworth, E., Easley, J., Hawkins, D., & Henriques, A. (1990). *Science education: A minds-on approach for the elementary years.* Hillsdale, NJ: L. Erlbaum Associates.

Ekstrom, R. B., Goertz, M. E., & Rock, D. A. (1988). *Educational and American youth: The impact of the high school experience.* London: The Falmer Press.

Elementary Science Study. (1965). *Kitchen physics.* St. Louis, MO: McGraw-Hill

Elementary Science Study. (1966/1969). *Mobiles: A guide for teachers*. St. Louis, MO: McGraw-Hill.

Elementary Science Study. (1976). *Mobiles.* St. Louis, MO: McGraw-Hill.

Emeric, S. (1987). Chemistry for kids: Pop-and-sniff experimentation. A high sensory impact teaching device. *Journal of Chemical Education, 64*, 797-798.

Field, T., Bernal, E., & Goertz, J. (2001). How gifted/talented students perceive FOSS program. *Understanding Our Gift, 13*(2), 3-5.

Fleer, M., Hardy, T., Baron, K., & Malcolm, C. (1996). *They don't tell the truth about the wind: Hands-on explorations in K-3 science*. (ERIC Documentation Reproduction Service No. ED396920)

Ford, M. P. (1997, March). *Descending the tower: Lessons learned in a first grade classroom.* Paper presented at the annual meeting of the American Educational Research Association. Chicago. (ERIC Documentation Reproduction Service No. ED409979)

Gega, P., & Peters, J. (1998). *Science in elementary education* (8th ed.). New York: Merril Prentice Hall.

Ginsburg, H. P. (1997). *Entering the child's mind: The clinical interview in psychological research and practice.* New York: Cambridge University Press.

Goertz, M. E. (1989). *Course taking patterns in the 1980s.* New Brunswick, NJ: Center for Policy Research in Education.

Griffith, J., & Morrison, P. (1972). Reflection on a decade of grade-school science. *Physics Today, 25*(6), 29-34.

Harrison, R. (June 14, 2002). *Wire mobiles*. Retrieved July 20, 2002, from http://www.wiremobiles.com/

Hawley, T. (1998). *Ready to succeed: The lasting effects of early relationships. An ounce of prevention fund and ZERO TO THREE paper.* Washington, DC: National Center for Infants, Toddlers and Families. (ERIC Documentation Reproduction Service No. ED449910)

Heffernan, M. (1997). *Horiculture rediscovered: The flowering of American schoolyards.* (ERIC Documentation Reproduction Service No. ED446965)

IDRA Newsletter. (1998, March). Math and science. IDRA focus. *IDRA Newsletter, 25*(3).

Inhelder, B. (1989). Autobiography. In G. Lindzey (Ed.), *A history of psychology in autobiography* (pp. 208-243). Stanford, CA: Stanford University Press.

Inhelder, B., & Piaget, J. (1958). Equilibrium in the balance. In B. Inhelder & J. Piaget, *The growth of logical thinking from childhood to adolescence: An essay on the construction of formal operational structures* (pp. 164-181, A. Parsons & S. Milgram, Trans.). New York: Basic Books. (Original work published 1955)

Intercultural Development Research Association. (1996, August). Organizing for schooling. IDRA Focus. *IDRA Newsletter, 23*(7).

Jackson, L. L. (1998). Who's paying for therapy in early intervention? *Infants and Young Children, 11*(2), 65-72.

Juraschek, W. A., & Grady, M. T. (1981). Format variations on equilibrium in the balance. *Journal of Research in Science Teaching, 18*, 47-79.

Kamii, C., & DeVries, R. (1993). *Physical knowledge in preschool education: Implication of Piaget's theory.* New York: Teachers College Press. (Original work published 1978)

Kamii, C., & Peper, R. (1969). *A Pigetian method of evaluating preschool children's development in classification*. Ypsilanti Public Schools, MI. (ERIC Documentation Reproduction Service No. ED039013)

Katz, L. G., & McClellan, D. E. (1991). *The teacher's role in the social development of young children.* Urbana, IL: ERIC Clearinghouse on Elementary and Early Childhood Education. (ERIC Documentation Reproduction Service No. ED331642)

Kliman, M. (1987). Children's learning about the balance scale. *Instructional Science, 15*, 307-340.

Koulourianos, E., & Marienau, V. (2001). *Improving students' confidence in writing achievement through the use of parent, student, and teacher interventions.* Unpublished Master's action research project, Saint Xavier University, Chicago. (ERIC Documentation Reproduction Service No. ED452268)

Kwak, H. (1995). *Science in a constructivist classroom: Progress in a five-year-old child's reasoning about water dynamics*. Unpublished doctoral dissertation, University of Northern Iowa, Cedar Falls.

Lawrence Hall of Science. (1995). *Full Option Science System grades 1-2: Balance and motion module.* Berkeley: The Regents of the University of California.

Lee, L. C. (1971). The concomitant development of cognitive and moral modes of thought. A test of selected deductions from Piaget's theory. *Genetic Psychology Monographs, 85*, 93-146.

Levitt, G. (2002, March). *Pensbury school district, Edgewood Elementary school.* Retrieved June 21, 2002, from http://keystone.fi.edu/visits/glorialevitt.shtml

Linn, M. C., Lewis, C. C., Tsuchida, I., & Songer, N. B. (2000). Beyond fourth grade science: Why do U.S. and Japanese students diverge? *Educational Researcher 29*(3), 4-14.

Lind, K. K. (1998, February). *Science in early childhood: Developing and acquiring fundamental concepts and skills.* Paper presented at the forum on Early Childhood Science, Mathematics, and Technology Education, Washington, DC. (ERIC Documentation Reproduction Service No. ED418777)

Lipman, J. (1976). *Calder universe.* New York: The Viking Press.

Lynch, J. (1967). *How to make mobiles*. New York: The Viking Press.

Maher, C. A., & O'Brien, J. J. (1980, April). *A study of the relationship between long-term memory and formal cognitive development for eighth-grade students: A confirmation of Piagetian theory.* Paper presented at the annual meeting of the American Educational Research Association, Boston.

Mann, M. (1972, November). *Identify and assist the development of high risk preschool children.* Paper presented at the annual meeting of the National Association for the Education of Young Children, Atlanta, GA.

Miller, L., & Bart, W. M. (1986). Patterns of nonverbal behavior among adolescents responding to a formal reasoning task. *Journal of Psychology, 120*(1), 51-57.

Molina, V. (1997). *Improving student listening skills through the use of teaching strategies.* Unpublished Master's action research project, Saint Xavier University, Chicago. (ERIC Documentation Reproduction Service No. ED409537)

National Center for Education Statistics. (1984b). *Science and mathematics educational in American high school: Results from the high school and beyond study. National Center for Education Statistics Bulletin (NCES 84-211b).* Washington, DC: U.S. Department of Education Office of the Assistant Secretary for Educational Research and Improvement.

National Commission on Excellence in Education. (1983). *A nation at risk: The imperative for education reform.* Washington, DC: U.S. Department of Education.

National Research Council. (1996). *National Science Education Standards.* Washington, DC: National Academy Press.

Nelson, O. A., & Winans, J. G. (1952). *Everyday physics.* Boston: Ginn.

New encyclopædia Britannica: Micropædia (15th ed., Vol. 8). (2002). Chicago: Encyclopædia Britannica, Inc.

Piaget, J. (1954). *The construction of reality in the child.* (M. Cook, Tans.). New York: Basic Books. (Original work published 1937)

Piaget, J. (1971). *The child's conception of the world.* (J. Tomlinson & A. Tomlinson, Trans.). London: Routledge & K. Paul. (Original work published 1929)

Piaget, J., Kamii, C., & Parrat-Dayan, S. (1980). Contradictions in the coordinations of observable facts (scales). In J. Piaget (Ed.), *Experiments in contradiction* (pp. 98-115, D. Coltman, Trans.). Chicago: The University of Chicago Press. (Original work published 1974)

Price, G. G. (1982). Cognitive learning in early childhood education: Mathematics, science, and social studies. In B. Spodek (Ed.), *Handbook of research in early childhood education* (pp. 264-294). New York: Collier Macmillan.

Rasmussen, J., & Lund, D. (2002). *Empowering children to change. No child left behind: The vital role of rural schools.* (ERIC Documentation Reproduction Service No. ED463106)

Rogers, R., & Voelker, A. M. (1970). Programs for improving science instruction in the elementary school, Part 1, ESS. *Science and Children, 7*(5), 35-43.

Robinson, D. N. (1982). *Toward a science of human nature: Essays on the psychologies of Mill, Hegel, Wundt, and James.* New York: Columbia University Press.

Russell, R. (1996). *Science and mathematics education reform: What do parents need to know to get involved?* (ERIC Documentation Reproduction Service No. ED400182)

Schliefer, M. (1995). Should we change our views about early childhood education? *Alberta Journal of Educational Research, 41,* 355-359.

Shin, E., & Spodek, B (1991, April). *The relationship between children's play patterns and types of teacher intervention.* Paper presented at the annual conference of the American Educational Research Association, Chicago, IL. (ERIC Documentation Reproduction Service No. ED332803)

Shultz, T. R., Mareschal, D., & Schmidt, W. (1994). Modeling cognitive development on balance scale phenomena. *Machine Learning, 16*, 57-86.

Shymansky, J. A., Kyle, W. C. Jr., & Alport, J. M. (1982). How effective were the hands-on science programs of yesterday? *Science and Children, 20*(3), 14-15.

Siegler, R. (1976). Three aspects of cognitive development. *Cognitive Psychology, 8,* 481-520.

Sinclair, H., Stambak, M., Lezine, I., Rayna, S., & Verba, M. (1989). *Infants and objects: The creativity of cognitive development.* San Diego, CA: Academic Press, Inc.

Solomon, R. (1964). *Alexander Calder: A retrospective exhibition.* New York: Guggenheim Museum.

Sprung, B. (1996). Physics is fun, physics is important, and physics belongs in the early childhood curriculum. *Young Children, 51*(5), 29-33.

Stefanich, G. P., Anderson, R., Cummings, C., Egelston-Dodd, J., Gerlovich, J., Hoffman, H. W., et al. (1985). *Addressing orthopedic handicaps in the science classroom.* (ERIC Documentation Reproduction Service No. ED258802)

Trumbull, D. (1990). Introduction. In E. Duckworth, J. Easley, D. Hawkins, & A. Henriques (Eds.), *Science education: A minds-on approach for the elementary years* (pp. 1-20). Hillsdale, NJ: L. Erlbaum Associates.

Vernon, P. E. (1976). Environment and intelligence. In O. Varma & P. Williams (Eds.), *Piaget, psychology and education: Papers in honour of Jean Piaget* (pp. 31-42). Itasca, IL: F. E. Peacock Publishers.

Webb, R. A., & Daurio, S. P. (1975). *Formal operations in very bright 8- to 14-year olds.* (ERIC Documentation Reproduction Service No. ED129437)

Weybright, L. D. (1972). *Developmental and methodological issues in the growth of logical thinking in adolescence.* Unpublished doctoral dissertation, University of Illinois at Urbana-Champaign, Illinois.

White, M. W., Manning, K. V., & Weber, R. L. (1955). *Practical physics* (2nd ed.). New York: McGraw-Hill.

Zigler, E. (1986). Should four-year-olds be in school? *Principal*, May, 10-14.

APPENDIX A

CONSENT FORM FOR CHILDREN AND PARENT/GUARDIAN

Dear Parents:

Your child has been selected to participate in a project to investigate children's understanding of balance and how best to promote learning in this area. Your child will be interviewed about his/her ideas about balance, using a standard classroom balance scale. He/she will then have the opportunity to engage in activities involving balance outside the classroom. These activities are designed to be both educational and enjoyable. There are no foreseeable risks or discomforts anticipated in this activity. Activities will be video taped for later analysis.

Your child's privacy will be protected by following the guidelines of the Regents' Center for Early Developmental Education. Children will be assigned an ID number, and your child's full name will not appear on data or in any reports of the data. Videotapes may be used for educational purposes in workshops, classes, and professional conferences. In such instances, your child will be referred to by his/her first name only.

Participation in this project is completely voluntary, and refusal to participate will result in no penalty or loss to your child. You may discontinue participation at any time, with no penalty or loss.

If you have any questions, please feel free to call me at the Regents' Center for Early Developmental Education, (319) 273-2101. You may also contact my advisor, Dr. Rheta DeVries, at (319) 273-2101 or the office of the Human Subjects Coordinator at the University of Northern Iowa, (319) 273-2748 for answers to questions about the research and the rights of research subjects.

Sincerely,

Seon Chun

I, ______________________, give permission to Seon Chun and the Regents' Center for Early Developmental Education to videotape, take photographs, and collect work samples of my child.

I understand that the above-mentioned materials collected of my child may be used to promote and teach best practices in early childhood education. I give permission to Seon Chun and the Regents' Center for Early Developmental Education to use the materials for educational purposes. This includes, but is not limited to, the distribution of Regents' Center for Early Developmental Education produced videotapes, the publication of articles, and the sharing of materials at conferences, teacher preparation classes and/or lectures. I also understand that my child will always only be referred to by his/her first name in order to protect his/her privacy.

By signing this form, I agree to give Seon Chun and the Regents' Center for Early Developmental Education all rights to materials collected of my child and release them from any and all claims arising out of, or resulting from, my child's appearance and/or statements.

Thank you for your assistance in our effort to improve the quality of early childhood education.

____
Printed Name of Child

____
Printed Name of Parent/Guardian

____
Signature of Child Date

____
Signature of Parent/Guardian Date

____
Signature of Investigator

APPENDIX B

PROTOCOL FOR PRETEST

Apparatus

- A primary balance scale
- A beam balance
- 40 hollow plastic cubes (3/8" x 3/8").

This protocol is prepared for pilot, pre-, and post-test. It consists of eight sections.

1. Equal-arm balance

(Start with introducing materials)

Hi! I brought some things I want to show you. Have you ever seen one like this before? This is a balance scale. And here are some cubes.

Ok, now, do you see the cups are straight across from each other? One is not higher than the other. We call this level. We'll call this the red cup and this blue cup.

2. Adding one cube

If I put one cube in the red cup, what do you think would happen to the red cup?

Could you show me how far it will go down? (With your hand).

Why do you think so?

What would happen to the blue cup (empty)?

⇒ (If a child says one of them will go down)

How much will the ---(red/blue) cup go down? How about the ---(blue/red) cup? Show me with your hand about where it will go.

(If says one goes further)

So the ---(red/blue) one will go up/down more than --- (blue/red) will go down/up?

Would the red cup go down at the same time the blue cup goes up? or does one move first?

⇒ If a child predicts the red cup and the blue cup both will go down.

What if I put one cube in both sides at the same time, what would happen?

(If a child says both will go down) How far do you think they will go down?

Show me with your hand.

(Let go of apparatus, so child can see the result.)

3. Adding two cubes

(Empty the cups)

What would happen if I put two cubes in each cup?

(Let child predict)

(If child predicts the red cup will go down and the blue cup will rise)

How much will the red cup go down? Show me.

How much will the blue go up? Show me.

(If says one goes farther) So the ---(red/blue) one will go up/down more than --- (blue/red) will go down/up?

(If a child says both will go down) show me with your hands where they will go.

(*Drop* both in, one side first and the other side next) What happened?

What makes that happen?

How do you know that?

4. Adding eight cubes

(Have child count 8 in your hand) Could you count 8 cubes and put them on my hand?

What will happen if I put 8 cubes in the red cup?

(If a child says the red cup goes down) Show me with your hand how far it goes.

And the blue cup. Show me where it will be.

How do you know that?

5. Adding two different kinds of cereals

(Fill a cup with corn-flake cereal) Can you guess how much do I need to use sugar-coated corn-flake cereal to make it level?

Do you want to try to make it level with sugar-coated corn-flake cereal?

6. Unequal-arm balance

Let me show you this (Make arms unequal with pin in 8^{th} hole. The red cup side of bar is shorter than the blue cup side.)

(Holding the arms level) What did I do?

What do you think will happen if I let go?

(Let beam go)

Can you make it level when it's like this? You can use these cubes.

7. Application (Transfer of knowledge to new apparatus)

(Show a beam balance with a tennis ball and cubes. The cubes are different than ones the researcher uses in the experiment with primary balance scale.)

(Start with the balanced beam)

(Put one cube onto the one side of the beam.) Can you make it level using these cubes?

(Put two cubes onto the one side of the beam with interval) Can you make it level using these cubes?

(Move the pivot so the beam is not balanced. Hold and ask,) What would it happen if I let go? Why?

Can you make it level not using the cubes?

APPENDIX C

PROTOCOL FOR POSTTEST

Apparatus

- A primary balance scale
- A beam balance
- 40 hollow plastic cubes (3/8" x 3/8").

This protocol is prepared for pilot, pre-, and post-test. It consists of eight sections.

1. Equal-arm balance

(Start with introducing materials)

Hi! I brought some things I want to show you. Have you ever seen one like this before? This is a balance scale. And here are some cubes.

Ok, now, do you see the cups are straight across from each other? One is not higher than the other. We call this level. We'll call this the red cup and this blue cup.

2. Adding one cube

If I put one cube in the red cup, what do you think would happen to the red cup?

Could you show me how far it will go down? (With your hand).

Why do you think so?

What would happen to the blue cup (empty)?

⇒ (If a child says one of them will go down)

How much will the ---(red/blue) cup go down? How about the ---(blue/red) cup? Show me with your hand about where it will go.

(If says one goes further)

So the ---(red/blue) one will go up/down more than --- (blue/red) will go down/up?

Would the red cup go down at the same time the blue cup goes up? or does one move first?

⇒ If a child predicts the red cup and the blue cup both will go down.

What if I put one cube in both sides at the same time, what would happen?

(If a child says both will go down) How far do you think they will go down?

Show me with your hand. (Let go of apparatus, so child can see the result.)

3. Adding two cubes

(Empty the cups)

What would happen if I put two cubes in each cup?

(Let child predict)

(If child predicts the red cup will go down and the blue cup will rise)

How much will the red cup go down? Show me.

How much will the blue go up? Show me.

(If says one goes farther) So the ---(red/blue) one will go up/down

more than --- (blue/red) will go down/up?

(If a child says both will go down) show me with your hands where they will go.

(*Drop* both in, one side first and the other side next) What happened?

What makes that happen?

How do you know that?

4. Adding eight cubes

(Have child count 8 in your hand) Could you count 8 cubes and put them on my hand?

What will happen if I put 8 cubes in the red cup?

(If a child says the red cup goes down) Show me with your hand how far it goes.

And the blue cup. Show me where it will be.

How do you know that?

5. Adding two cubes in one cup and one cube in the other cup

(Empty the cups)

What would happen if I put two cubes in red cup and one cube in blue cup?

(Let child predict) Why? What makes you think that?

(Drop the cubes in)

Is there any way you can make the bar level without adding or taking out cubes?

6. Adding two different kinds of cereals

(Fill a cup with corn-flake cereal) Can you guess how much do I need to use sugar-coated corn-flake cereal to make it level?

Do you want to try to make it level with sugar-coated corn-flake cereal?

7. Moving a cup

If I want to put two cubes in the red cup and one cube in the blue cup, is there any way I can make it level without putting or taking out cubes from the red cup and/or the blue cup?

What if I move the red cup from here (at end of arm of red) to here (sixth hole in arm, with the blue cup at end, holding arm level)? What do you think will happen if I let go?

8. Unequal-arm balance

Let me show you this (Make arms unequal with pin in 8^{th} hole. The red cup side of bar is shorter than the blue cup side.)

(Holding the arms level) What did I do?

What do you think will happen if I let go?

(Let beam go) Can you make it level when it's like this? You can use these cubes.

9. Application (Transfer of knowledge to new apparatus)

(Show a beam balance with a tennis ball and cubes. The cubes are different than ones the researcher uses in the experiment with primary balance scale.)

(Start with the balanced beam)

(Put one cube onto the one side of the beam.) Can you make it level using these cubes?

(Put two cubes onto the one side of the beam with interval) Can you make it level using these cubes?

(Put three cubes in beside of one side of the beam and two cubes in beside of the other side of the beam) I am just wondering if there is any way I can make the beam level when I put three cubes in one side and two cubes in the other side. Is there any way to do that?

Why? Why not?

(Move the pivot so the beam is not balanced. Hold and ask,) What would it happen if I let go? Why? Can you make it level not using the cubes?

APPENDIX D

PROTOCOL FOR INTERVENTION ACTIVITIES

Materials

- Two dimensional basic shapes – circle, triangle, and square- of felt cut by the researcher into different sizes
- Dowels (1/4 in. X 19.5 in.) sprayed with cracked paint
- Three dimensional materials such as miniature fruits,
- A stand (24 in. X 28 in. X 15 in.) made by the researcher using dowels (7/16 in.) and plastic connector for hanging mobiles
- String

The questions and procedure for the intervention activity will vary depending on children's reactions. However, the researcher will use following questions with flexibility.

Questions

- Have you ever seen a mobile before? Can you tell me how the mobile you saw looked?
- What do we need to do first to make a mobile?
- How can we make this bar level?
- What would happen if you put this shape here?
- What makes it tilt?
- If I want to hang this shape here (one end of a bar), what do I need to do to make it level?
- Is there any other way you can make it level instead of adding or switching shapes?
- Can you make a two-tier mobile? Or can you make a mobile using more than one bar?

APPENDIX E

CODING TABLE FOR PRETEST AND POSTTEST

Grade:	Name:	Age: years months	Sex: F M

1	1 cube Red	
	Red	
	Why	
	How far length	
	Blue	
	How far length	
	Length	
	Move at the same time	
	1 cube Red & Blue	
2	2 cubes Red & Blue	
	Red & Blue	
	Why	
	How far	
	Try	
	Why	
	How do you know	
3	8 cubes in Red	
	Red	
	How far	
	Why	
	Blue	
	How do you know	
	Level	
4	Cereal	
	Make same amount	
	Regular in Red Sugar in Blue	
	Why	
5	2 cubes in Red 1 cube in Blue	
	What will happen	
	Why	
	Level not using cubes	
	Move R middle	
	Level	
	Move fulcrum	
	Level	

6	Unequal-arm: move fulcrum	
	What did I do	
	What will happen	
	Why	
	Level not using cubes	
	Level using cubes	
7	Beam balance	
	One cube Left	
	Level	
	Two cubes left	
	Level	
	3 cubes on left, level using 2 cubes	
	Move fulcrum – what happen – why	
	Level using cubes	
	Level not using cubes	

APPENDIX F

CODING TABLE TO DETERMINE

CHILDREN'S DEVELOPMENTAL LEVEL IN BLANCE

Name: Grade

Stage	Characteristics	Pre	Post
1A	Both cups go down at the same time		
	Each cup at a time moves – lack of coordination		
1B	Putting an object in one cup does not act upon the cup on the other side of the balance (that is, in a unidirectional way)		
	One cup will fall more than the other rises		
	Cups will both go down a little bit		
	One cup will move first		
	Numeric symmetry		
2A	Hesitation		
	The arms will move at the same time		
	The cups will move to the same height		
	The cups may just go down a little bit		
2B	No hesitation and no errors		

Level	

APPENDIX G

CODING TABLE FOR INTERVENTION ACTIVITIES

	Grade					
	1			3		
	I	II	III	I	II	III
Level (Tier)						
1st						
2nd						
3rd						
Symmetry						
Shapes						
Bars						
Numbers						
Colors						
Compensation						
Adding						
Taking Out						
Switching						
Moving						
Distance & Weight						
Show						
Explain						
Do Not Show						
Coordination						
Show						
Explain						
Do Not Show						
Level W/O adding						
Yes						
No						
Frustration						
It won't work						
It's hard						
Visit restroom						
Sigh						
Hit sticks						
Wondering						
Peer teaching						
Collaboration						
Trading						
Helping						
Paying attention						
Perturbation						
Aha moment						
Pause to think						
Coherence						
Consistent						
Inconsistent						

APPENDIX H

A SAMPLE TRANSCRIBED NOTE

19 (1 of 1)

4-② Brian (w/ Alex) Int – III

5920

1) a ⑤ 2) → change sticks

3) b ⑪ 4) b "I made it level." knows ★ 1st.

5) b [S] What will happen if 2 ~~take~~ off? right
"This side (b⑤) will go up."
→ takes one off

6) b → c ⊕
c ⓒ

1:02:45 7) b [S] Add another stick.
Δ takes ~~block the~~ b

8) d ⓛ "I'll do exactly what Alex does." peer-learning. modeling

9) d ⓜ e → pushes it out right 10) d → e

1:04:35 -40 11) e "Actually if you get, one, the bottom one's level, you'll get them all leveled." whole system coordinate btw lower & upper

1:05:35 (A) :48 12) d e → →

"Oh~ I know." (move e to the F) "A-ha" moment, the pivot
"If you put it close to that, it will tip, so you gotta put them in the middle." ~~[illegible]~~ Archimedes

end the first session