Science in a constructivist classroom: Progress in a five-year-old child's reasoning about water dynamics

Hyang-Lim Kwak

University of Northern Iowa

Copyright ©1995 Hyang-Lim Kwak

Follow this and additional works at: https://scholarworks.uni.edu/etd

Part of the Curriculum and Instruction Commons, Educational Psychology Commons, Elementary Education Commons, and the Science and Mathematics Education Commons

Recommended Citation

Kwak, Hyang-Lim, "Science in a constructivist classroom: Progress in a five-year-old child's reasoning about water dynamics" (1995). Dissertations and Theses @ UNI. 798.
https://scholarworks.uni.edu/etd/798
INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.
SCIENCE IN A CONSTRUCTIVIST CLASSROOM: 
PROGRESS IN A FIVE-YEAR-OLD CHILD’S REASONING 
ABOUT WATER DYNAMICS

A Dissertation
Submitted
In Partial Fulfillment
of the Requirements for the Degree
Doctor of Education

Approved:

Dr. Rheta L. DeVries, Advisor

Dr. Rebecca K. Edmiatson, Committee Member

Dr. Linda M. Fitzgerald, Committee Member

Dr. Carolyn Hildebrandt, Committee Member

Dr. John K. Smith, Committee Member

Hyang-Lim Kwak
University of Northern Iowa
December 1995
SCIENCE IN A CONSTRUCTIVIST CLASSROOM:
PROGRESS IN A FIVE-YEAR-OLD CHILD'S REASONING
ABOUT WATER DYNAMICS

An Abstract of a Dissertation
Submitted
In Partial Fulfillment
of the Requirements for the Degree
Doctor of Education

Approved:

Dr. Rheta L. DeVries, Faculty Advisor

Dr. John W. Somervill, Dean of the Graduate College

Hyang-Lim Kwak
University of Northern Iowa
December 1995
SCIENCE IN A CONSTRUCTIVIST CLASSROOM: PROGRESS IN A FIVE-YEAR-OLD CHILD'S REASONING ABOUT WATER DYNAMICS

Hyang-Lim Kwak

Abstract

The purpose of the study is to understand changes in a target child’s reasoning about water dynamics, specifically, draining and movement of water in tubes. The study also focuses on development and evaluation of activities and teaching strategies. The activities were conducted with all children in the preschool at a public elementary school in Iowa as part of the regular classroom constructivist program inspired by Piaget’s work. Using Piaget’s theory to provide insights into the child’s reasoning and knowledge, analysis focused on the child’s construction of regularities between his actions and reactions of water, and on the construction of relationships based on these regularities. Functional relationships included those (a) between sizes and positions of holes in plastic glasses and the resultant nature of the draining, and (b) between height of water in tubes and flow. Analysis also took into account the role of contradiction in the child’s growing consciousness of regularities and relationships.

In this study, the child constructed physical knowledge and logico-mathematical knowledge in the course of experiences with water draining and water movement in tubes. Whereas the child showed progress at the conceptual level for water draining, he showed only progress at the practical level for water movement in tubes. Even though his progress in water movement in tubes was made only at the action level, this is viewed as an abundant and necessary source of future progress in conceptualization. The study is important in providing an analysis that demonstrates that children in water activities are not “just playing,” but that when materials and interventions challenge children’s reasoning, they do in fact, make progress in knowledge and reasoning. Teacher interventions that promoted progress in reasoning included fostering observation of regularities, encouraging hypotheses and their testing, fostering comparisons, and promoting consciousness of actions and reactions (including contradictions).
Acknowledgement

I owed deep debts to many people during my work on this dissertation. Completing this dissertation is attributed to big supports and encouragement from those people. I would like to express my gratitude.

First, my deepest thank from all my heart goes to Dr. Rheta DeVries, my advisor and mentor, who enriched me by her tremendous work to bridge Piaget's theory to early childhood education. Moreover, by suggesting that I read many of Piaget's books selected with her sharp insights, she helped me to see and interpret my data with new eyes. While I was struggling with reading Piaget's books, she offered me lots of time for my understanding and encouraged me to complete this work.

I would also like to thank my other committee members, Dr. Rebecca Edmiaston, Dr. Linda Fitzgerald, Dr. Carolyn Hildebrandt, and Dr. John Smith who gave their critiques and advisement with open minds. They always gave me warm encouragement and sometimes in a friendly way pushed me to finish my work.

My deepest thanks are extended to the children and the teacher who allowed me to work with them and to gain insights into children's reasoning. The children, specifically my target child, provided me with rich sources through which I could understand Piaget's theory. While working with the constructivist teacher, Christie Sales, who became a close friend, I learned a lot from her cooperative attitudes and her enthusiasm to promote children's reasoning. I highly appreciate her collaboration with me in developing activities and teacher interventions.

I would also like to thank Barb Haas who gave her summer break time to transcribe my data. My appreciation also goes to Dr. Kyung Woo Lee who has always supported me. She introduced me Dr. Rheta DeVries and suggested that I study under her. I would like to thank all my friends who allowed me to share my frustrations and encouraged me during the writing of this dissertation. Finally, I would really like to thank my mother and my family who have been waiting for my returning to Korea with patience.
# TABLE OF CONTENTS

**LIST OF FIGURES** ....................................................................................................... vii

**Chapter**

1. INTRODUCTION ...................................................................................................... 1

2. REVIEW OF LITERATURE .................................................................................. 3

   * Piagetian Theoretical Foundation ....................................................................... 3
   * Knowledge and Experience .............................................................................. 3
   * Structural Stages .............................................................................................. 5
   * The Constructive Process in Development of Knowledge and Reasoning .......... 7

* Studies Related to Water Knowledge ............................................................. 12
   * Water Level .............................................................................................. 12
   * Water Conservation ................................................................................ 14
   * Draining ....................................................................................................... 16

* Physical Knowledge Activities in Constructivist Education ............................... 16
   * Definition of and Rationales for Physical-Knowledge Activities .................. 16
   * Principles of Teaching Physical-Knowledge Activities .............................. 17
   * Physical Knowledge Activities and Science Education ............................. 19

* Water Activities in Early Childhood Curriculum ............................................ 22
   * Water Activities in Traditional Early Education ...................................... 22
   * Constructivist Water Activities ................................................................... 24
   * Constructivist-Supported Literature on Water Activities ........................... 25

* Research Questions ............................................................................................ 26

3. METHOD ..................................................................................................................... 28

* Participants ........................................................................................................... 28

* Materials and Procedures .................................................................................. 28

   * Session 1: Water Draining I ......................................................................... 29
   * Session 2: Water Draining II .......................................................................... 31
   * Session 3: Catching Water on the Pegboard I ............................................... 31
<table>
<thead>
<tr>
<th>Chapter</th>
<th></th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Session 4: Catching Water on the Pegboard II</td>
<td></td>
<td>33</td>
</tr>
<tr>
<td>Session 5: Water Movement in Tubes I</td>
<td></td>
<td>33</td>
</tr>
<tr>
<td>Session 6: Water Movement in Tubes II</td>
<td></td>
<td>34</td>
</tr>
<tr>
<td>Session 7: Water Movement in Tubes III</td>
<td></td>
<td>34</td>
</tr>
<tr>
<td>Session 8: Water Movement in J- and S-shaped Tubes</td>
<td></td>
<td>34</td>
</tr>
<tr>
<td>Session 9: Making Fountains I</td>
<td></td>
<td>36</td>
</tr>
<tr>
<td>Session 10: Making Fountains II</td>
<td></td>
<td>36</td>
</tr>
<tr>
<td>Session 11: Water Squirter with a Target</td>
<td></td>
<td>37</td>
</tr>
<tr>
<td>Theoretical Foundation for Analysis of Child’s Reasoning</td>
<td></td>
<td>38</td>
</tr>
<tr>
<td>Relation between Action and Thought</td>
<td></td>
<td>39</td>
</tr>
<tr>
<td>Physical Knowledge</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>Equilibration</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>Role of Contradiction</td>
<td></td>
<td>42</td>
</tr>
<tr>
<td>Consciousness</td>
<td></td>
<td>43</td>
</tr>
<tr>
<td>Functions</td>
<td></td>
<td>47</td>
</tr>
<tr>
<td>Conservation</td>
<td></td>
<td>48</td>
</tr>
<tr>
<td>Seriated Correspondences</td>
<td></td>
<td>49</td>
</tr>
<tr>
<td>Negotiation Strategies and Shared Experience</td>
<td></td>
<td>49</td>
</tr>
<tr>
<td>The Rationales for Analysis of Teacher’s Intervention</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Promoting Children’s Reasoning</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Building a Cooperative Atmosphere</td>
<td></td>
<td>51</td>
</tr>
</tbody>
</table>

4. RESULTS

| Session 1: Water Draining I |       | 52   |
| Session 2: Water Draining II |       | 72   |
| Session 3: Catching Water on the Pegboard I |       | 80   |
| Session 4: Catching Water on the Pegboard II |       | 86   |
| Session 5: Water Movement in Tubes I |       | 107  |
| Session 6: Water Movement in Tubes II |       | 120  |
| Session 7: Water Movement in Tubes III |       | 125  |
Chapter | Page
--- | ---
Session 8: Water Movement in J- and S-shaped Tubes | 127
Session 9: Making Fountains I | 131
Session 10: Making Fountains II | 134
Session 11: Water Squirter with a Target | 140

5. SUMMARY AND DISCUSSION | 148
Progress in the Child’s Reasoning over a Series of Water Activities | 148
Curtis’s Structure of Water Knowledge and Limitations in Structure of Reasoning | 149
Curtis’s Constructive Process during Water Activities | 150
Evaluation of Teacher’s Interventions | 154
Prompt the Child’s Reasoning by Engaging in his Problem as a Companion | 154
Foster Observation and Construction of Regularities | 155
Encourage Hypotheses and Testing Hypotheses | 156
Foster Comparison and Construction of Relationships | 156
Promote Consciousness of Actions | 156
Promote Interchange of Ideas among Children | 157
Foster Consciousness of Contradictions | 157
Foster Predictions | 157
Foster Causal Reasoning | 157
Non-Effective Interventions: Different Agenda or Interest from the Child’s | 158
Evaluation of Water Activities | 158
The Activities Gave the Child Opportunities to Act on Objects and Observe the Results | 159
The Activities Inspired the Child to Make Hypotheses and Test Them | 159
The Activities Inspired Experiences that led to Contradictions between Expectations and Results | 159
The Activities gave the Child Opportunities to Cooperate with Others | 159

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>There were Limitations of the Activities: Building Air Pockets in Tubes</td>
<td>160</td>
</tr>
<tr>
<td>6. CONCLUSION</td>
<td>161</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1.</td>
<td>Glasses presented for session 1</td>
</tr>
<tr>
<td>2.</td>
<td>New glass for session 2</td>
</tr>
<tr>
<td>3.</td>
<td>New materials for session 3</td>
</tr>
<tr>
<td>4.</td>
<td>Reservoir</td>
</tr>
<tr>
<td>5.</td>
<td>J-and S-shaped tubes on the pegboard</td>
</tr>
<tr>
<td>7.</td>
<td>New materials for session 9</td>
</tr>
<tr>
<td>8.</td>
<td>Materials for session 11</td>
</tr>
<tr>
<td>9.</td>
<td>The process of the grasp of consciousness</td>
</tr>
<tr>
<td>1.1.</td>
<td>Emptying 1Bb glass above 1Mb glass</td>
</tr>
<tr>
<td>1.2.</td>
<td>Comparing 1Bb glass with 1Mb glass</td>
</tr>
<tr>
<td>1.3.</td>
<td>Comparing 1Sb glass with 1Mb glass</td>
</tr>
<tr>
<td>1.4.</td>
<td>A series of experimentation with 1Sb glass</td>
</tr>
<tr>
<td>1.5.</td>
<td>Switching the position by reciprocal assimilation, draining and catching</td>
</tr>
<tr>
<td>1.7.</td>
<td>Accommodating his action to side hole glass by tipping</td>
</tr>
<tr>
<td>1.8.</td>
<td>Exchanging the top 1Sb glass for 1Bb glass to see the curving stream from 2Mbs and then switching the position to drain it into the 1Bb glass</td>
</tr>
<tr>
<td>1.9.</td>
<td>Coordinating draining from two glasses into one glass</td>
</tr>
<tr>
<td>1.11.</td>
<td>Draining 1Bb glass into the stacked glasses to try to see the curving stream from the outside 2Mbs of the stack</td>
</tr>
<tr>
<td>1.12.</td>
<td>Switching 2Mds to 1Bb after draining from each hole of 2Mds</td>
</tr>
<tr>
<td>1.14.</td>
<td>Trying 2Mdsdh to see what happen to holes of it</td>
</tr>
<tr>
<td>1.17.</td>
<td>Coordinating draining from his glasses into Nathan’s</td>
</tr>
<tr>
<td>1.18.</td>
<td>Coordinating two experiment</td>
</tr>
<tr>
<td>2.1.</td>
<td>Catching water streams by the order of draining from the holes of 2Mbs</td>
</tr>
<tr>
<td>2.2.</td>
<td>Considering both streams at the same time</td>
</tr>
<tr>
<td>2.3.</td>
<td>Catching water streams according to the order of draining from 2Mbs by plugging bottom hole first</td>
</tr>
<tr>
<td>2.4.</td>
<td>Stacking two glasses with water and watching water stop from side hole</td>
</tr>
<tr>
<td>Figure</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>2. 5.</td>
<td>Taking stacked glasses apart by noticing water stop from the side hole</td>
</tr>
<tr>
<td>2. 6.</td>
<td>Showing his interest in curving stream</td>
</tr>
<tr>
<td>2. 7.</td>
<td>Demonstrating by the teacher</td>
</tr>
<tr>
<td>2. 8.</td>
<td>Trying to match up the holes in the sides of each glass</td>
</tr>
<tr>
<td>3. 1.</td>
<td>Inventing an arrangement to drain from side-hole glass on the pegboard</td>
</tr>
<tr>
<td>3. 2.</td>
<td>Engaging in catching curving stream on the pegboard by the teacher’s demonstration and watching water miss the glass when the water stream arcs lower</td>
</tr>
<tr>
<td>3. 3.</td>
<td>Catching water streams from the side holes on the pegboard by the teacher’s intervention</td>
</tr>
<tr>
<td>3. 4.</td>
<td>Coordinating all water in one glass</td>
</tr>
<tr>
<td>4. 1.</td>
<td>Placing glasses in the holders in a vertical line</td>
</tr>
<tr>
<td>4. 2.</td>
<td>Exchanging 1Mms for 1Bb to make water go through all three glasses</td>
</tr>
<tr>
<td>4. 3.</td>
<td>Trying to make curving stream</td>
</tr>
<tr>
<td>4. 4.</td>
<td>Replacing 1Bb in the top holder to make curving stream from 1Mms</td>
</tr>
<tr>
<td>4. 5.</td>
<td>Adding more glasses in the system of draining</td>
</tr>
<tr>
<td>4. 6.</td>
<td>Lacy’s failure to make curving stream into 1Bb</td>
</tr>
<tr>
<td>4. 7.</td>
<td>Sharing experience with Lacy</td>
</tr>
<tr>
<td>4. 8.</td>
<td>Coordinating all water into his bottom glass by rearranging Lacy’s glasses</td>
</tr>
<tr>
<td>4. 9.</td>
<td>Making water from the both systems end up in the bottom 1Mms</td>
</tr>
<tr>
<td>5. 1.</td>
<td>Making water flow from reservoir into glass</td>
</tr>
<tr>
<td>5. 2.</td>
<td>The situation that gave Curtis a contradiction</td>
</tr>
<tr>
<td>5. 3.</td>
<td>Experiencing contradiction by trying to recycle water and then watching water come out when he put the end of tube down lower</td>
</tr>
<tr>
<td>5. 4.</td>
<td>Encountering with air problem</td>
</tr>
<tr>
<td>5. 5.</td>
<td>Extending tubes and putting the end of tube down lower</td>
</tr>
<tr>
<td>6. 1.</td>
<td>The materials to give Curtis a simple arrangement</td>
</tr>
<tr>
<td>6. 2.</td>
<td>Attaching his tube to Nathan’s to see water come out of funnel</td>
</tr>
<tr>
<td>6. 3.</td>
<td>Putting funnel down lower when water did not come up</td>
</tr>
<tr>
<td>7. 1.</td>
<td>An arrangement by Curtis with Nathan</td>
</tr>
<tr>
<td>Figure</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>8. 1. Pouring water into long end of J-shaped tube and watching water come out the short end of it</td>
<td>128</td>
</tr>
<tr>
<td>8. 2. Trying to connect J- and S- shaped tube</td>
<td>129</td>
</tr>
<tr>
<td>8. 3. Cooperating with Tyler to pour and catch water</td>
<td>130</td>
</tr>
<tr>
<td>9. 1. Making fountains</td>
<td>131</td>
</tr>
<tr>
<td>9. 2. Trying to recycle again</td>
<td>132</td>
</tr>
<tr>
<td>9. 3. Adding a “fountain” glass to his fountains</td>
<td>133</td>
</tr>
<tr>
<td>10. 1. Putting the end of tube into his fountains</td>
<td>134</td>
</tr>
<tr>
<td>10. 2. Trying to send water through tube from lower glass to higher glass</td>
<td>137</td>
</tr>
<tr>
<td>10. 3. Blowing into tube when water did not go up from lower glass to higher glass</td>
<td>138</td>
</tr>
<tr>
<td>11. 1. Squeezing baster at target in the standing position</td>
<td>141</td>
</tr>
<tr>
<td>11. 2. Reservoir moved from the pegboard to the place where the children can see it</td>
<td>143</td>
</tr>
</tbody>
</table>
CHAPTER 1
INTRODUCTION

The aim of the research reported here is to study changes in a child’s reasoning about water dynamics within the constructivist paradigm that is informed by Piaget’s work. The study also focuses on development and evaluation of activities and teaching strategies in terms of progress in the child’s reasoning. Piaget (1974/1976, 1974/1978, 1974/1980) showed that young children think in qualitatively different ways than older children and adults (DeVries & Kohlberg, 1987/1990) about a wide variety of physical phenomena, including water dynamics. The study, as one approach for constructivist education, is an effort to take into account the ways in which young children reason.

Water activities are widely used in early childhood classrooms. Due to the affinity of young children for water, educators have long proposed that water experiences naturally belonged to the realm of early childhood education. Many textbooks of early childhood education (Althouse & Main, 1975; Bender, 1969; Gordon & Browne, 1985; Harlan, 1992; Hartley, Frank, & Goldenson, 1952; Johnson, 1928; Landreth & Read, 1942; Spodek, Saracho, & Davis, 1991; Weber, 1969; Wolfgang & Wolfgang, 1992) include water activities as an integral part of the curriculum. As a material from the natural world with which children are interested in playing, water is viewed as being within a context where learning can occur (Bender, 1969).

However, from the constructivist perspective, traditional uses of water activities are much too limited and do not offer sufficient stimulation to promote children’s reasoning (DeVries et al., 1992). Yet, constructivist studies of water activities leave room for improvement. Water activities were not developed with modifications based on children’s reasoning within a phenomenon. The goal of this study is to further develop the constructivist approach to using water activities in preschool classrooms.

The aim of this study is to critique traditional uses of water activities, to evaluate published recommendations for using water activities in early childhood classrooms, to develop activities based on children’s reasoning, to try to promote children’s reasoning, and to study the effectiveness of constructivist interventions in the course of classroom activities. The Piagetian theoretical foundation for this research is presented, followed by a
summary of the constructivist research on children's reasoning about water level, conservation, and draining. General principles of teaching physical knowledge activities in constructivist education and their relation to science education are discussed. Review of the use of water activities in traditional early education is followed by a summary of constructivist work on water activities. Limitations in this constructivist work lead to the effort in this study to develop further activities based on children's reasoning during previous water activities. Reviewing the literature on intervention strategies gives practical ideas for implementing the study in the classroom.

This study will add to the body of knowledge on children's reasoning about water dynamics. In showing how to develop teaching strategies, this study will be helpful for teachers who want to implement their own constructivist curriculum. Accordingly, this study is expected to contribute to teacher education in the context of the constructivist perspective. Development of a series of water dynamics activities will enrich the early childhood curriculum.
CHAPTER 2
REVIEW OF LITERATURE

Piagetian Theoretical Foundation

Constructivist approaches to teaching young children require us to understand the learner. Piaget’s theory provides relevant insights into children’s learning, so it is essential to understand his theory in early childhood education. In this study, specifically in terms of water dynamics, Piaget’s theory will provide clues as to how to promote children’s water knowledge.

Piaget’s theory focuses on knowledge and experience. Piaget considered two aspects in the course of development of knowledge, that is, stages and constructivism. Thus, in the constructivist approaches in which how children learn is regarded as an important matter, both structural stages and functional constructivism need to be considered. DeVries and Kohlberg (1987/1990) argue that educators sometimes focus solely on either the structural or the functional aspect of Piaget’s work. This study pursues a balance between these two theoretical aspects. In this section, Piaget’s theory is reviewed regarding knowledge and experience, structural stages, and the constructive process in knowledge and development.

Knowledge and Experience

According to Piaget (1975), contact with the environment leads to experiences through which knowledge develops. It develops through experiencing in relation to actions on objects—how they move, how they change position and shape, and how they change in their relation to themselves and other objects (Piaget, 1937/1954). In other words, he viewed knowledge as being constructed by a knower who actively interprets experience.

Physical experience is interaction with objects in external reality that involves mental actions which abstract the properties of objects and events. For example, experience shows that a ball rolls down an incline and that water does not flow uphill without pressure. Physical experience leads to physical knowledge which is derived from the objects themselves. Physical knowledge is a category of knowledge acquired by means of the experience of external objects (Piaget, 1971). The source of physical knowledge is thus mainly in the object. The child obtains information from objects by empirical abstraction—reasoning about properties of objects. In empirical abstraction, the child focuses on a certain aspect of the object and ignores others. Physical knowledge which is derived from the objects themselves results from physical experience.

Logico-mathematical experience involves knowledge acquired from reflection on one's actions, and not from the objects themselves. In logico-mathematical experience, the individual introduces into objects characteristics they do not have. In Piaget's view, the child comes to know something about number not through direct physical experience with the objects themselves but by considering his/her own actions by a process of reflective abstraction—reasoning about relationships among reflections on objects. The child first notices one of his/her own actions. Next, the "action noted has to be 'reflected' (in the physical sense of the term) by being projected onto another plane--for example, the plane of thought as opposed to that of practical action" (Piaget, 1971, p. 320).

Therefore, logico-mathematical experience leads to logico-mathematical knowledge which consists of relationships created by the child among actions on objects. The fact that there are more blocks (the whole) than blue ones (the part) is an example of logico-mathematical knowledge. Another example is the principle of horizontality of water level. According to Piaget (1975/1977), "a water level can be 'observed' as not horizontal because it is conceived as depending only on the form of the jar and as not bearing any relation to outside references" (p. 45). Young children's thought is limited to the inside of the bottle, and they therefore cannot coordinate spatial relationships into a coherent system. As a result, children assume that the water level will "tip" with the glass.

The source of logico-mathematical knowledge is thus mainly in the subject. The logico-mathematical knowledge the child gains from logico-mathematical experience is
derived not from objects, but from her/his mental action bearing on the objects. Logico-
mathematical knowledge is constructed by reflective abstraction which is very different
from empirical abstraction. While information about physical properties is abstracted from
the objects themselves, in reflective abstraction, knowledge derives from the child's action
of creating relationships among objects. Thus, logico-mathematical knowledge should
never be taught in a pure and abstract form in the preschool years (Forman & Kuschner,
because it is constructed from relationships the child herself/himself creates among objects
when she/he has logico-mathematical experiences with them.

Piaget also mentioned social-arbitrary knowledge as a third type of knowledge.
Social-arbitrary knowledge is arbitrary truths on which people agreed conventionally (such
as the fact that there are no school classes on Sunday) and rules on which people agreed by
coordination of points of view (such as the rule that people do not cross the road on the red
light). Therefore, its source is in people. DeVries and Kohlberg (1987/1990) indicate that
"Social-arbitrary knowledge is similar to physical knowledge in that it requires specific
input from the external world. However, this content must also be structured within some
logico-mathematical framework" (pp. 21-22). Thus, social arbitrary knowledge, too, is
not entirely separate from logico-mathematical knowledge.

Children's thoughts about water can be physical experience and knowledge as well
as logico-mathematical experience and knowledge. It can also involve social-arbitrary
knowledge when children acquire verbal expression in relate to water and other materials.
From experiences with water dynamics, children can construct their reasoning and
knowledge about the movement of water, as well as their general intelligence.

Structural Stages

For Piaget, stages are a description of operational structures in mental activity
which shows that children’s thoughts are qualitatively different from older children’s or
adults’. Piaget (1946/1970) defined four broad periods, each of which is characterized by
a unique form or structure of reasoning. He called these periods stages, that is,
sensorimotor stage, preoperational stage, concrete operational stage, and formal operational
stage. Piaget distinguished the structure of most preschool children as a preoperational
stage which is "simultaneously an extension of the sensorimotor stage and the basis of the future concrete operations" (p. 712). Thus, for Piaget, these stages express the structural aspects of children's cognitive development.

According to Piaget (1946/1970), the child thinks differently at different stages because she/he organizes experiences in different ways at each stage. The interaction between a child's active thought and the environment or experience leads the child's unique thought patterns at each stage. According to Piaget, characteristics of preoperational thought include lack of reversibility, incoherence, and instability.

Lack of reversibility can be demonstrated in Piaget's task dealing with the conservation of liquid. After being shown two identical transparent glasses which are filled with equal quantities of water, then one is poured into a third glass which is taller and more narrow. The nonconserving child thinks that the third one has more (Piaget & Szeminska, 1941/1952). Incoherence can be seen in a case of floating and sinking. If flatness is a criterion to explain floating, not being flat must logically be a criterion to explain sinking. However, "the positive criteria do not necessarily have corresponding negatives in the other pile" (Kamii & DeVries, 1978/1993, p. 32) when they classify the pile of things that float or sink.

The young child does not recognize the incoherence in her/his logic. Taking an example from a film about rollers (Kamii, DeVries, Ellis, & Zaritsky, 1975), DeVries and Kohlberg (1987/1990) explain a case of instability. One 4-year-old child makes catapults using rollers and boards. That is, he puts an object on the end of a board supported at the fulcrum by a roller. While most of the time he has no problem putting the object on the "down" end of the board and jumping on the other end, at one moment he places his sponge on the raised end, instead of placing it on the lower end. However, he becomes aware of a need to correct only at the moment when he is about to jump on the "down" end. This reveals the unstable nature of the system of relationships.

For Piaget, the sequence of the stages cannot be changed but the mental structures in each stage develop gradually and can be stimulated by education. DeVries (1978) comments on the nature of the structural stages: "For Piaget, the stages simply signify the mental structures which enabled him to show that knowledge, especially logic, is not
innate, but develops itself little by little” (p. 76). Clarifying the significance of the stages, she draws the educational implication that stages are the structures that reflect developmental progress, which is the aim of education. The educational implication of stages, according to Kohlberg (1987), is that educational experiences can lead movement to the next stage of development. Piaget (1946/1970) recognized this as well: “Some pedagogical interventions can, of course, accelerate and complete spontaneous development” (p. 712), even though the sequence of the constructions cannot be changed by them.

However, description of the stages themselves do not show the constructive process in development of operational structures. DeVries (1978) notes that Piaget’s stages do not describe anything in terms of how children move from one stage to the next. She draws from the constructivist aspects of Piaget’s theory the notion that the child moves from one stage to the next through exercising her/his present reasoning thoroughly and constructing her/his knowledge at each stage. Therefore, when focusing only on the stages, “one misses entirely the theme of Piaget’s theory, constructivism which deals with the process of development” (p. 77).

Having considered the nature of stages, we can conclude that the importance of Piaget’s stages for educators is that children’s reasoning is integrated and transformed in quality through experience. Therefore, the significance of stages for educators is (a) children construct knowledge rather than learning through direct social transmission, and (b) educators can sometimes assess children’s development in terms of stages in classroom activities.

In this study, the participant, a child five years of age, will be expected to reason at the preoperational stage. The goal is to understand how the child constructs his knowledge about the movement of water during water activities.

The Constructive Process in Development of Knowledge and Reasoning

In Piaget’s theory, the constructive process in knowledge and development describes how children learn and construct their knowledge. In this section, the role of action which is important in the construction of the world and the role of error, of
contradiction, and of cooperation that are demonstrated in the course of constructing knowledge will be reviewed to understand children’s constructive processes.

**Role of action in knowledge and development.** According to Piaget’s theory, action is essential for young children to develop their reasoning and knowledge. Piaget (1936/1952, 1937/1954) discussed how young children construct their knowledge and reasoning in the course of acting on objects. In other words, action is the source of knowledge and intelligence. DeVries and Kohlberg (1987/1990) comment that “For the child up to about 7 or 8 years, thought is still closely related to physical action. In one sense, mental development may be described in terms of gradual freeing of thought from action” (p. 20).

During the sensorimotor period, the infant begins to construct knowledge by observing what happens when pushing, pulling, shaking, and dropping objects, and by putting into relationship all the differences in the reactions of objects. However, his/her focus is mainly on physically observable content. During the preoperational period, the physical and logico-mathematical aspects of actions are still undifferentiated and the main interest is still in the physical and observable result of actions. Gradually depending less on the physical action, the children progressively create and coordinate relationships, which are still limited and unstable.

As already discussed in terms of knowledge and experience, Piaget (1964, 1969/1972, 1970, 1946/1970, 1970a/1972, 1970b/1972, 1971/1974) distinguished two types of action which lead to two different types of psychological experience. Two kinds of knowledge result from these experiences; one which is oriented toward the specificity of each object and one which is oriented toward what is general. Piaget referred to the first aspect of action as simple or empirical abstraction which leads to physical knowledge and the second aspect of action as reflective abstraction which leads to logico-mathematical knowledge. Since action on objects always has these two aspects, the general structure of thought, that is logico-mathematical thought, develops in the course of constructing specific physical knowledge.

From Piaget’s perspective, action includes the mental process as well as the physical. Thus, action in Piaget’s theory cannot be interpreted by the empiricist
assumption that knowledge is derived directly from observation and manipulation of objects alone (Kamii, 1981). Knowledge is constructed by the child through actions on objects.

In this study, water dynamics are sources that offer the child a variety of possibilities for action. Specifically, the materials offered with water, such as flexible tubes and containers with holes, are expected to facilitate children's actions on water.

Role of error in knowledge and development. Piaget's research (1936/1952, 1974/1976, 1974/1978, 1974/1980) showed that children's erroneous ideas result because children reason or make inferences from observing the events within the framework which they have already constructed, that is, by means of assimilation. Piaget (1946/1970) viewed assimilation as essential to constructing knowledge. However, according to him, if assimilation alone is involved in development of knowledge, children cannot acquire new content and there would be no cognitive adaptation in their structure. Piaget used the term "accommodation" to explain this process. Piaget defined accommodation as "any modification of an assimilatory scheme or structure by the elements it assimilates" (p. 708). Thus, development occurs by these two processes of adaptation.

According to Piaget (1946/1970), however, assimilation and accommodation may exist in different ratios in children's mental activity. When assimilation and accommodation are in balance, which is termed equilibrium, Piaget said that there would be the proper domain of intelligence. According to Piaget, "such an equilibrium exists at all levels, in the early development of intelligence in the child as well as in scientific thought" (p. 709). However, it is more or less difficult to attain and to maintain this fundamental equilibrium between assimilation and accommodation, depending on the level of intellectual development and the new problems encountered. During the early development of intelligence in the child, because assimilation leaves little room for accommodation, the child naturally has erroneous thoughts.

Thus, children's erroneous thoughts show that they are using their reasoning at their present level. Forman and Fosnot (1982) define the child's erroneous thought as "a logical extension of certain firmly believed assumptions" (p. 189). According to them, erroneous ideas which the child first has are eventually contradicted and after that, she/he
makes some attempts to eliminate the contradictions by restructuring (that is, accommodating).

Showing children's many erroneous thoughts through experiments with young children, Piaget gave us insights about what the child does know and how the child reasons. According to Piaget and Inhelder (1956), for example, the child who is in the second stage of water knowledge has the erroneous idea that the water will stay at the upper side of the bottle when the bottle rests on its side. Kamii and DeVries (1978/1993) observed another example of error in relation to draining. According to them the child reasons that when a container has holes both on the side and the bottom, water leaks only from the bottom hole when the container is in a standing position. The child reasons that in order to make the side hole leak, the container needs to be turned with the side down. While the child experiment with her/his erroneous ideas, she/he gradually realizes that the ideas were wrong and tries to correct them. Thus, when the child shows erroneous ideas during the activity, she/he is in actively endeavoring to understand how water behaves. This is construction of knowledge.

In this study, many erroneous thoughts about the movement of water are expected during the activities, which would show that children are still constructing that knowledge.

Role of contradiction in knowledge and development. According to Piaget (1974/1980), contradiction is important in the construction of equilibrated structures. Discussing the relations between contradictions and disequilibrium, Piaget explained how contradictions arise, become conscious, and are transcended. According to Piaget, contradictions occur from the disequilibrated mind which results from insufficient compensation between affirmations (perceiving only positive characteristics such as that water flows from a container's hole) and negations (perceiving negative characteristics such as that water does not flow up hill). Piaget points out that children tend to focus on affirmations but neglect negations which are the source of disequilibrium and give rise to contradictions.

Piaget (1974/1980) distinguished two different sources of contradictions: first, contradiction between schemas, that is, internal conflicts, and second, contradiction between a child's prediction, that is, an anticipatory schema, and an external result that fails
to conform to the prediction. In the first case of contradiction, transcendence results "by accommodation of one with the other and by reciprocal assimilation with endogenous construction of negations as well as affirmations" (p. 290). It usually remains unconscious for a long time until the child becomes capable of transcending it. In the second case of contradiction, negation is imposed externally by the new event, instead of being constructed internally. It becomes conscious fairly rapidly.

Piaget stressed that the child's contradiction cannot be merely corrected or exchanged but must be transcended internally. According to Piaget, transcendences are effected with "two interdependent processes, one extensional, the other in comprehension: a widening of the referential and a relativization of notions" (p. 292). These two processes are constructive and parallel "since the first, by widening the field, introduces new elements and consequently new relations, thus rendering the notions present at the outset more flexible" (p. 292).

In this study, water properties surprise children when they act on it with a variety of materials. For example, the child is surprised when she/he who has erroneous idea about the side hole sees water leaking from the side hole. Accordingly, contradiction is expected to arise in their acts and thoughts during the water activities. The teacher's interventions aim to make children conscious of contradictions between anticipations and results. When children feel the contradictions during water activities, it is expected that there will be progress in children's development in water knowledge.

Role of cooperation in knowledge and development. Piaget (1965/1995) viewed social factors as bearing a causal relation to cognitive development. This means that social elements can accelerate or delay intellectual functioning. In other words, social development changes intellectual structures and therefore it could be the source of new knowledge or new cognitive operations.

One of the social factors that affects intellectual development is the relationships between adults and children. Piaget (1932/1965) distinguished two types of relationships between adults and children; one is cooperative relationships and the other is constraint relationships. The difference between these two types of adult-child relationships is a matter of the exercise of power. In a cooperative relationship, the adult minimizes his or
her authority in relation to the children and empowers them in their behaviors or in their thoughts. By exercising their ability to control their own actions and thoughts, the children gradually construct internally coherent knowledge, morality, and personality.

In this study, the teacher plays an important role in the course of children's construction of water knowledge by establishing cooperative interpersonal relationships among children and between teacher and children. Thus, a cooperative classroom atmosphere established by the teacher is the fundamental context in this study.

Studies Related to Water Knowledge

In this section, reviewing the existing research on water gives some information about children's cognitive development in relation to water. These studies were inspired by Piaget's work. Studies of children's conceptions of water have focused on water level, conservation, and draining.

Water Level

One of the most common methods of assessment of reasoning about water is the child's performance on a water level task. Piaget and Inhelder (1956) assessed children's knowledge and reasoning about water level by asking the children to draw a water line on pictured vessels tilted to various angles in the frontal plane. They argued that reasoning about water level develops through discrete stages with children attaining new spatial reference systems at each stage. They concluded that water level understanding was developed by the age of 8 or 9, even though there were a few who did not develop an understanding until about age 12.

In this study, Piaget and Inhelder (1956) distinguished 4 stages in children's knowledge of water level. The children were asked to anticipate the position of water in a tilted bottle. According to Piaget, at stage 1 (up to 4-5 years), the child is unable to depict and represent the water as a plane surface. At stage 2, the lines indicating the surface of water are drawn without regard to the sides of the jar itself as well as without regard to any external reference system. At stage 3, the child is able to draw it as no longer parallel with the bottom of the bottle even though she or he still fails to co-ordinate her or his predictions with any fixed reference system outside the bottle. At stage 4 (beginning around 7-8
years), the child is able to realize the horizontal. Piaget thus showed that children have different reasoning about water level at broad developmental stages.

Since Piaget and Inhelder (1956), many water level studies have been done. These studies can be divided into two types: studies of developmental differences and studies of training effects (Beilin, 1965; Beilin, Kagan, & Rabinowitz, 1966; Brainerd, 1979, 1982; DeLisi, 1983; Ford, 1970; Kahlichman, 1988; Liben, 1978; Liben & Golbeck, 1980; Signorella & Jamison, 1978; Thomas, Jamison, & Hummel, 1973; Tomas & Turners, 1991). A number of investigators examined developmental differences among age groups and agree with Piaget that performance improved with increasing age on horizontality tasks. Other investigators studied effects of training children on Piaget's tasks. They tested the effects of training on water level representation in jars tilted at various angles and concluded that training resulted in improved performance but there was no transfer to different shaped-jars. The general finding was that training does not result in structural progress in reasoning.

In the above studies, direct training does not seem to lead to children’s structural progress. None of those training methods included classroom activities. The training methods used in those studies were tasks developed for experimenters’ purposes rather than activities based on children's interests and purposes. For example, Belin et al. (1966) used perceptual training in which the children anticipate and then see if their thought was right. They also used verbal program training in which they gave the children some questions such as “Does this glass have a water line?” or “The middle one is horizontal. Is this line horizontal?” then the children were supposed to answer “Yes” or “No.” In their study, the children were given a verbal program made of 30 training responses. However, the children were not actively engaged in their experiment and their own interests; rather the experimenter tried to impose the concept with the tasks.

DeVries (1986) distinguishes between tasks and activities, pointing out that tasks and activities differ in terms of whose interest prevails. In other words, adults’ interests drive tasks, and children’s interests drives activities. Within tasks, the children cannot explore and test their own ideas, and they cannot experience constructive process by means
of equilibration, disequilibration, and reequilibration. It thus seems important to develop classroom activities and teaching strategies to promote children's progress in reasoning.

This study seeks to develop activities in which children can be actively engaged in their own experimentation and interests over the semester. It also tries to develop effective teacher interventions by accepting children's own ideas and letting them experiment with their initiative. The activities and the teaching strategies developed in this study are expected to show a difference between the results from the Beilin, Kagan, & Rabinowitz's study and results in this study regarding progress in children's reasoning.

**Water Conservation**

The original conservation studies were performed by Piaget and Szeminska (1941/1952). They discussed how the child's initial understanding of conservation is derived from a general undifferentiated concept of invariance which provides the basis for subsequent more specific quantifications and measurements. They distinguished three stages in the development of the concept of conservation of continuous quantities. The first stage is an absence of conservation, the second is an intermediate type, and the third is the acquisition of conservation. Piaget sought to explain how these concepts result from a process of elaboration, that is, equilibration, not merely in simple observation of real events.

On the other hand, Inhelder, Sinclair, and Bovet (1976), using an apparatus allowing the flow of liquids, attempted to promote children's reasoning about water conservation. They asked the children to predict what would happen and then to compare these predictions with what actually happened when they experimented. They concluded that the child's initial level of development was an important factor in determining the child's ability to construct knowledge and to progress during the training session. In other words, the main factor that determines progress is the child's ability to integrate information drawn from the experiment.

According to Inhelder et al. (1976), the children who were at the preconservation level generally made no progress. They comment:

As long as the child does not incorporate the observable features of the situation into a system of inference allowing him to link the various observations made in the successive phases of the experiment, he cannot make any progress. The
discrepancy between observation and prediction does create a certain unease in the child's mind, but at this developmental level he is not yet capable of organizing the successive observations into a coherent system of schemes. Consequently, he is not aware of the contradictions between his predictions and observations and he cannot make the correct inferences that would lead to correct predictions. (p. 54)

However, they also comment that most of the children who made no progress were nevertheless perfectly able to apprehend "all the relevant observable features of the situation that the more advanced child seemed to use for solving the problem" (pp. 52-53). In the case of the children who were at an intermediate stage, there were striking changes. They concluded that the observable features are equilibrated only when the child is capable of integrating them into the structures he or she already has.

Since the child participants in this study are mostly 5 years old, most of them are presumed to be at stage 1 or 2 in water level as described by Piaget and Inhelder (1956). The results of Inhelder et al. (1976) suggest in this study we might not be expected to produce any structural progress in children's reasoning. However, their study does not deal with the same water phenomena of this study. Moreover, their training does not meet constructivist criteria for good educational activities: even though they allowed the children to handle the apparatus themselves, the training experience was more of a task for the children rather than an activity. The experiments were performed for the experimenter's purpose, not for the children's like in the studies regarding water level. In addition, the training sessions on water conservation lasted just 20 to 30 minutes for each of the four sessions.

The implication of this study is that if teachers take time to observe and determine children's reasoning and plan appropriate activities carefully, the children will make better progress in reasoning about water dynamics. Piaget (1946/1970) himself argued that "educational efforts can accelerate children's progress in stages" (p. 721). As discussed in the previous section, this study tries to use classroom activities in which children can have physical experiences that lead to logico-mathematical experiences. In this study, the children choose water activities with their own interests and experiment with their own initiative, not with the experimenter's purposes.
Draining

Little or no empirical research has been done on children's conceptions of draining. However, Kamii and DeVries (1978), reporting informal classroom research, said that children showed their preoperational ideas about the movement of water streaming out of containers. This study offers new insights about children's conceptions of draining.

Physical-Knowledge Activities in Constructivist Education

As discussed above, young children construct physical-knowledge by acting on objects. In this section, physical knowledge activities will be discussed in terms of definition, rationales and teaching principles, and reconsidered in relation to science education.

Definition of and Rationales for Physical-Knowledge Activities

The term “physical-knowledge activity” was created by Kamii and DeVries (1978/1993), based on Piaget’s theory about physical knowledge. As Piaget emphasized the child’s action on objects in the course of development of physical knowledge, Kamii and DeVries conceptualize physical-knowledge activities as all activities in which children act on objects and observe the reactions. Working with teachers and children, they developed a number of physical knowledge activities. Using materials such as rollers, target ball, inclines, the pendulum, and water, they focus on children’s reasoning while acting on objects as well as teachers’ interventions to help develop children’s further thinking.

Physical-knowledge activities aim to promote reasoning through children’s spontaneous interests in figuring out how to do things. A child’s actions on objects can derive from his or her desire to see what will happen. At times, the child has his or her own hypothesis to test in experimentation. Kamii and DeVries (1978/1993) also indicate that physical knowledge activities are for the construction of logico-mathematical knowledge as well as physical knowledge.

With these rationales, they propose four criteria of good physical-knowledge activities. According to them, the child must be able to produce the phenomenon, to vary his or her action, to observe the reaction, and the reaction must be immediate. Having conceptualized these criteria, they distinguish two types of physical-knowledge activities,
that is, the movement of objects and changes in objects. Water activities can fall into both of these types. Movements of water include draining and water level. Changes in water include freezing, evaporating, and condensing.

In this study, the focus is on movement of water with which children act on and observe. Because the child participants in this study are mostly in the preoperational stage, changes in water are not expected to give them phenomena to act on and observe. In this study, water draining and water movement in tubes provide the children with phenomena which they can act on and observe the results.

**Principles of Teaching Physical-Knowledge Activities**

Having conceptualized the definition, rationale, objectives, criteria, and types of “good physical-knowledge activities,” Kamii and DeVries (1978/1993) elaborate the principles of teaching physical-knowledge activities in terms of four ways of acting on objects and questions to promote reasoning. Reviewing these teaching principles will help this study to develop water activities.

Kamii and DeVries (1978/1993) explain the following four ways which guide creating physical-knowledge activities to promote children’s reasoning: (a) to act on objects and observe their reaction, (b) to act on objects to produce a desired effect, (c) to be aware of how to produce the desired effect, and (d) to explain causes. They maintain that “the best activities for preschool children involve the first two types of actions - acting on objects and seeing how they react, and acting on objects to produce a desired effect” (p. 51). However, they also indicate that children can have logico-mathematical experiences within good physical experiences. In other words, children try to reason and think in the course of acting on objects. With these guidelines, this study tries to develop activities which intrigue children enough to want to act on and figure out water phenomena.

In physical-knowledge activities, using questions is one way to know and promote children’s present reasoning. Piaget (1974/1976) implied the importance of using questions in teaching, discussing the relationship between what children do at the level of practical intelligence and how they conceptualize what they do. According to him, although children are able to produce desired effects at even a young age, when asked how they succeeded, they failed to describe what they did and gave different descriptions. This
means children sometimes do something without being conscious of their action. Chaille and Britain (1991) suggest that if teachers ask the right questions and observe the children who engage in the activity, each activity can be extended in many different directions. Duckworth (1987) also comments that asking “the right question at the right time can move children to peaks in their thinking that result in significant steps forward and real intellectual excitement” (p. 5). Teachers’ questioning can give children the possibilities to be aware of what they are doing and promote their reasoning.

Recognizing Piaget's study, DeVries and Kohlberg (1987/1990) suggest questions to determine what the child is thinking and interact with her/him based on her/his thinking. Questions are suggested in terms of four ways to promote children’s reasoning:

1. “What do you think will happen if you do X?” (p. 98) to encourage children to predict, and act on objects and observe their reactions;

2. “Can you do X?” (p. 98) and “Can you find anything else that you can do X with?” (p. 98) to encourage children to act on objects to produce a desired effect;

3. “How did you do X?” “Which way works better (or is easier)?” “How is (another child) doing X differently?” (p. 98) and, “Does it make any difference if you do X?” (p. 98) to encourage children to be aware how to produce the desired effect;

4. “Why does X happen?” or “I wonder why X happened? (p. 98) to allow children to explain causes.

In this study, these questions are expected to promote children’s acting on water with other materials, observe the results, and reason and think about the water phenomena.

In addition, Kamii and DeVries (1978/1993) suggest teachers to encourage children to cooperate with other children. They also suggest teachers to introduce an activity “in a way that maximizes children’s initiative” (p. 52). It is possible for teachers to take a long time to explain how and what to do with an activity. However, over explanations can cause children to lose interest in the activity itself. According to Piaget, due to the lack of understanding in language before forming conceptions, long explanations before experience are not helpful for children. In this study, children come to the water table in pairs to have possibility for cooperation in activities. They are also introduced to the activities by the teacher at grouptime, focusing on children’s initiative.
Physical Knowledge Activities and Science Education

As discussed above, physical-knowledge activities focus on children’s reasoning while acting on objects. In contrast to physical-knowledge activities, traditional science education has focused on teaching of scientific knowledge. Kamii and DeVries (1978/1993) criticize the traditional approach in science education:

- Science education emphasizes content and specific bits of scientific knowledge, even when it attempts to be a “process,” “discovery,” or “concept” approach (p. xi)
- Science education basically unloads adult-organized content on children (p. 5)
- Traditional science programs are based on the empiricist assumption that the child learns through the five senses (by looking at things, smelling them, hearing them, touching them, and tasting them) and through language (as he has things explained to him). (p. 21)

From their perspective, approaches in science education generally do not focus on children’s constructive process but emphasize the acquisition of scientific concepts. Contrasting with science education, physical knowledge activities focus on children’s actions on objects, reasoning, and constructing knowledge in their own ways. Forman and Landry (1992) make a similar distinction between the cognitive developmental approach and science. Howe (1993) also mentions that “early science education focuses more on the processes and content of science. . . . there are specific ideas and activities that are thought to be a necessary part of children’s education” (p. 228).

This perspective is supported by Pollak’s view (1993). Pollak suggests that the primary goal of science education is not to have or acquire any particular scientific knowledge or content, but to create a context within which to hold such knowledge. He emphasizes that without such a context, scientific knowledge can only be held on what he calls the “having mode.” In contrast, when the context is focused, the children are allowed to be in the “being mode” which is characterized by engagement. Pollak suggests constructivist science education as a way of promoting the spirit of science.

Some constructivist educators feel that it is important to assess children’s misconceptions in order to know how to challenge these. While constructivist science educators see the long-term goal of correct scientific knowledge, they seek to reform the science curriculum to promote children’s reasoning and change their preconceptions. Some constructivist science educators find a paradox in the goal of science teaching to impart new
schemata that do not fit children's existing schemata (Carey, 1986). In order to know how to foster children’s reasoning, it is necessary for teachers to determine children’s erroneous ideas. Ledbetter (1993) argues that if an erroneous framework is undetected, it is difficult for the teacher to help children learn new concepts. Howe (1993) says that the misconceptions which children have about natural phenomena need to be elicited and challenged. Appleton (1989) also states that teachers need to identify children’s preconceptions as a first step to intervene. He shows that when teachers reinforce children’s existing ideas as right or wrong, children stop thinking or reasoning and merely wait for correct information. In this kind of situation, children keep their misconceptions and do not acquire the new conception which is desired by teachers.

Children come to classrooms with many erroneous ideas about how things happen, which is called misconceptions or naive theory. In science education, the goal is to change children’s misconceptions. Schumacher and colleagues (1993) indicate:

An extensive literature has grown in attempting to explain why . . . scientific misconceptions appear so resilient and difficult to change. The large majority of this work has centered on the kinds of knowledge structures children and adults have about scientific concepts and the particular features of these structures which make them resistant to instructional intervention. (p. 4)

From the above statements, it appears that the difficulty in changing children’s scientific misconceptions is in direct teaching without considering their present reasoning or respecting their erroneous ideas.

From a constructivist perspective, children’s mistakes should be regarded as opportunities for their intellectual growth. Explanation by the teacher does not necessarily help the young child to change wrong ideas or misconceptions. Forman and Landry (1992) explain that “Children have constructed, through high level thinking, their own theories about physical events. . . Thus the science teacher cannot just say to the student, ‘Let’s forget your misconceptions and learn the correct explanations for these events’” (p. 177). Thus, the teacher needs to determine and understand what the children’s erroneous thoughts or misconceptions are, and help them reconstruct their knowledge in a meaningful context.

From this viewpoint, the approach to physical-knowledge activities by Kamii and DeVries (1978/1993) is a forerunner of recent work in science education. Howe (1993)
indicates that “their (Kamii & DeVries, 1978/1993) methods and goals are compatible with what many science educators of today would advocate for young children” (p. 227). This shows that the approaches in early science education are tending toward the approaches in the constructivist paradigm. In fact, the current trend in science education for all levels is toward constructivism. Matthews (1993) comments:

Constructivism inspires science education reform programs, is the subject of major international conferences, is the topic of hundreds of journal articles, and is the foundation of many science teacher training programs where constructivist teaching methods are widely advocated. (p. 359)

Thus it appears that the approach in physical-knowledge activities is an endeavor to provide science education for young children from the constructivist view.

Constructivist science education based on Piaget’s theory is criticized in that it is focused on the cognitive aspects, ignoring the social interaction. Wheatley (1991) states:

Constructivist learning is accomplished by constructing and elaborating schemes based on experiences; it is very much a personal matter... Because constructivists state that each person constructs knowledge for her/himself and, in fact, construct their own reality, they have been accused of ignoring the role of social interaction in learning. (p. 11-12)

However, realizing that Piaget and Inhelder (1966/1969) included socialization as one of the four factors in cognitive development, Wheatley stresses that learning is stimulated within social interaction. Wheatley concludes that the teacher establishes settings for meanings and provides the children with activities which promote restructuring of ideas at a higher level within cooperative groups.

In constructive classroom, the cooperative sociomoral context is crucial for intellectual development. Science educational applications of isolated cognitive aspects of Piaget’s theory result in reductions of the theory and lead to practices which are subject to criticism. What is missing is the aspect of Piaget’s work which deals with the parallels between cognitive and sociomoral development. Piaget (1948/1973) suggested that educators need to facilitate children’s full development in a social context characterized not only by cooperation with other children, but also cooperation with adults. In fact, Kamii and DeVries (1978/1993) establish two sets of aims for physical-knowledge activities, that is, socioemotional objectives and cognitive objectives. They emphasize that the
conceptualization of socioemotional objectives came “in light of Piaget’s constructivism because these characteristics are necessary for construction to take place” (p. 40).

In this study, water activities will be provided not for scientific conception about water from the traditional approach for science education but for reasoning about water phenomena from the perspective of constructivist science education, in other words, physical-knowledge activities. Thus, water provides the content for children to reason and think about. The study aims to develop water activities for both socioemotional and cognitive purposes as Kamii and DeVries intended.

**Water Activities in Early Childhood Curriculum**

In early childhood curriculum, approaches to water activities have been changed based on viewpoints on the educational value of water. In this section, water activities in traditional early education will be compared with those in constructivist education.

**Water Activities in Traditional Early Education**

In traditional early education, water has been viewed as a raw play material from the natural world which allows children to develop fully into healthy, happy, and delightful persons who are able to cope with and solve problems in the world (Almy, 1967; Bender, 1969; Cohen, 1973; Hartley, Frank, & Goldenson, 1952; Hill, 1977; Scarfe, 1962). In this section, traditional approaches to water activities will be discussed in terms of the play therapy approach and the child developmental approach.

**Play therapy approach.** The value of water play in Freudian psychology was related to emotional and even therapeutic benefits (DeVries, 1992). According to Hartley et al. (1952), the benefits of water play include “basic sense experience,” “the feeling of mastery,” “satisfactions for the immature,” “outlet for aggression,” “relaxation and absorption,” and “liberating effects.” In this approach, water play is justified as experiences for only emotional development.

**Child development approach.** As a result of Dewey’s emphasis on the child’s purposes and problem solving (Braun & Edwards, 1972), the value of water activity shifted from the Freudian approach to child development including intellectual benefits. Within this approach, water play was justified as experiences for social, symbolic, mathematical, and language development. Gordon and Browne (1985) and Crosser (1994)
argue that water play promotes children's development in terms of emotional growth, language development, creativity, social growth, learning mathematics and science, cognitive development, and physical coordination.

These traditional approaches do not focus on children's reasoning about water phenomena. None of these approaches considers the mental structures in terms of equilibration. Within only emotional value, children's intelligence and personalities cannot be fully developed. Unlike the play therapy approach, the child development approach discusses all aspects for development. However, this approach sometimes tries to teach water conceptions through direct teaching or with simple observation. Kamii (1981) indicates the weakness of this approach is that it is based on empiricist assumptions about how children learn.

Some examples show the weakness of this approach. Beaty and DeRusha (1987) developed a number of water activities. For example, in terms of language and math development, they describe an activity in which children record the names of objects and their respective weights during the water activity “sink or float.” They prepare the sheet saying, “My boat is made of ______. It can carry ____ weights.” Children write down the appropriate words and numbers. For conservation, they provide several containers for children to pour into and ask which container will hold more water. This approach is appropriate in that they try to integrate water into all the areas; however, they fail to focus on the main point which is to promote children’s reasoning about water phenomena. Hildebrand (1971) also suggests volume as one of the scientific contents to learn. According to Hildebrand, it is through pouring from one container to another, pouring a beverage at the snack table, or measuring ingredients during cooking projects, that the child learns about volume. However, as already discussed above, without considering children’s equilibration in mental structures, direct teaching or simple observation does not lead to progress in conservation. Moreover, the concept of volume is not constructed at the preoperational stage.
Constructivist Water Activities

The cognitive rationale for activities with water has been conceptualized with regard to the developmental framework of constructivist education based on Piaget's theory. In this framework, water is dealt with as physical-knowledge phenomena.

Water as physical-knowledge phenomena. Piaget's theory leads to a view of water as material with which children can construct physical knowledge that leads to logico-mathematical knowledge. Water is the object observable by the children in external reality. Water is the object with which children can create relationships when they use it with other materials such as tubes and containers with holes. With water, children simultaneously can have both physical and logico-mathematical experiences.

Water can be poured, squirted, sprayed, splashed, sprinkled, pumped, and combined with other substances to produce movement and changes in objects. From the constructivist perspective, water is a good material for physical knowledge activities. Water phenomena involving the movement of objects include water level and draining, and water phenomena involving changes in objects include evaporation, freezing, and melting. According to Piaget's theory, the movement of water gives young children physical phenomena with which they act and experiment, exercise their own ideas, and try to overcome contradictions between their expectations and results.

In summary, water activities are educationally valuable in that they involve possibilities for young children to construct knowledge about water dynamics. In addition, they provide an excellent context for development of the very structure of reasoning and intelligence.

Physical-knowledge activity approach to water. Kamii and DeVries (1978/1993) tried to improve children's reasoning and experimentation in water dynamics with flexible and transparent tubes and containers with holes. Forman and Hill (1984) also devised some water activities as a way of changing perspective and making functional relations. For example, in the Pipe Put Together, they set up the water table with a complicated maze-like structure of pipes and joints, and children pour water into several openings. In this activity, children predict where it is going to come out and race to catch it. As a variation of this activity, they encourage children to reason by setting up two water tables side by side.
with one table remaining empty. In this activity, children are encouraged to move the water from one table to the empty one through the plastic pipe that was used in the Pipe Put Together. With this variation of the activities, Forman and Hill show how to develop further activities within the same water phenomenon.

Constructivist-Supported Literature on Water Activities

Water activities are found in many books. However, most books are limited to suggesting activities, or simply listing the materials and processes. This is not helpful for teachers in that they give clues about only what to teach, not how to teach. Only a few books (African Primary Science Program [APSP], 1973; Crahay & Delhaxhe, 1988; Elementary Science Study [ESS], 1971; Hill, 1977; Zubrowski, 1981) go beyond these limited possibilities. The activities in these books reflect the constructivist paradigm. The activities are not merely suggestions of materials and processes. These also include how to observe and develop the activities in terms of children's learning.

APSP (1973) presents good examples for water activities and the situations in which the teacher observes and develops children's activities. For example, giving children tins with holes, this program shows how to observe and develop children's activities about streaming in the following way:

Do the children let the water dribble out or do they let it make a stream? Do any of the children try to fill a bottle carefully? This is the time to add something to the water play which can be used as a funnel. Are children watching the streams of water as they pour it from bottles and tins? Do they have any tins with single holes in them? Water streaming through a little hole breaks into drops sooner than water does when streaming through a big hole. When children use tins with holes in the bottom to fill bottles, do they use the solid stream or the dripping one? (pp. 4-5)

This program helps teachers to think about what children think during the activity time and suggests intervention with regard to streaming. While this approach gives some appropriate activities and clues about how to intervene and observe, it does not help teachers know how to develop a series of water activities building on each other and promoting reasoning over time.

ESS (1971) focuses on water flow in tubes with an apparatus for the tubes on a peg board which aims for children to be able to develop their insight about water level. With this apparatus, children design different ways to make the water flow in the flexible
tube on the board. It emphasizes that teachers need to help children pursue their own questions and answers. It says that “It is better science for a child to come up with his own answers (however naive) than it would be for him to ‘mind read’ the teacher” (p. 10). This program does not include the preschool level.

Focusing on the teacher’s intervention with questions and water accessories such as plastic squeeze bottles and plastic tube, Hill (1977) presents starting points for some activities that evolved out of children’s own ideas. For example, when children played with plastic squeeze bottles provided by the teacher, one child said “Hey, look how far I can squirt” (p. 14) and the children tried to squirt the water farther. When they were provided with a rigid plastic tube, they tried to find and use different materials such as a funnel to fill it. In this activity, Hill emphasized the teacher’s role to intervene in appropriate moments with questions and materials.

Synthesizing the above activities, they are useful, as already discussed, in that they are good examples showing how to approach children’s water activities. They reflect the constructivist paradigm in that the child was allowed to evolve and pursue his or her own idea and the teacher tries to help the child to extend his or her idea. However, none of these programs offers detailed insight into children’s reasoning as it develops in activities and over time, as the proposed study will do.

**Research Questions**

The purpose of this study is to promote the child’s reasoning about water dynamics and develop and evaluate teaching strategies and activities in terms of the child’s progress. Specifically, the following questions are addressed:

1. How does the child’s reasoning progress over a series of activities? What does the child know and how does he reason about water phenomena while engaging in water activities?

2. What kinds of activities promote children’s reasoning about water dynamics in classroom activities?
   a. In what ways do the activities engage children’s interests and purposes?
   b. In what ways do the activities extend children’s interests and purposes?

3. What are productive interventions in children’s water activities?
a. What kinds of interventions by the teacher promote progress in reasoning and knowledge?

b. What kinds of interventions seem not to promote progress?
CHAPTER 3

METHOD

Participants

The participants in this study were one teacher and one child aged 5.5 years selected from a preschool classroom located a public elementary school in Iowa. In this study, the teacher collaborated with me to develop the activities and teaching strategies. Activities were done for all children in the classroom as part of the regular classroom constructivist program. The child who participated in this study was selected because of his constant interest and active attitude in most activities. This study was reviewed by The Committee for the Protection of Human Subjects at the University of Northern Iowa.

Materials and Procedures

The materials used in this study were colored water, a water table, a pegboard with holders (for glasses and tubes), transparent plastic glasses (hereafter referred to as glasses) with holes, 30-inch lengths of transparent tubing, a transparent 2-liter plastic beverage bottle for a reservoir, pop bags for targets and basters attached to tubes for water squirtsers. Clear materials and colored water were presented so that the children could see the water movement inside of them well. The holes on glasses were made by an electric drill to get good water streams and were marked along their circumference with the black marker so that the child can see the hole well.

During the 1995 spring semester, the teacher introduced each activity and piqued the children’s interests. Children usually came to the activities in pairs which provided the possibility for cooperation in the activities. A child could choose to participate in all or none of the activities and was allowed to come and go as he/she chose during the water activity. The target child, Curtis, sometimes came with another child and sometimes came alone.

In this study, eight different water activities were presented to the children. Curtis sometimes chose the same activity two or three times. However, he did avoid two activities. Thus, he participated in six activities over the course of eleven sessions. In the first four sessions, glasses with holes were presented at the water table so that the children could experiment with draining. In the next four sessions, tubes were presented to allow
the children to experiment with water movement (or water level). Finally, glasses with holes and tubes were combined. According to a pilot study (Kwak, 1993), for young children, draining is an easier task than water movement in tubes so the former was introduced earlier than the latter. Every succeeding activity was prepared based on children’s reasoning and interests in the foregoing activity. Every water activity was videotaped by the author. Two cameras were used to videotape for later analysis. Videotapes were transcribed in terms of verbalism and physical behaviors with the materials.

While developing the activities and teaching strategies, the teacher and I made hypotheses about what children would do with the materials and the interventions, and experimented from the children’s viewpoint to develop better interventions. From our experimentation, the plans were modified, and then implemented. To do this, every session was discussed with the teacher and sometimes with a discussion panel (the committee members, the teacher, and the researcher). Periodically, the teacher was asked to think back about how she pursued each activity, how the activity or materials worked to improve the children’s reasoning, why she used certain interventions, and what the children’s thoughts might have been during the activities. In addition, the teacher was asked to think about what kind of activity would be needed to expand the children’s reasoning next time. Through collaboration with the teacher and the discussion panel, the activities and materials were developed and improved.

The exact materials, procedures, and rationales for each of the sessions will be described in more detail below. In these descriptions, the following notation will be used:

- B = Big hole
- b = bottom position
- h = height or high position
- M = Medium hole
- s = side position
- m = middle position
- S = Small hole
- d = different
- 1 or 2 = the number of holes on glass
- 1 = low position
- ND = not discernible from videotape
- U = unintelligible

**Session 1: Water Draining I**

**Materials:** During this first activity, the following containers (see Figure 1) were introduced at the water table:
One with a big bottom hole 1/2 inch in diameter, indicated in drawings with a triple stream (1Bb)

One with a medium bottom hole 1/4 inch in diameter, indicated in drawings with a double stream (1Mb)

One with a small bottom hole 1/8 inch in diameter, indicated in drawings with a single stream (1Sb)

One with a medium hole on the side (1Ms)

One with two medium holes one on the bottom and one on the side (2Mbs)

One with two medium holes at different side (2Mds)

One with two medium holes at different side at different heights (2Mdsdh)

Figure 1. Glasses presented for session 1

Procedures and rationale: In this first activity on draining, the children were presented with glasses that already had holes in order to help them focus on the phenomenon of draining. The transparent glasses enabled them to look at the water level inside as well as the water leaking out. In this activity, the bottom holes varied according to three different sizes and the side holes varied according to different positions in order to promote reasoning about the effects of these variations. For the 1Ms and 2Mbs glasses, the sizes of the glasses were varied. However, in the discussion panel it was decided to keep the glasses the same size so that the children could compare them. Regarding these holes, the children had the possibility to construct the following regularities and relationships:

The regularity that when the container has a hole, the water runs out of it; bottom hole glasses empty completely but side hole (except 2Mbs) glasses do not
The relationship between the position of hole and the nature of draining
The relationships between the sizes of holes and the temporal order of emptying
The relationships between the positions of the holes and the direction of water stream or the order of cessation of leaking

First, the three different bottom holes were presented to the child and then the side holes. 1Ms, 2Mbs, 2Mdms, and 2Mdsdh were presented in order. Experience with bottom holes was expected to offer the possibility for a contradiction with experience with side holes.

Session 2: Water Draining II

Materials: For this session, the children had choices of any glasses that they used in the previous session. In addition, the following new glass (see Figure 2) was presented to them:

One with two same-size holes at different heights (2Msdh)

Figure 2. New glass for session 2

Procedures and rationale: This session was based on the same rationale as the first session. As a second opportunity to experiment with draining, the teacher let the children choose any glasses so that they could experiment according to their own agenda. However, the teacher gave a new glass (2Mssdh). With this glass, they had the opportunity to construct more precise ideas about the cessation of draining according to the height of the hole.

Before we moved to the next activity, some children were presented with the opportunity to experiment with making holes in glasses. The children chose the position of the holes, and the teacher made those holes with an electric drill. However, the teacher and I found that it was too dangerous to use the drill in front of them. Unfortunately, before Curtis got this activity, we quit this.

Session 3: Catching Water on the Pegboard I

Materials: In this session, the following materials (see Figure 3) were presented to the children:
A pegboard

Holders for glasses, made of wire

Pitchers

Glasses: ones with high side holes (1BHs, 1MHs, and 1SHs)
ones with middle side holes (1BMs, 1MMs, and 1SMs)
one with low (near the bottom of the glass) side holes (1BLs, 1MLs, and 1SLs)

Figure 3. New materials for session 3

Procedures and rationale: In the previous activities, the children tried to drain water from one glass to the others by holding one over another and sometimes setting a third glass in the water table. Because of the children's interest in draining with a series of glasses, the pegboard with holders was devised to enable the child to arrange a series of glasses by inserting them into the holders on it. This was designed to aid the children's experimentation with stacking glasses to see one drain into the other. The rationale was basically the same as the previous two sessions. However, on the pegboard, the children had the possibility to compare the differences in the holes more systematically.

The pegboard was put over the tub placed on the floor (taken out of the water table to enable children to reach the pegboard). The same glasses used in the previous sessions were presented to the children with the new glasses. The new glasses were provided due
to the children’s interests in the side hole in the previous sessions and gave the children a possibility to construct the relationships between the heights of the holes and the order of cessation of leaking and between the sizes of the holes and the order of emptying. At first, the teacher put one holder in the pegboard to give the children an idea of how to use it. Pitchers were provided to enable them to pour the water into the glasses.

Session 4: Catching Water on the Pegboard II

**Materials:** The materials were the same as in session 3.

**Procedures and rationale:** Having observed children spontaneously arranging a series of glasses, each one emptying into the next, the teacher and I provided an opportunity for children to continue to explore such possibilities. In this session, the children started with three holders already in a vertical line.

Session 5: Water Movement in Tubes I

**Materials:** In this session, the children were presented with the following materials:

- A pegboard
- Holders for the tubes and glasses
- The same set of glasses used previously
- Transparent tubes 30-inches in length, 1/2-inches in diameter
- Clear tube connectors (cut out of thicker tube) 2-inches in length
- A clear reservoir with a valve attached to turn it on or off (made with a 2 liter pop bottle with the bottom cut off) (see Figure 4)

![Figure 4. Reservoir](image)

**Procedures and rationale:** In this session, we shifted to water movement in tubes because the children’s interest in draining had decreased. It was expected that the new materials, the reservoir and the tubes, would result in new interest. At first, the reservoir itself was expected to play the role of drainer for the children. The children could control
the draining from the reservoir by turning the valve on or off. The teacher let them explore and experiment for a while. Then the children had a possibility to create the following regularity and relationships by moving water from the reservoir through the tube to the glass:

- The regularity that if the end of the tube is placed higher than the water level in the reservoir, water will not flow into the glass
- The relationship between the water level in the reservoir and water level in the tube
- The relationship between draining/not draining and the on/off positions of the valve

The children still used the glasses from the previous sessions to receive water from the tube. They could extend the tube by hooking another on it using connectors, and they could arrange it on the pegboard.

**Session 6: Water Movement in Tubes II**

**Materials:** In this session, the materials were the same as in session 5, except that funnels were added in order to make filling tubes easier.

**Procedures and rationale:** This session was an extension of the previous session.

**Session 7: Water Movement in Tubes III**

**Materials:** The materials used in this session were the same as in the previous session.

**Procedures and rationale:** This session had the same rationale as the previous session.

**Session 8: Water Movement in J-and S-Shaped Tubes**

**Materials:** The following materials were presented in this session:
- Tubes in 30-inch lengths
- Funnel
- Pitchers

For this session, we put the tubes in J-shaped and S-shaped arrangements on the pegboard (see Figure 5).

**Procedures and rationale:** In the previous three sessions, when continually moving the free tubes, the children encountered problems with air pockets in tubes when they made complex arrangements by hooking several pieces of tubes together. That made it difficult
for them to think about water level. Thus, the teacher and I prepared a fixed arrangement in order to make it easier for them to become aware of water level.

Before engaging in this activity, the children had an opportunity at group time to think about and discuss with the teacher and other children what will happen to water in these tubes. We expected this group discussion to prompt the children to experiment with these tubes and think about the water level. Specifically, the children had the opportunity to observe and construct the following regularities:

The regularity that water overflows from the short end when water is poured in the tall end of the J-shape tube (Figure 6a)
The regularity that water in the tall end will stay at the same level as in the short end of the J-shaped tube when water is continuously poured into the short end (Figure 6b)

The regularity that water will not fill the S-shaped tube but will stay in the tube at the same level in the left and right ends of the first half of the S when water is continuously poured into the left end (Figure 6c)

The regularity that to make water go through in the S-shaped tube, the left end needs to be made higher than the hunched part (Figure 6d)

Session 9: Making Fountains I

Materials: In this session, the following materials were presented to the children:

- A pegboard
- Holders for glasses and tubes
- All glasses used in previous sessions
- New glass with several holes to make a “fountain” (Figure 7)
- Big clear plastic glass with two bottom holes (Figure 7)
- Tubes: a thick one 1/2-inch in diameter (that he used before) and a thin one 1/8-inch in diameter
- Basters for squirters

Figure 7. New materials for session 9

Procedures and rationale: In this session, we tried to combine the draining from the holes and the water movement in tubes. The children had the possibility to focus on the draining by making fountains, and then moved to the water movement in a tube by draining from a tube into the fountain they made.

Session 10: Making Fountains II

Materials: After the previous session, Curtis wanted to save the apparatus he made, so he used it again with other materials that he used in the previous session. In addition, we added one reservoir at first, then added one more later.
Procedures and rationale: In this session, Curtis had a chance to connect his apparatus through the tube to the reservoir that was added by the teacher so that he had a possibility to observe both the water levels in the reservoir and the tube. Thus, the child could construct:

The regularity that the tube must be put lower than the water level in the reservoir in order to make his fountain keep going

Session 11: Water Squirter with a Target

Materials: In this session, the following materials were presented.

A pegboard
A reservoir attached to Y-shaped valve (see Figure 8)
Water squirtsers (made with basters attached to tubes) (see Figure 8)
Targets (pop bags) (see Figure 8)

![Diagram of materials](image)

Figure 8. Materials for session 11

Procedures and rationale: In session 10, the children were still struggling with the water level but showed interest in using the baster. That interest inspired the creation of this activity. In this session, we gave the children a goal in keeping with their interest. In
order to succeed (to hit the target), they needed to put the baster lower than the water level in the reservoir. Thus, they had the possibility to construct:

The relationship between the water levels in the reservoir and in the tube

In this activity, the reservoir was attached to the Y-shaped valve so that two tubes could be hooked to it. Two basters from the one reservoir gave the child opportunities to compare the effects of actions resulting when one child might hold his baster lower enough to get water in it while the other child might not.

After this session, the teacher and I prepared another activity, "Making a shower for dolls." With this activity, the teacher and I tried to give the child more opportunities to think about the water levels in tubes as well as the draining. However, we provided this activity for just one day and had no chance to involve the target child because of a scheduling problem at the end of the semester.

Theoretical Foundation for Analysis of Child's Reasoning

The water activities presented in this study generally deal with the acquisition of concepts of physical knowledge including properties of objects and causal relationships. Furthermore, the study of a child's experiment with water is situated in the larger context of the general evolution of intelligence. Even though the studies by Piaget were not performed in the classroom, it is useful to go back to Piaget's theory to interpret the water activities in this study. Piaget's theory can help us understand how a child's water play serves to develop both knowledge and intelligence. Here, I will discuss the aspects of Piaget's theory that aid in understanding the process of progress in Curtis's reasoning. First, theoretical foundation is drawn from Piaget's theory, especially from his theory of the relation between action and thought, physical knowledge, equilibration, consciousness, functions, the role of contradiction, conservation, seriated correspondence, and negotiation strategies and shared experiences. Regarding the negotiation strategies and shared experiences, I will review Selman's work that was developed based on Piaget's theory involving socio-moral development. Then, I will discuss how the study applies Piaget's theory.
Relation between Action and Thought

Piaget (1974/1978) discussed the relation between action and thought in terms of coordinations of action that become interiorized. These interiorizations become conceptual co-ordinations in which thought moves from the most elementary grasp of consciousness to the highest conceptualization. According to this theory, action in the early years comprises an autonomous form of knowledge ("know-how") which is conceptualized later as "knowing-why." In other words, although limited in the early years to "know-how," a material or physical and causal co-ordination leads to knowledge and structures that foreshadow operational structuring (which makes possible transitivity and reversibility). Just knowing how to do something (practical knowledge) is not conscious in the sense of a conceptualized understanding (conceptual knowledge); however, it nevertheless constitutes the source of operational thought.

Piaget (1974/1978) also talked about success and understanding in terms of action and thought. Success, that is, "What must I do to succeed?" is simply the effective utilization (just knowing how to do something) while understanding, that is, "Why do things happen this way?" brings out the reason for things. Piaget found a head start of practical success over conceptual comprehension in young children. That means success by co-ordination of action is a prerequisite to understanding for young children. Piaget also argued that in the elementary successes, conceptualization lags behind action.

For example, acting on the water and glasses with holes, specifically, holding one glass to drain over the other, at first is autonomous action, that is, simple action without any conceptualization of the relationship between the size of holes and the order of emptying. However, observation of the water streaming out of the holes (the external results of the action) results in cognizance (at first, the most elementary awareness of action) and leads to engaging in thinking about the sizes of the holes and the order of the emptying.

Piaget (1974/1978) also distinguished levels in terms of the grasp of consciousness and the effects of conceptualization on action. At level 1A, the child focuses on the results of the action with cognizance (consciousness) lagging behind action, and at level 1B, the child begins drawing conceptualization and action together. However, cognizance still lags...
behind the action. At level 2A, there is a reverse influence of conceptualization on action. What conceptualization then supplies to action is a reinforcement of powers of anticipation and possibility, so there is a correct anticipation of the effects of the action.

**Physical Knowledge**

Physical knowledge develops through experiencing in relation to actions on objects—how they move, how they change position and shape, and how they change in their relation to themselves and other objects (Piaget, 1937/1954). These physical interactions with objects involve mental action which leads to knowledge of the properties of objects by simple (empirical) abstraction.

For instance in draining, when the child holds a 1Bb glass over a 1Sb (both full), he is informed of the fact that the water in 1Sb still leaks while the water in 1Bb stops leaking. For another example, in water movement in tubes, when the child keeps putting water in the short end of the J-shaped tube, he is informed of the fact that the water does not go up to the long end. Instead, the short end overflows. This observation is clearly empirical with regard to observable features of his action.

According to Piaget (1974/1976), physical knowledge provides the primary source or contents for logico-mathematical knowledge by reflective abstraction. In fact, Piaget argues that the two are not entirely different because, in the psychological reality of the young child's experience, the two are inseparably linked. Thus, acting on objects by simple abstraction leads to logico-mathematical experience by reflective abstraction.

The physical data that the water in 1Sb still leaks while the water in 1Bb stops leaking give the child contents to compare and with which to make relationships. With physical experiences with each different position of holes, the child has the possibility to begin thinking about the differences and creating relationships (for example, a bottom hole makes the glass empty completely but the side hole alone does not).

**Equilibration**

Piaget (1975/1985) argued that the equilibration of cognitive structures explains the course of the development of knowledge. According to him, every cognitive equilibrium involves two fundamental processes. The first process fundamental to equilibration is assimilation and the second is accommodation. Piaget defined assimilation "as the
incorporation of an external element, for example, an object or event, into a sensorimotor or conceptual scheme of the subject” (p. 5). Piaget explained that assimilation occurs when internal and external elements interact. It also occurs by interaction between internal elements, schemes or subsystems, which Piaget termed reciprocal assimilation. Reciprocal assimilation occurs when two schemes are applied to the same object or when they are coordinated with one another without external content. When the child is using three glasses (by holding two and setting one in water) and also cooperating with the others to drain or catch, he needs to coordinate his lower and middle glasses as both drainer and catcher. Here, reciprocal assimilation occurs in terms that two schemes, draining and catching, are applied to the same object, his lower glass with which he both catches and drains. Thus, he is coordinating two schemes, draining and catching, by reciprocal assimilation. According to Piaget, accommodation is the process that takes account of the details of the elements being assimilated. Every assimilatory scheme is accommodated to the elements it assimilates. When the child assimilates side hole to the cognitive structure of bottom hole by putting water over the side hole, he also accommodates his action to the side-hole glass by tipping it. Like assimilation, accommodation is also generalized to relationships between subsystems and to relationships that integrate subsystems into totalities. Thus, assimilation accompanied by accommodation constitutes equilibration.

In this activity, equilibrations occur through assimilation and accommodation. At first, the child has knowledge that water comes out of holes. However, with different sizes of holes and different positions of holes, he assimilates them into his previous structure or accommodates their properties in relation to water. For example, with 1Mms glass, he assimilates the side hole into the structure of the bottom hole by putting water over the side hole by tipping it. At the same time, he accommodates to the different positions of holes by recognizing the different properties between the bottom hole and the side hole.

In the case of draining, when the child tries to drain from the side hole at first, accommodatory differentiation of schemes occurs in the course of being assimilated. The draining scheme, for example, cannot be applied in the same way to the bottom-hole glass and the side-hole glass. Thus, he accommodates the different properties of the bottom-hole
and the side-hole. In constructing relationships between the size of hole and the order of emptying, the child co-ordinates them by the process of assimilation but at the same time, he differentiates the properties of different sizes of holes by the process of accommodation. With 2Mbs glass, he accommodates the nature of draining in relation to the position of the hole by draining from the side hole first, plugging the bottom hole, then, draining from the bottom hole and later, unplugging it.

Role of Contradiction

According to Piaget (1974/1980), the role of contradictions whose elimination is an essential factor of development involves disequilibria and the reestablishment of equilibrium. Thus, contradiction plays an important role in the construction of the equilibrated structures. Piaget argued that contradictions occur because children tend to focus on affirmations but neglect negations which are the source of disequilibrium. With the J-shaped tube, even though the short end overflows and the water does not go up to the long end when the child keeps adding water in the short end, he continues putting water in it and reasons the water will go up. In other words, the child neglects negation. He just focuses on affirmations that adding more water in the container will increase the water level in it.

Piaget distinguished between two different sources of contradictions: first, contradiction between schemas, and second, contradiction between a child’s prediction, that is, anticipatory schema, and an external result. In the first case of contradiction, transcendence results “by accommodation of one with the other and by reciprocal assimilation with endogenous construction of negations as well as affirmations” (p. 290). Contradiction between schemas usually remains unconscious for a long time until the child becomes capable of transcending it. In the second case of contradiction, negation is imposed externally by the new event, instead of being constructed internally so it needs to be situated within a wider referential for transcendence. It becomes conscious fairly rapidly. According to Piaget (1974/1980), these contradictions are transcended and develop into equilibrated state by “two interdependent processes, one extensional, the other in comprehension: a widening of the referential and a relativization of notions” (p. 292). In
other words, by extending the field of thought, the physical experience introduces new elements and consequently the possibilities for new relations.

In the case of draining, the child’s action on the glass with a side hole results in a contradiction to the child who observed the bottom hole drain first. The bottom-hole glass drains completely but the side-hole glass does not. The bottom hole also makes water come out straight down but the side hole makes it curve. The experiment with the bottom hole leads to a false expectation with the side hole. Here, Curtis experiences contradiction with the side hole. With a 1S glass, he predicts, “I think the water will come out here.” However, when he sees the water coming out of the side hole, making a curve, he reacts with a startled response. He might expect that water would come straight down as it does from a bottom hole. Thus, there is simultaneous extension of the referential and relativization of the action of the water streams in terms of position of holes.

In the case of draining, a negation is imposed by the new event (for example, curving stream from the side hole) that has appeared. This becomes conscious to the child at that moment. However, in the case of water movement in tubes, a contradiction occurs between two schemas. That is, when the child added water to glasses, he learned that they become more full. However, when the child adds water in lower glass to send the water through the tubes to higher glass, the the water does not go through to it. Because of the existing scheme of addition, the child does not become conscious of the latter.

**Consciousness**

According to Piaget (1974/1976), consciousness plays the role of leading the child from the material action to the conceptualization. In other words, consciousness, which Piaget called cognizance, of an action scheme transforms it into a conceptualization.

In the course of conceptualization, Piaget found the general law that “cognizance proceeds from the periphery to the center—these terms being defined as a function of the path of a given behavior” (p. 334). In other words, cognizance starts from the periphery and moves toward the center of the action in order to reach its internal mechanism (recognition of reasons of the selection or the modification) as he showed by a figure to explain it (see Figure 9).
Figure 9. The process of the grasp of consciousness (Piaget, 1974/1976, p. 335)

Here, the meaning by S is the action of subject and by O is the property of an object. According to Piaget, two-way interactions occur between these two, S and O. During these interactions, the child becomes conscious of his action and the property of the objects which Piaget expressed as cognizance from the periphery (P) to both centers (C and C'). Piaget emphasized two points; “The first is that the internal factors at first escape the subject’s consciousness” (p. 335). The second is that “knowledge does not proceed from the subject or from the object, but from interaction between the two, thus from point P” (p. 335) of Figure 9, “which is peripheral to both the subject (S) and the object (O)” (p. 335).

From the periphery (P), cognizance proceeds toward the center (C) of the child’s action and simultaneously in the direction of the center (C') of the object’s properties. According to Piaget, these cognitive steps toward the two centers C' and C are always dependent on each other, that is, correlative, and “this correlation constitutes the basic law both of the understanding of objects and of the conceptualization of actions” (p. 335). In other words, when the two-way interactions occur, the child differentiates the properties of objects from the result of his actions and this differentiated concept leads to his action to become more differentiated. Thus, the cognizance of the action and object starts moving from the very elementary conscious state, that is, periphery, to the very conscious state, that is, center of action and object.

Piaget pointed out that cognizance originates with the pursuit of a goal which leads to the conscious noting of success or failure. In case of failure, the child modifies actions, in a sense seeking the reason for the failure. This leads to cognizance of more central regions of the action. By observing the object, the child thus may begin to become conscious of what is essentially a lack of accommodation of the scheme to the object. By observing the action, the child becomes aware of the means used and of how he might
modify or perhaps replace them. Through such a two-way movement between object and action, cognizance extends from the periphery P to the centers C and C'.

For example, when the child is first faced with glasses with holes, he is operating in the periphery of the undifferentiated material action ("know-how" as opposed to "knowing-why") and the undifferentiated understanding about draining. At first, when he just drains one glass into the other, his goal is simple draining. Thus, according to the goal, he uses most immediate and external action. By observation of the result of his material co-ordination, he starts being aware of his action and accommodating his action by holding the glasses side by side to compare them. With this co-ordination, he also starts being aware of the objects, that is, different sizes and different positions of the holes. Thus, his initial internalization of his action and the externalization of objects (being conscious about the relationship between the size of the hole and the order of emptying) start moving toward both centers, that is, understanding of draining from glasses with holes and conceptualization of his actions.

The child's understanding about the bottom hole seems to distort his anticipation about the side hole in terms of the direction of water stream. On the other hand, his understanding about the bottom hole leads him to put water over the side hole (by tipping the glass) in order to make the situation with the side hole comparable to the one with the bottom hole. Differentiating his action and his understanding about draining, he moves one step more towards two centers C and C', that is, he gradually becomes conscious of the result of his action with regard to draining.

In the case of the water squirter, the child pursues his goal of hitting the target using the water squirter and notices his failure. He attempts to figure out the solution. However, at first, he is not conscious of the water level in the reservoir. Later, the child accommodates his action by lowering the squirter and then finally, he starts being conscious of the water in the reservoir even though he still does not consider the water level in it.

In the case of water movement in tubes, the child is more likely to distort conceptually what he observes, instead of perceiving it without modifications. When he predicts that adding more water in the lower left end of the S-shaped tube will make the
water go through the higher hunched part of it, he does not seem to be able to observe the details of the result of his action on water. The negative reaction, that is, water does not go up to the higher part of the tube, does not seem to enter in his mind, whereas the positive fact, that is, water goes up when he adds more water while the water is still increasing in the tube, reinforces his false assimilation (that adding more water will increase the water level in tubes, thus the water will eventually go through the hunched part of the S-shaped tube). These results cause a delay in conceptualization of water level.

According to Piaget, lack of adaptation occurs at the periphery P of the action, which gives cognizance a double and opposite direction toward C (the action itself) and toward C' (the object). However, Piaget indicated that cognizance may progress without any lack of adaptation, in other words, the action’s goal may be achieved without any failures. In this case, progress in cognizance results only from the assimilating process itself. Finally, Piaget argued for two general processes in the course of becoming more conscious. “Firstly, there is a reciprocal but alternating action of the subjects’ observations of the object on those of the action and vice versa. Then, with the establishment of a relationship between them, inferential coordinations follow” (p. 344).

In the case of draining, the child seems to show progressive consciousness without any lack of adaptation. However, in the case of water movement in tubes, he shows the lack of adaptation of his action to the water in tubes. In the former case, the goal (comparing the draining from the different glasses with holes) and the action’s results are ‘cognizable,’ while in the latter case, the assimilatory process does not allow him to think simultaneously about objects and actions. Thus, he has difficulty with the continual two-way movement between each observation (the child’s action and the properties of the objects) in his assimilatory process.

In the case of the water squirter, progress in cognizance is particularly slow. Despite some successes by accident, the child does not conscious of the position’s relation to movement of water. With gradual partial successes, the child discovers that when the reservoir is placed in a higher position, the squirter gets water in it. This progress in cognizance of the action, owing to observation of its effects on the object, does not immediately lead to corresponding progress in the recording of observations of the object,
because the child still thinks that the high position of the reservoir or the low position of the
water squirter allows him to hit the target without considering the position of the water
squirter in relate to the water level in the reservoir. The exchange between observation of
the water level in the reservoir and the tube, and his action does not result in his
understanding that the water level in the reservoir should be higher than the position of the
water squirter.

**Functions**

According to Piaget, Grize, Szeminska, and Bang (1968/1977), the pre-operational
child establishes a series of one-way relationships which he called pre-operational
"functions" (in the mathematical sense), expressed in the formula, $y = f(x)$. However, the
nature of 'prefunctions' is essentially qualitative while that of functions from operatory
constructions is quantitative. In other words, pre-operational functions are merely
correspondences to globally conceived actions. For example, in the activity with draining,
functions exist as an initial causal relation. Here, "$x$" will be the hole and "$y$" will be the
draining. Thus "$f$" will be the relationship of dependency of "$y$" on "$x$.''

Piaget (1975/1985) argued that functions are expressions of the schemes of
assimilation of actions and constitute the common source of operations and causal systems.
Such a function expresses a dependence, whether it occurs between properties of objects
(for example, between different sizes of holes) and speed/order of draining which are
variable or whether it is established between characteristics which are inherent in actions
(for example, one glass’s draining into another is a function of holding a glass over the
other as well as a function of the hole). Accordingly, functions are generalizations that are
distinguished from simple relations which result only from limited comparisons.

At the first stage, the function is drawn from the observation of facts, and this
occurs prior to any causal comprehension. Thus, the function is reduced to a simple
physical regularity or law. At first, an initial pair between "$y$" and "$x$" is established. Once
the child discovers a function, he immediately applies it to the other variables. In draining,
an initial pair in a function starts with a regularity, such as "1Bb glasses empty very fast."
Then, by the scheme of assimilation of the action, that is, draining = $f$ (holes), the child
constructs another regularity that "1Sb glasses empty very slowly." In this way, he applies
the functions he discovered before to the other variables, different sizes of holes, consolidating the scheme. The regularities lead to functions. Here, he finds that the dependency is the size of the hole. In other words, slow draining is a function of a small hole and fast draining is a function of a big hole. Thus, functions are casual relationships established by reproductory assimilation, that is, the process of simple repetition of an action.

In the case of the different positions of the hole, the child initially shows the most primitive of functions: an assimilation of the structure assumed to exist in side-hole glass to the structure observed in bottom-hole glass. In other words, he proceeds by simple applications. Therefore, the point of departure for the formation of functions is the assimilation to a scheme of action. At first, the child expects to rediscover this structure (bottom hole) in side-hole glasses without taking into account the different positions of holes. However, observation of the result of action makes necessary a modification.

According to Piaget, functions derive from two modes of abstraction, simple abstraction and reflective abstraction. The contents of a relation are drawn from objects while logico-mathematical links are drawn from co-ordinations of actions which are formed by result of an activity of the child. Thus, according to Piaget, functions are the instruments by which physical laws as well as logico-mathematical structures are established.

The relations between draining and the different sizes of holes in glasses and the different positions of holes on glasses certainly exist. The child acquires these facts as physical data when he acts on water and glasses with holes. However, they are not related until they are compared by a knower. By functional assimilation, that is reproductory assimilation, the child constructs logico-mathematical structures, that is, different sized and positioned holes are variable in draining.

Conservation

"Conservation" in this activity does not mean the same as in Piaget’s classical tasks such as conservation of liquid quantity or volume. Here, conservation, that is rudimentary and precursor to operational conservation, means holding a regularity or relationship in
mind. It happens much earlier than the classical conservation that signifies concrete operations.

In this activity, Curtis develops conservation of the properties of different sizes of holes and different positions of holes in relation to water. At first, he shows instability with the property of a side hole in terms of tipping to make the glass empty but later he conserves it in this session. Curtis also comes to conserve the functions with dependence on the size of hole and the position of hole.

Seriated Correspondences

In seriations or ordered sequences, if \( A < B \) and if the correspondence or application is expressed by \( A' < B' \), the proportion will be: \( B' \) is to \( B \) as \( A' \) is to \( A \). Here, the child finds the seriations that 1Bb glass empties fast, 1Mb glass empties less fast, and 1Sb glass empties more slowly and hole B > hole M > hole S. By connecting the two series, he establishes the seriated correspondence, 1Bb > 1Mb > 1Sb and big stream > medium stream > little stream.

Negotiation Strategies and Shared Experience

Negotiation strategies and shared experiences among children in classrooms provide the social context of cognitive development. Piaget (1965/1995) emphasized that social development is the context for cognitive development. Selman (1980) conceptualizes interpersonal understanding in terms of negotiation strategies and shared experiences based on Piaget’s theory.

Negotiation strategies are characterized by interaction with some tension, that is, disequilibrated interpersonal dynamic. The disequilibrium can be mild or strong according to the situation in which the tension occurs between individuals. Shared experiences describe interactions where the interpersonal dynamic has no tension, that is, it is in equilibrium. Shared experiences, which are usually relaxed and friendly, promote connection and intimacy between individuals. Selman distinguished the developmental levels of negotiation strategies and shared experience as the four levels: egocentric impulsive level (level 0), unilateral one-way level (level 1), reciprocal reflective level (level 2), mutual third-person level (level 3). For example, when the partner stops cooperating in draining, the child uses level 2 negotiation strategies expressing persuasion and the the
partner also shows level 2 negotiation strategies by choosing to defer to the wish of the other. Thus, they continue to cooperate to drain and catch. When the child is engaged with another child during the activity with draining, they giggle with each other (level 0) or reflect on the previous time they played together (level 2).

The Rationales for Analysis of Teacher’s Intervention

In this study, the teacher’s interventions generally focus on two aspects; one is promoting the children’s reasoning and the other is establishing a cooperative atmosphere in the classroom to support the children’s reasoning. Even though Piaget himself was not an educator, he commented that “educators must find an active methodology in teaching” (Piaget, 1972, p. 27). For Piaget, the teacher’s role is to create intellectually and socially active interventions.

Promoting Children’s Reasoning

According to Piaget (1972), the teacher can promote children’s reasoning by stimulating their reflective abstraction. Piaget distinguished two types of knowledge: physical knowledge by empirical abstraction and logico-mathematical knowledge by reflective abstraction. When the child acts on objects, he or she can have physical experiences and construct physical knowledge by observing the results of his actions or the objects’ actions. However, in the case of logico-mathematical knowledge, the child has to make a relationship in his or her mind from the observation of the results.

Based on Piaget’s theory, Kamii and DeVries (1978/1993) develop four types of questions to promote children’s reasoning: the question for prediction (“What will happen if . . .?”), the question to make the child produce a desired effect (“Can you . . .?”), the question to make the child become aware of how one produced a desired effect (“How did you do that?”), and the question to make the child explain cause (“Why . . .?”). For example, the teacher asks the child, “What do you think will happen when you put water in this glass (or in this end of the tube)?” so she prompts him to predict the result before acting on the object. In another instance, the teacher tries to prompt him to think about the causal relationship by asking, “Why did water stop from the side hole (of the 2Mbs)?” or “Why do you think that N.’s (squirter in the low position) is working and yours (squirter
in the high position) isn't?" These questions encourage the children to construct physical
knowledge and logico-mathematical knowledge in the course of water activities.

Piaget (1972) also mentioned that the teacher needs to provide the materials and the
situations with which the children can experiment and research their own problems. For
example, in this study, the teacher let the child make his hypothesis and experiment with it
by stacking the clear glasses with holes and trying to drain from the stack of glasses to see
the result of his expectation. In another instance of water squirting, the teacher provides a
situation in which he seeks to find a solution by lowering the squirter with his purpose and
interest in hitting the target. Providing appropriate materials is essential to promote
children's reasoning.

**Building a Cooperative Atmosphere**

Piaget's theory leads to the view that cognitive development cannot be separated
from social development. Piaget (1932/1965) distinguished two types of relationships
between adults and children: one is cooperative relationships and the other is constraint
relationships. According to Piaget (1965/1995) cooperative interaction between the adult
and the child is important in the course of constructing children's reasoning and
knowledge. Piaget also emphasized cooperative interpersonal relationships among
children. For Piaget, these relationships are the fundamental context for intellectual
development.

Within cooperative and mutual relationships, the teacher minimizes exercising his or
her power in relation to the children and maximizes the children's autonomy in their
behaviors and thought. By exercising their ability to control their own actions and
thoughts, the children gradually construct internally coherent knowledge. For example, in
this study, the child constructs his own theory, 'water goes down easier than up high,'
within the cooperative atmosphere in which his erroneous ideas are accepted by the teacher.
CHAPTER 4
RESULTS

The results of the study are drawn from the 11 sessions that were performed in the classroom with an individual child and a teacher. Although the target child came to the water table with other children, the descriptions focus only on him. The practical descriptions are made with interpreted commentaries to link Piaget’s theory with practical classroom events. The following descriptions will show how the child progresses in his reasoning and thinking regarding draining and water movement in tubes in the course of acting on water and other materials that were developed in this study. They also show how the constructivist teacher can develop a series of activities and evaluate teaching strategies. Here, selected segments, presented in the order which they were performed, are analyzed. The first number on figures reflects the number of the session, and the second number indicates the order within the session.

**Session 1: Water Draining I**

Curtis comes to the water table, joining Lynseah (who leaves soon) and the teacher. At first, C. is guided by the teacher’s cooperative manner to act on the bottom-hole glasses. The following vignette shows how he moves from material action to construct correspondences in the course of acting on water with the bottom-hole glasses.

T: (Showing him a glass with a medium hole in bottom) Can I ask you a question before you start?

Here the teacher expresses respect for Curtis. Rather than directing him to wait in an authoritarian manner, the teacher asks his permission to postpone his activity in order to answer her question.

C: (Nods.)

T: (Giving him a 1Mb glass) Can you tell me what’s going to happen if you put water in there?

The teacher prompts him to predict and think about the results of his actions before acting on the objects. She is also assessing his knowledge about draining with this question.

C: It’s gonna come out that hole.

This prediction shows that Curtis already understands the regularity that water will flow from the hole.

C: (He inspects one glass and then another, holding the 1Mb glass in his other hand. He
then chooses a 1Bb glass from the water and observes as the water streams from the hole in
the bottom. He immediately holds the 1Bb glass above the 1Mb glass and watches the top
glass empty, filling the bottom glass [see Figure 1.1]. He drops the top 1Mb into the
water but immediately picks it up, and pours a little water out.)

Figure 1.1. Emptying 1Bb glass above 1Mb glass

As soon as Curtis is faced with the action of water coming out of a 1Mb glass, he reacts
immediately (material action) by holding a 1Bb glass above it. He observes the action of
the water streaming out of the holes. He may be interested in the water staying in the 1Mb
glass even though the water in the 1Bb glass is gone. At this point, C. is probably not
consciously comparing the streams from the two different sized glasses. It is possible to
say that this action leads him to observe the phenomenon that the lower glass fills as the top
glass empties.

C: (C. looks at L.’s glass held high and watches the water stream. He then stacks two
glasses together and takes them apart, drops one glass, turns the 1Bb glass over to look at
the big hole, dips it in water, holds it up, and observes the stream. While still holding the
1Bb in one hand, he picks up the 1Mb with the other, he lifts them [each containing
approximately the same amount of water] side by side, and observes the water streaming
from both glasses [see Figure 1.2].)

Figure 1.2. Comparing 1Bb glass with 1Mb glass

Having seen that the Bb glass emptied first, Curtis modifies his action by lifting both
glasses above the water side by side. Curtis is clearly observing the action of the water
streaming from the two glasses, with one continuing after the other has stopped. The
observation suggests that Curtis is comparing the two streams and, perhaps, the two
glasses.

T: Curtis, why do you think this one empties so fast?
With this intervention, the teacher prompts Curtis to think about causality. The question has an assessment function as well as a teaching function. The teacher's question focuses on speed, but no evidence suggests clearly that Curtis is thinking about speed. It would have been better to ask, "I wonder why this one (bigger hole) empties before the other?"

C: 'Cause that has a bigger hole.

Curtis moves from material action to correspondence by employing the comparative relationship. According to Piaget, Curtis develops logico-mathematical correspondence by reflective abstraction. Curtis understands something about the relation between the size of holes and order of emptying. He notices the order of emptying is determined by the size of the hole in the glass. This results in a one-to-one function. Thus, here, he is establishing an initial pair between big hole and emptying first, i.e., the order of emptying as a function of the sizes of the holes. This function which is drawn from the observation of facts, here, is immediately understood as a causal link.

T: So, if it has a bigger hole, it goes out faster?

The teacher reflects and elaborates his idea with this intervention. However, it might have been better to say "first" instead of "faster."

C: (Nods. He picks up 1Mb and 1Sb glass and looks at bottom holes.)

T: Which is going to empty first of those two?

Here the teacher prompts Curtis to make a prediction, to think about the results of his actions before acting on the objects.

C: (Indicates 1Mb glass) This one. (He dips glasses in water and holds them up side by side simultaneously, observing the water coming out [see Figure 1.3].)

Figure 1.3. Comparing 1Sb glass with 1Mb glass

Previously, he examined the 1Bb and the 1Mb but now he is comparing the 1Mb and the 1Sb. Earlier, he determined the order of emptying, Bb>Mb. Using that knowledge, he now predicts Mb>Sb. Thus he is generalizing it, in other words, he is extending the scheme to the new pair of glasses which are judged equivalent to the preceding ones by generalizing assimilation.

T: Let's see if you were right. Were you right?

C: Mmm-hum.

T: How did you know?
C: 'Cause that one (1Mb) has a bigger hole than that one (1Sb).

T: 'Cause that one has a bigger hole than that one? Oh, yea.

In this vignette, C.'s immediate action makes him observe the water phenomena from the two different sized holes and compare them to the other pair of glasses. Here, his cognizance starts leaving the periphery of material action and moves toward the center of his actions and the properties of the water in the glasses with the different sized holes. In other words, he is gradually conscious of the order of emptying from the different glasses. The teacher prompts him to think about causality and helps clarify his idea by questions that match his interest. The transparent glasses with different sized holes allow him to observe the different phenomena, the order of emptying.

In the following descriptions, C. does more comparison with three different sized bottom hole glasses. The reader will notice that C. uses the 1Sb glass throughout his experiments. Figure 1.4 shows the summary of his actions for the following vignette. Arrows follow the placement of 1Sb in a series of actions that seem to be systematic experimentation. Here, he has the possibility to construct the relationship between the sizes of the holes and the order of emptying. However, at points, Curtis's construction of knowledge about draining are clearly evident.

C: (He drops 1Mb glass and touches the water stream coming from the 1Sb glass.)

T: That one's (1Sb) taking a really long time, isn’t it?

The teacher is drawing attention to the resulting action of the small bottom hole, promoting observation.

C: Yea. (He sets the 1Sb in water so that it catches the water coming from another 1Sb he is still holding, dips the 1Mb he dropped and holds it above the 1Sb in the middle. He watches the glasses until the top 1Mb empties [see Figure 1.4a]. When a wave moves the glass floating on the water, C. accommodates by moving his two glasses, so the streams continue to flow into it.)

His next actions suggest that he observes that the top 1Mb empties as the middle 1Sb fills. He also shows his coordination of catching and draining so that 1Sb in the middle is simultaneously catching and draining by setting one more glass in water as seen in Figure 1.4a.

C: (When the top 1Mb glass empties, he drops it and picks up the 1Sb glass he previously placed in water [now full], he holds it briefly above another 1Sb glass he is still holding [still partially filled with water] [see Figure 1.4b].)

Here, the 1Sb which was previously a recipient, becomes a drainer. He immediately drops the bottom 1Sb, perhaps because he notices that the two of them are the same. Possibly, he rejects one of 1Sb glasses so quickly, because he knows that both glasses have the same order of emptying, i.e., Sb = Sb but it is unclear why he rejected the 1Sb.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
emptying 1Mb above 181

above another
but rejecting one
quickly

going back to “a”
to empty 18b above 1Mb

switching the position

recipient & drainer simultaneously (like item in series)

Figure 1.4. A series of experimentation with 1Sb glass

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
C: (Drops the bottom 1Sb in water, picks up 1Mb, and holds it above another 1Sb [see Figure 1.4c].)

Here, the drainer, 1Sb, becomes the recipient. He shows a type of reciprocity or reversibility in his action.

C: (C. observes until the top 1Mb empties and then drops it. As he holds the leaking bottom 1Sb, he sets another glass [hole Not Discernible] in the water under it. While he touches the water coming out of the 1Sb, the ND glass floats away. He then places the 1Bb in the water under it. He picks up the 1Mb again, places it above the 1Sb, and watches the water drain into it [see Figure 1.4d]).

Here, the 1Sb becomes a recipient and drainer simultaneously in the same way that an item in a series is larger and smaller at the same time. Thus, he has the opportunity to coordinate these relations.

C: (C. switches the positions of the two glasses when the top 1Mb gets empty, so the 1Sb in the middle becomes the top one [see Figure 1.4e]. He observes a small stream of water coming out of the 1Sb, shakes it lightly, watches water drain into the 1Mb for several seconds, and then drops 1Mb into the water.)

Shaking 1Sb suggests that he observes that the top 1Sb flows slowly but wants to make it drain faster as the bottom 1Mb keeps emptying.

C: (Picks up the full 1Bb from water and holds it under the 1Sb, watching the 1Bb empty as the 1Sb still drains [see Figure 1.4f].)

He seems to be comparing the Bb and the Sb but it is not clear. This is the first time C. has used 1Bb as a recipient when he could see the result of drainage from the 1Sb.

C: (C. switches the positions of these two glasses when the bottom 1Bb is almost empty. Noticing no water left in the 1Bb, now the top, he dips it in the water and holds it above the 1Sb [Figure 1.4g]. He then dips the top 1Bb in the water and holds it above the 1Sb. C. repeats this one more time then drops the top glass, when he sees the bottom 1Sb overflowing.)

He seems to understand the order of emptying from the 1Bb and the 1Sb, i.e., Bb>Sb.

C: (Now, C. holds only the 1Sb that is really full with both his hands, and observes water coming out of the small hole [see Figure 1.4h].)

Through the entire experiment shown in Figure 1.4, as he focuses on the results of his actions, C. is applying the functions he discovered at the beginning of this session to new
variables, glasses with different sized holes. Thus, he is generalizing the first relation (between size of hole and order of emptying). He seems to be interested in comparing the small hole with the other holes. As seen in Figure 1.4, he has kept the 1Sb glass throughout. He never puts it down or discards it, putting it above or under the big, medium, or the same-size hole. He seems to notice that it takes a longer time for water to come out of it than the others. Shaking the slow glass that is half full as if he can make it faster suggests this inference. This might have been systematic experimentation. These experiments are interrupted by the teacher trying to get another child to anticipate what will happen to the water with the glasses. After 1.4h, he goes back to the comparison by holding the full 1Bb and the full 1Sb above the water side by side [see Figure 1.4i] and then holding the 1Bb above the 1Sb [see Figure 1.4j]. He goes back to the experiment shown in Figure 1.4g. He compares the 1Bb and the 1Sb one more time and seems to be conscious of the different functions of the 1Bb and 1Sb as he observes the recipient 1Sb overflow as the drainer 1Bb empties.

The teacher now gives him a side-hole glass (1Ms), expecting he will be surprised or experience contradiction as he observes the action of the water as a result of the properties of a 1Ms. The following vignette shows C.'s surprise and puzzlement with the side-hole glass in terms of the water trajectories and the nature of draining.

T: (Giving him a new 1Ms glass) I'd like you to take a look at this glass. Let's see what you think will happen with this glass.

The teacher tries to call his attention to the side hole and offers a glass that will present a new phenomenon for C. to observe.

C: (Looks at hole and tries to dip glass in water.)

T: Before you try it, what do you think is going to happen with it? Can you tell me what you think is going to happen?

The teacher prompts prediction of what will happen with the water.

C: I think the water will come out here.

His understanding of side hole seems to be undifferentiated from the bottom holes. He simply thinks that the water will come out of the hole. Another question, “Do you think all the water will come out of it?” would clarify his expectation about the side hole.

C: (C. dips 1Ms in water and lifts it up with both his hands.) Eeee! (When the water spurts out onto his arm, he makes a startled sound and quickly turns the hole away from himself.)

Even though he predicted that water would come out that hole, he is clearly surprised to see water coming out of the side hole, making a curve. He might have mistakenly anticipated that the water would come straight down as it did from a bottom hole.

T: Oh-h-h.
Here, the question, "What is happening?" or "Why did you turn the glass? or "What surprised you?" would have been helpful to clarify what made him surprised.

C: (Watching the water stream out of the side hole, he immediately catches that water with the 1Sb glass, he holds to the side of 1Ms under the curving stream [see Figure 1.5a]. When the curving stream stops just below the side hole [see Figure 1.5b], he pauses for a second to look at it then switches the glasses, putting the 1Sb glass directly above the 1Ms glass [see Figure 1.5c].)

![Figure 1.5](image)

Figure 1.5. Switching the position by reciprocal assimilation, draining and catching

Curtis quickly shows that he now understands the difference in the water trajectories of bottom-hole and side-hole glasses. He shows reciprocal assimilation by knowing that a catcher can become a drainer.

C: (As the water level in the 1Ms glass decreases, the arc of the curving stream decreases and eventually ceases, leaving the water to trickle down the side of the glass. When this happens, C. alternates the top 1Sb and the bottom 1Ms. He drops the 1Sb glass, looks at the water which is level with the side hole in the 1Ms glass, pours it out, and looks at the hole.)

By pausing for a second when the water stops level with the side hole, pouring the water out and looking for the hole, Curtis appears to be puzzled. In the previous experiments, he observed that the glass with a bottom hole empties completely. With this new glass, he appears to experience disequilibrium. The glass does not empty. Perhaps he wonders why the water stays there. The teacher gives him the opportunity to feel conflict and become aware of the different properties of the water flow from the bottom-hole glass and the water flow from the side-hole glass.

In the following vignette, C. assimilates the side-hole glass into the cognitive structure of the bottom-hole glass and then shows his interest in making the curving stream.

C: (C. watches the water come out of the 1Ms glass, feels it with his hand, and holds up the 1Sb glass to catch that water. When the water is about to stop level with the side hole,
he tips the glass sideways until water covers the hole and it drains out into the 1Sb [Figure 1. 7]. At this time, a little bit of water also flows over the rim of the glass.)

He assimilates the 1Ms glass into the cognitive structure he has already developed concerning the bottom hole and also accommodates his action to the properties of the side hole by tipping it. Thus, he succeeds in making water come out of the side hole when the glass is placed horizontal to the surface of the water. This illustrates Piaget's (1975/1985) argument that “Every assimilatory scheme tends to incorporate external elements that are compatible with it” (p. 6). However, it is practical assimilation, not conceptual assimilation.

![Figure 1. 7. Accommodating his action to side hole glass by tipping](image)

C: (C. puts both glasses in water, after filling them, tips the top 1Ms over the 1Sb and lifts them together above the water. He pours the water out of the two glasses before they empty completely.)

It is interesting to see C. lift the 1Ms from the water, continuing the assimilation using his idea of converting a side hole to a bottom hole.

C: (C. looks at holes in several glasses and finally chooses a 1Ms and a 1Bb. He dips them in the water and holds the 1Bb glass above the 1Ms glass. He repeats this action but this time shakes the top glass lightly.)

T: (looking at his shaking of the glass) You’ve got another tornado in there. You can see that tornado, Curtis?

Teacher’s question seems not in keeping with Curtis’s preoccupation. She should have asked, “What are you trying to do by shaking it?”

C: (No answer and just repeats the action two more times, watching water coming out of both the 1Bb and the 1Ms.)

He does not answer because his interest is not in making a tornado but probably in making water flow faster.

C: (C. then drops the top 1Bb, picks up the 1Sb, and holds it above the 1Ms. He quickly drops the 1Sb, retrieves the 1Bb, and again holds it above the 1Ms. He dips the 1Bb glass
in the water and holds it above the 1Ms. He repeats this action seven more times, sometimes shaking it lightly. During this entire process, C. is observing the water streams.)

He seems to be interested in the curving water stream. In order to continue this phenomenon, he keeps water flowing from the top 1BB to the lower 1Ms. At one point, he uses the 1SB on the top but quickly discards it. He seems to prefer the faster draining glass. He even shakes the 1BB as if to make it drain faster. It seems that coordination of filling and draining is mastered.

The teacher gives C. another new 2Mbs and she prompts him to observe the holes and predict what will happen. When he sees water coming out of both holes, his prediction is confirmed. When the side hole stops draining, the teacher tries to help him think about the relationship between the position of the hole and the nature of draining. He shows he has constructed the regularity that water needs to be over the hole to come out of it. By reacting to the teacher’s ‘why’ question, he demonstrates that he answers questions when the questions are generated from his interest. The following vignette proves this point when the teacher asked questions that did not work. C. also demonstrates his differentiation of the properties of the 1SB and 1BB glasses and his coordinations of draining from two glasses into one glass.

C: (He picks up a 1SB from water and holds it above the new 2Mbs, containing water below the side hole [see Figure 1. 8a]. He observes water draining into the 2Mbs, drops the top 1SB, exchanges it for 1BB, dips it in water, and holds it above the 2Mbs. He quickly repeats this dipping and draining action seven times, observing water streams [see Figure 1. 8b]. He shakes the top glass a couple of times as if wishing to make the water come out faster. Seeing the curving stream draining from the 2Mbs, he moves the top 1BB down to catch the water from the side hole [see Figure 1. 8c].)

Figure 1.8. Exchanging the top 1SB glass for 1BB glass to see the curving stream from 2Mbs and then switching the position to drain it into the 1BB glass

C. seems to want to continue observing the water draining from the new glass with the two holes, specifically from the side hole. He seems to switch focus from catching bottom stream to catching side stream. This is suggested by shaking the 1BB above the 2Mbs and

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
by the exchange of the top ISb for the 1Bb when he can not see the curving stream from the 2Mbs. He seems to differentiate the ISb and 1Bb glasses in terms of their effectiveness in filling the 2Mbs glass. From his action of filling the 2Mbs repeatedly and quickly, it would appear that he wanted the curving stream to continue. He must have realized that if the water got below the side hole, this curving stream would stop.

T: (She moves her 1Ms glass close to Curtis’s bottom 1Bb glass.) Your glass’s (the bottom 1Bb glass) not getting full. How come?

The teacher tries to make him reason about the size of side hole and its stream in relation to the size of Bb’s hole and its stream.

C: (Shrugs.)

His agenda seems to be different than the teacher’s. He is interested in making the curving stream come out and catching it.

C: (C. moves his bottom glass to catch the teacher’s water, [Figure 1. 9a] and simultaneously, sees that the water stream from his top 2Mbs misses the other glass. Continuing to catch the teacher’s water with his 1Bb, C. moves his top 2Mbs down so that the teacher’s water can flow down to his two glasses [Figure 1. 9b].)

He coordinates draining from two glasses into one glass.

T: Why isn’t that one, that top glass (Curtis’s middle 1Bb) getting full?

The teacher tries again to make him think about the relationship between the size of the hole and the speed of draining.

C: ’Cause it’s coming out of that hole.
He does not mention the size of hole. It is unclear what Curtis means. It might have helped to clarify Curtis’s idea if the teacher had asked “What do you mean?” or “Tell me some more about that.” It is possible that C. is reasoning about the input in relation to the output, i.e., the subtraction is bigger than the addition in terms of his top 1Bb shown in Figure 1. 9b.

T: ‘Cause it’s coming out of that hole?

C: Uh-huh (yes).

T: Oh, mine quit. Why’d it quit?

The teacher tries to make him aware of the nature of draining out of side hole.

C: I don’t know.

Last time, he answered, “‘Cause it’s past that hole” but this time he simply says he does not know. He might be too engaged in his interest, that is, making curving stream, or he might want to be disengaged from the teacher’s ‘why’ questions.

C: (Meanwhile, stacks his two glasses together, takes them apart, and drops them in water.)

T: (Asks Nathan) Is there anything I can do to make it come out?

C: (Keeps watching the teacher’s 1Ms glass that has water below side hole and picks one glass from water.)

T: What could I do to get the rest of the water out of here?

C: I don’t know.

Last time when he had the same situation, he tipped it so that water could come out. However, here he just replies that he does not know. The teacher’s question might interrupt his interest in answering another question of his own. He continues his experiment by stacking the 1Sb into the 1Mbs and observing a small bit of water coming out the bottom hole of the outside 1Mbs. He might have expected that water comes out of both holes of the outside 2Mbs of the stack. This is suggested by close observation of the full stack with no curving stream. The teacher interrupts his experiment again with her own agenda.

T: (Showing the 1Ms glass) Do you have any idea what we can do to make this water come out?

The teacher’s question seems not in keeping with Curtis’s preoccupation.

C: (Shrugs.)

T: Can you try it? (Giving him the 1Ms glass) Try to make that water come out.
C: (Starts to look at the bottom but then just checks to see if there is a hole in bottom by touching the middle part of the bottom with his finger, then tips it so that water comes out of the side hole.)

His behavior shows that he is still occupied with the 2Mbs. Even though he sees the water is not coming out of the bottom, he touches the bottom where the hole is in the 2Mbs.

C: (Looking at the teacher) That works.

He succeeded previously with the same behavior. Earlier he assimilated the side hole into the structure of the bottom hole. It might have been unstable. However, it is possible that he was not willing to react to the teacher’s question because of his own reasoning about the draining from the stacked glasses. Nevertheless, here, Curtis conserves knowledge about the properties of the side hole and from now on, he has no problem with tipping it to get the rest of the water out of any side-hole glass. Now he is fully aware of the hole and interiorizes its action.

T: Yeah, that works. What did you do?

With this question, the teacher tries to make him aware of his successful action.

C: I just put the water over the hole and it came out here.

Now, he conceptualizes and clearly understands it. From now on, this conceptualization starts guiding the action.

T: You just put the water over the hole and it came out there? Well, that worked pretty slick.

After reacting to the teacher’s question, he goes back to his previous experiment, that is, draining from the stacked 1Bb and 2Mbs glasses. He holds the full 1Bb above the stack quickly several times to fill it (see Figure 1.11). He seems to have a hypothesis that the

\[ \text{Figure 1.11. Draining 1Bb glass into the stacked glasses to try to see the curving stream from the outside 2Mbs of the stack} \]

side hole will drain by quickly adding water in the stack. He seems to consider only the outside 2Mbs glass of the stack and does not think the effect of these stacked glasses is just the same as that of the inside glass. Obviously, C. was occupied with his own interest.
This vignette shows that it is important for the teacher to be engaged in the child's reasoning, in order to intervene most effectively.

The following short vignette shows that he prefers 1Bb glass to fill the bottom glasses.

T: (Showing new 2Mds glass) What do you think will happen if you use this one?

C: It will come out that one and that one. (He dips 2Mds glass in water, holds it up, and watches water come out two holes, then catches it into the stacked 1Sb and 2Mbs he is still holding as shown in Figure 1.12a-b. He rejects the new 2Mds glass soon and switches to the 1Bb [Figure 1.12c].)

He seems to conclude that it is not good to catch water from the two side holes because he cannot catch both of them together and also it stops soon. This is implied by his subsequent choice of a 1Bb.

In the following vignette, the teacher suggests the children race with the different sized bottom holes and leads C. to seriated correspondence.

T: (Showing three glasses each one with different sized bottom holes: big, medium, and small) Guys, do you see these? If I fill all of them full with water, which one is going to get empty the fastest?

C: (Points at 1Bb glass.)

He clearly knows that the 1Bb glass empties first.

T: Do you think so? Shall we try?

C: And then that one (1Mb) will get empty and that one (1Sb) will.
T: Do you think this one will get empty fastest? And then that one and then that one. Why?

C: 'Cause that's the biggest, that's a middle size and that's a little size.

Obviously, he is making a relationship between the size of hole and the temporal order of emptying from them. By acting on each hole and comparing each one with the others, he shows he constructed the seriated correspondences between size of hole and order of emptying.

T: Ah-h-h. This is the biggest, this is the middle size and that's the littlest. So you think this one will stay full the longest? Huh?

The teacher shows she has understood and hopes to help consolidate his consciousness of the relationships.

C: Uh-huh (yes).

T: Shall we try it?

C: Uh-hum.

T: Let's try. I need some help though. I can't do this by myself. What if we all took one. Could we do that?

By asking them to help her, in a cooperative manner, she is leading them to participation in a systematic comparison.

C: (Trying to pick the 1Bb up) OK, I take this one.

He knows what he needs to choose to win in this race.

T: You want that one? (To Nathan) Which one do you want? Wait, wait. Let's go up at the same time, alright? OK. Somebody want to say, go?

The teacher gives regulation to them to do the experiment by encouraging them to say "Go," instead of doing it herself.

C: Go. (Holds up his glass at the same time with Nathan and the teacher. Sees his gets empty first.)

T: Boy, Curtis, were you right? Did the biggest one get empty first?

C: (Nods) Then that one and then that one.

T: Yup, you were right. The biggest hole gets empty first. And then the medium size hole. And last of all the skinny little hole.

The teacher is recapitulating his observation. He shows he constructed the seriated correspondences between size of hole and order of emptying in this vignette.
In the following vignette, the teacher helps C. to think about the relationships between the nature of draining and the positions of the holes on the glass by her cooperative and egalitarian interventions.

T: (Showing new 2Mdsdh glass) You want to try that one? What do you think is going to happen with that one? Which hole do you think will have water coming out the longest?

The teacher prompts him to predict with these holes.

C: (Observing holes) I don’t know. (After observing some more) I’ll try it.

He seems to have no understanding of this glass. Since his previous experiences do not seem to enable him to generalize, it appears that he has not yet constructed either practical or conceptual understanding of this 2Mdsdh glass.

T: OK.

C: (Dips it in water, holds it up, and observes water coming out two ways. Holds the 1Ms glass above it and observes glasses draining and catching [see Figure 1.14].)

Figure 1.14. Trying 2Mdsdh to see what happen to holes of it

T: (Holding up the new 2Mdsdh glass with water below high hole)

I think I’ll try. I’ve only got one hole with water coming out of it. Hum.

Here, the teacher verbalizes what happens, but with an intention to guide Curtis to observe the properties of the new glass in terms of the position of the hole and the nature of draining.

C: (Still holding his 1Ms and 2Mdsdh glasses, watches the teacher’s action.)

N: Now it’s coming out these sides.

T: Now it’s coming out both sides.

C: (Looks at Nathan’s glasses, dips the 1Ms in water, holds it above the 2Mdsdh again and observes water coming out.) I’m going to (U).

N: Now it’s not coming out of this side.
T: Now it's not coming out of that side? Why not?

C: (Drops the top 1Ms glass, dips the 2Mdsdh in water, holds it up, observes water coming out of both holes, and feels water stream with his finger. Holds 1Ms glass above it and when water stops leaking from the high hole of the 2Mdsdh, exchanges the 1Ms glass for the 1Bb glass.)

He obviously wants to keep observing water coming out of two holes by changing the top glass to the big hole. He seems to show again his awareness of the larger stream from 1Bb.

T: Mine's only coming out of this side, too. I wonder why. (Fills glass and lifts it up again) Whoop! Now it's coming out of both sides. Whoop! Now it's only coming out of one side. I can't figure it out.

With this intervention, the teacher is trying to help him become conscious of the difference in the draining from the two holes at different heights. She is prompting him to think about the relationships between the nature of draining and the positions (heights) of the holes on the glass. By inviting him to help her figure it out, rather than questioning in a manner showing that she knows all, she behaves and talks as if she is his peer. So reducing her authority, she is leading him to think.

C: (Dips the 1Bb glass in water, holds it above the new 2Mdsdh one more time, and observes water draining.) I know. (Pointing at each hole) This is the lowest and this is the highest.

In the previous instance, when the teacher asked him, "Why'd it quit?" or "What could I do to get the rest of the water out of here (from 1Ms glass)?" he just answered he did not know for both of them, even though he could answer it before. Those questions seemed to discourage reasoning. However, this time he keeps thinking and finally figures it out. It shows that the teacher's cooperative and egalitarian attitude works more effectively than the authoritarian attitude. The teacher's question also focuses on Curtis's interest in the 2Mdsdh this time.

T: Oh, this is that lowest and that is the highest. Does that make a difference?

The teacher comments about his idea.

C: (Holds 1Ms glass above the 2Mdsdh glass and drops the 1Ms. Again holds the Bb glass above it.) Yea.

T: Why do you suppose that makes a difference?

With this question, the teacher tries to get him to conceptualize the causal relationship.

C: (Pointing at the hole of the teacher's 2Mdsdh) 'Cause the water went past the highest.
He is clearly sure about it but it is still at the level of practical intelligence. This time the "Why?" question works. It seems to work when the teacher's why question is directly related to something that he is engaged in reasoning about.

T: The water went past the highest, so it quit?
C: Uh-huh.

T: Oh-h-h. You guys are so clever. (To Nathan) Curtis says the water went past the highest hole. Now it won't come out.
C: (Dips 1Bb in water, holds it above the 2Mdsdh twice, drops the 1Bb, holds only the 2Mdsdh up with his both hands, and observes water coming out of two holes. Again dips the 1Bb in water and holds it above the 2Mdsdh two more times and drops the top one, then observes water coming out of two holes of the full glass.)

He looks quite interested in observing the water streaming out of this 2Mdsdh glass.

T: (Dipping her glass in water and holding it up) Isn't that interesting? When the water goes past the highest hole, then it quits, huh? Then it only goes out of one hole.
C: Look at mine.

T: Look at yours. I see yours is coming out of both holes.
C: (Feels water stream coming out of lower hole with his hand, picks the 1Ms, catches that water into it, and observes the phenomena.)

By the teacher's intervention, C. differentiates his thinking about the properties of the new 2Mdsdh glass in terms of the position (height) of the hole and the nature of draining.

Curtis and Nathan start to cooperate when the teacher leaves. In this vignette, C. shows practical coordination of physical actions and social cooperation, sharing experiences and negotiating with N.

C: (Picks up two glasses from water and drains 1Mb into 1Ms.)
N: (Tipping his 1Ms glass) Whoa, it's faster. Look, it's going.

Nathan wants to share his experiment with Curtis.

C: (Moving close to Nathan) Yea. (Holding two glasses, moves close to Nathan so that his lower glass can flow to Nathan's glass [Figure 1.17].)

Curtis replies to Nathan's talking by moving close to him and combining and coordinating the two experiments with him. It is practical coordination of physical actions and social cooperation. He shows excellent mastery with making side hole drain into a glass.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Figure 1.17. Coordinating draining from his glasses into Nathan's

C: But when these are like this . . . that, it will . . .

Curtis tries to talk about the phenomena but he is interrupted by Nathan.

N: (Interrupting Curtis) Look, it's going through the sides.

C: (Changes the top glass to the full 1Sb.)

N: (Holds 1Mb glass under his 1Ms [see Figure 1.18].)

Figure 1.18. Coordinating two experiment

C: (Changes the top 1Sb to the 2Mbs glass. Brings water once again and changes it to the stacked glasses [1Ms and ND bottom hole]. Holds the stacked ones very high above his 1Ms so the water hits his face.)

N: (Drops his bottom glass.)

C: (U) The water is coming out and washing my face. N: (Laughs.)
They are sharing an experience together with water. According to Selman (1980), shared experiences are usually relaxed and friendly, and promote intimacy between individuals. Here, they show level 1 shared experience.

N: (Dips his glass in water and holds it up.) Now, it will come out. (Touching the water stream coming out of his 1Ms glass) Look it. Look what it's like.
C: (Drops the stacked ones, keeps holding 1Ms, dips it in water, and holds it above Nathan's 1Ms.)
N: Look, Curtis, (pointing to the water stream coming out of Curtis's 1Ms glass) now it's coming this way and (pointing to the water stream coming out of his 1Ms) now it's coming this way. (Then, holds up one more bottom-hole glass [ND] under his 1Ms glass to catch the water.) Look it, it's going. On two sides, look it, Curtis.
C: (Holds 1Sb glass above his 1Ms glass. Now he co-operates with Nathan again as shown in Figure 1.18.)
He looks thoroughly engaged in making the water system drain. To reply to Nathan, he responds by acting.
C: (Drops the top 1Sb soon and looks for another glass) What's the biggest? Ah-ha! (Changes the top 1Sb to the 1Bb he just found and holds it above his 1Ms. Dips the 1Bb in water and holds it above the 1Ms. Keeps doing it.)
He again shows his knowledge that the Bb glass makes water go through faster.
N: (Drops his bottom glass, changes his hands to hold the 1Ms, still catching Curtis's water. Picks up the glass he dropped and holds it under his 1Ms to catch the water.)
Now, it's coming this way.
C: (Keeps dipping the 1Bb in water and holding it above his 1Ms.) Look at this. I'm getting a lot of water, ain't I?
Obviously he wants to keep water going through into Nathan's so as to keep co-operating.
N: Yeah. And look, it's going down both of them. Oh, this is all going, Curtis. Mine's so, look at mine, Curtis. Ours is full.
They chat some more about topics not related to the water activity, still cooperating with glasses. After awhile, N. says, "Oh, you've got two cups and, look, it's coming through these! Look at, it's coming through these! Wow!" C. replies, "It's just like a marble thing," using level 2 shared experience. By previous knowledge, he reasons and makes a relationship between the running water and the marble as it rolls down a marble run. After that when N. tries to stop cooperating by dropping his glass, C. says, "Please don't stop,"
using level 2 negotiation strategies. In this vignette, C. coordinates the water draining from his two glasses into N.'s by cooperating with him.

Session 2: Water Draining II

The teacher lets the children choose glasses from among those they used before. At first, Curtis chooses a 2Mbs glass and observes the water streaming from two holes of the 2Mbs. Here, he considers two streams from the 2Mbs at the same time by draining one in his glass and the other in Andrew's (A).

C: (Gets another 2Mbs soon and starts catching water from one to another. Catches the water streaming out of the side hole first [see Figure 2. 1a] and then moves to catch the water streaming out of the bottom hole when the side hole stops leaking [see Figure 2. 1b]. Again dips the top one in water and holds it over another but this time catches just the water streaming out of the bottom hole.)

He seems to understand the side hole stops leaking first and then the bottom hole does.

Figure 2. 1. Catching water streams by the order of draining from the holes of 2Mbs

C: Dips it again and does the same. Moves close to A. so that his other water streaming out of the side hole can go down to the glass which A. is holding in water (see Figure 2. 2).

Figure 2. 2. Considering both streams at the same time

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
He is trying to co-operate with A. Now, he is considering both streams at the same time by draining one stream into his glass and the other stream into A.'s.

C: (To Andrew) Watch. (Observes it until the water stops from the side hole.)

After that, C. again does the same behavior as shown in Figure 2.1.

C: (When the curving stream stops, moves his top glass straight over his bottom one to drain the rest of the water, looking at Andrew's glass.)

C. withdraws his glasses from A.'s because A. is interested in making fountains by pressing his glass in water. However, he shows progress from draining one by one from the two holes of the 2Mbs to draining both at the same time in his and A.'s glasses.

The teacher and three boys make fountains for awhile by A.'s discovery. Meanwhile, N. tries to plug the side hole of the 2Mbs. When the teacher talks about it with N., the other two show their interest, too. Here, C. uses N.'s idea but shows his progressive intelligence.

T: (Talks about plugging the hole in response to Nathan. (To Nathan) Oh, you plugs yours? You're getting good at plugging, aren't you?

A: (Imitating it) I am (U), too.

T: What? Oh, you plug yours, too? How did you plug yours?

A: (Showing that he is plugging the hole with his finger) I get putting my finger over the hole.

T: Just putting your fingers over the hole?

C: (Stops holding his glasses to make water flow into Andrew's, sees that Andrew is plugging the hole. Drops the top one, tries to plug both holes of the 2Mbs but gives it up. Dips the glass in water, putting his finger over the bottom hole, holds it up, and makes the water come out of only the side hole. Observing it, immediately moves it to Andrew's glass in order to make the water flow into that. When the water stops flowing from the side hole, moves his glass straight over Andrew's glass and unplugs the bottom hole so that the rest of the water can flows into there [Figure 2.3].) Look at this, Andrew.

He co-operates with them by imitating plugging. However, he does not only imitate but also elaborates that behavior. He discovers another thing with this behavior. In other words, he is assimilating the 2Mbs to the 1Ms and then the 2Mbs to the 1Mb by plugging the bottom hole and then unplugging it when it stops leaking. He is also accommodating his action to the properties of the 2Mbs glass. He makes water come out of the side hole first by plugging the bottom hole, then unplugs it to make the rest of water come out of the bottom hole when water gets lower than the side hole. So he is surely aware of the
order of emptying from this 2Mbs glass. Having established that practical correspondence, he goes on to functions [order of draining = f (size of holes)]. He also conserves the types of water trajectories from different holes by predicting correctly the direction of the water stream out of the hole when moving his glass directly over Andrew's. He looks as if he is pleased with himself, with what he found out, and wants to share it with Andrew.

At this time, the teacher misses C.'s interest and tries to give him her agenda. The three boys keep their interests and the teacher realizes the children's interest differs from hers. She withdraws her agenda and later tries it again. Here, C. shows that he conserves the knowledge about the nature of draining from the side hole. Since the teacher knows that C. constructed that knowledge, she seems to invite C. to show his idea to the other two who do not know yet how to drain the water below the side hole of the 1Ms.

T: Look, my water (in the 1Ms glass) is not coming out anymore.

Again, she does not see Curtis's agenda. She is trying to make them aware of the nature of draining from the side hole.

C: (Looks at that but repeats what he was doing as shown in Figure 2. 3.)

N: Water is not high.

T: What could I do to get it to come out, do you think, Andrew?

A: Fill it back up.

T: Fill it back up? Will that work? Let's see. (Pouring water into that glass) Ah-ho.

C: (Still drains his two holes into Andrew's.)

T: Look at. Here I am again with my water in my glass--it won't come out. (Talks with Nathan some more.) How do I get that bottom part out, though? Hum.

N: I don't know.
C: (Looks at the teacher’s glass, turns his glass over, observes the holes, and touches his bottom hole with his finger, then looks at the teacher’s glass again.)

He seems to recognize the difference between his glass and the teacher’s glass.

T: Curtis? Do you have any suggestion? How am I going to get the water out of the bottom part?

C: (Tipping his glass) Tip it like this.

He is conserving the practical knowledge about draining from the side hole.

T: Tip it?

C: Uh-huh, like that.

T: Could you come over here and show me how to tip it so that I can get it out?

C: (Moves over and tips the teacher’s glass.) Tip it like that.

T: Oh, tip it like that so you can get it come out? OK.

C: (Goes back to his place.)

T: Oh, yea, look, Curtis was right.

The teacher confirms that C. constructed the knowledge about the nature of the draining of the side hole and at the same time, she helps the other two by C.’s demonstration.

In the following vignette, C. tries to drain from the side hole of the stacked glasses without considering both the holes of the inside and the outside glasses. He experiences a contradiction and also shows his interest in the curving stream here.

C: (Stacks two 2Mbs glasses together in water and holds them up. The curving stream comes out but stops soon [Figure 2.4]. When the curving stream stops coming out, tilts

![Figure 2.4: Stacking two glasses with water and watching water stop from side hole](image)

his head to look at it and touches the side hole where the water came out, and takes them apart. Looks at this part and that part of the two glasses.)

He seems to want to drain all water from the stacked glasses but he does not consider both holes in the inside glass and the outside glass. Thus, here, he seems to feel
contradiction because the curving stream stops coming out of the stack but he still sees water over the hole where the curving stream came out. However, at first, he does not seem to recognize that the water he sees is in the inside glass of the stack and the hole of the inside glass is blocked with the outside glass. He did not try to match the holes to point in the same direction and also the side hole of the inside glass goes a little bit higher than the one on the outside when it is stacked.

A: (Holds his glass under Curtis's.)

C: (Dips them in water, stacks them again in water, holds them up. Because the curving stream does not come out at all this time, again tilts his head to look at the side hole, touches it, and just takes them apart by lifting the top one out of his bottom one [Figure 2.5]. Still keeps draining his two glasses into Andrew's glass and observes it until his two glasses empty.)

Figure 2.5. Taking stacked glasses apart by noticing water stop from the side hole

C: (When his two glasses get empty) Now, let the water come out of the hole. (Dips his two glasses in water and again holds them over Andrew's [unclear whether he gets the curving stream or not]. Observes it until the top one gets empty, dips it in water, drains it from the curving stream into his bottom 2Mbs [Figure 2.6a] and when the curving stream is about to stop, tips it to drain more from the 2Mbs, observing it [Figure 2.6b].) He figures out that the stacked glasses do not work very well to produce a curving stream. When he says, "Now, let the water come out of the hole," he might mean the side hole. He obviously wanted to make water come out of the side hole of the stacked ones. Because it does not work, he takes them apart and drains from the side hole, tipping it even though its bottom hole is also draining as shown in Figure 2.6. His interest seems to be in the curving stream from the side hole. A. leaves him and C. shows more interest in the curving stream by pouring water from one to another several more times to keep watching it. While he is watching the curving stream, sometimes he catches it and sometimes he tilts his head to look at it.

The teacher introduces him to another new 2Msdh glass and C. shows that he conserves the knowledge (seems to be practical knowledge) that the lower hole will leak the longest.
Figure 2.6. Showing his interest in curving stream

T: Guys, did you see this cup? If I put this cup in the water, what’s going to happen?

C: (Drops his two glasses and stretches his hand to take the new 2Msdh.)

T: Don’t put it in yet. I want you to tell me what you think . . .

The teacher wants to know his prediction before he experiments with it.

C: It will come out that hole and that hole (indicating the holes).

His verbalized thinking about this glass is undifferentiated.

T: Do you think so?

If the teacher had asked him, “Which hole goes the longest?” she could have known if he has conceptualized the relationships between the order of emptying and the position of the hole.

C: Uh.

T: (Giving him the 2Msdh glass) You want to try it?

C: Yea. (Observes the holes and turns it over to look at the bottom. Dips it in water, holds it up, and observes water coming out.)

C: Yes, I was right.

T: Yes, sure, you were right.

C: (Immediately picks the 2Mbs up from water and holds it under the new 2Msdh.)

T: Which one is going to go the longest?

The teacher prompts him to compare two holes at different heights.
C: (Dropping the bottom 2Mbs) Uh, this one (the lower hole of 2Msdh).
He is sure the lower hole goes longer; however, it might be still practical knowledge.

T: Why that one?

C: (Picks the 2Mbs again and keeps catching the water still coming out of the 2Msdh.) 'Cause that one is lower.
He seems to construct the knowledge that lower holes drain longer.

T: 'Cause that one is lower. Ah-h-h.

C: (Tips the top 2Msdh to make the rest of all water come out.)

T: I notice you tipped it. Why did you tip it?

C: (Dropping the 2Mbs in order to answer the teacher) So it would come out this hole and that hole (pointing to each hole of 2Msdh).

C: (Tips the top 2Msdh to make the rest of all water come out.)

T: Ah, so it would come out those holes. Alright.

C: (Observes the holes, turns it over to look at the bottom [no hole in it], and drops it.
Picks up the 2Mbs again and observes the holes. Picks another 2Mbs up to pour water in the other 2Mbs he is holding, repeats pouring five more times and sometimes holds it up higher to observe the water streaming out of the bottom hole.)

In this vignette, the teacher helps C.'s reasoning to differentiate by using the questions that match and extend his interest.

In the following vignette, C. shows that he constructs the relationships between the heights of the water level in the glass and the different water trajectories from it.

T: You know what I've been noticing today when I've been playing. Can I put this down, Nathan? I've been noticing, look at this, Curtis?
Will you look at this while I am doing this?
The teacher tries to make him aware of the trajectory of the water stream from the side hole.

C: (Drops all in water and observes her doing.)

T: (Demonstrates catching water stream from the 1Ms glass to the other glass [see Figure 2. 7].) Look at what I've been noticing. Watch what happens to my water.

C: Hum.
Figure 2.7. Demonstrating by the teacher

T: Would you tell me what’s happening?

C: Hum, that’s going lower in the half way, water goes to it... going this way to the glass (drawing the water level line on the glass from which water came out).

From his observation, he makes a relationship between the heights of the water levels and the trajectories of the water stream from the side hole.

T: As the water gets lower, it goes this way to the glass?

C: (Nods)

T: I’ve been noticing that, too. Interesting, isn’t it? (Dipping her glass in water to show water coming out one more time)

C: (Dips the 2Mbs in water, holds it up, and observes water coming out but dumps water out of it soon.)

T: Look, there it is.

In this vignette, the teacher’s intervention leads to him to reasoning and thinking.

In the following vignette, C. tries to match the stack’s inside glass’s hole to the outside’s. Now, he considers both of the holes of the inside and the outside at the same time. By doing that, he coordinates two sets of relationships.

C: (Still holding the 2Mbs, scoops up water with the 2Msdh pours the water out of the two glasses, and sets the 2Mbs down. Turns the 2Msdh until he finds the hole in the side of the glass. Holds the glass in the left hand and places fingers on the hole in the side of the glass. Picks up the 2Mbs in the right hand and pours the water out of it. Puts the 2Msdh into the 2Mbs, trying to match up the holes in the sides of each glass [Figure 2. 8a]. Sees that the holes don’t match. Pulls the glasses apart and sticks the 2Mbs in the 2Msdh, trying to get the holes to match up [Figure 2. 8b].)
This time, he seems to believe that he needs to match the holes of stacked glasses to make water come out of those holes. Thus he is differentiating his action related to the nature of draining from the stacked glasses, specifically in terms of the side hole. Previously, he just considered the outside hole so he felt the contradiction when he still saw the water over the hole. However, this time he eliminates the contradiction by himself and re-equilibrates his cognitive structure about draining. In other words, he considers both holes of the outside and the inside at once in order to drain from the stacked glasses. Thus he coordinates two sets of relationships; one is about the inside glass and the other is the outside glass. This seems to be conceptualized knowledge, rather than practical knowledge because he tries to match the holes before he puts water in them, even pouring out the water entered accidentally. Noticing that the holes do not match at first, he switches the positions of the glasses. Then, he puts water in them to see the results (in his next action). In other words, his concept leads his action this time. Previously, by just stacking them in water and holding them up, he tried to make water streams come out of the holes of them without considering whether both holes match up (see Figure 2.4). Thus, here, he shows his progress.

C: (Dip the stack of the 2Mbs and 2Msdh in water, holds them up. Observing water coming out, dips the ND glass in water, pours it into the stacked ones.)

Even though he tried to match up the holes, it does not work very well when the water comes in them. Nevertheless, he shows progress in his reasoning by considering those holes in the stacked glasses at the same time.

**Session 3: Catching Water on the Pegboard I**

In this session, the teacher and I give the children a pegboard sitting over the water tub on the floor. Previously, Curtis showed his interest in draining through more than three glasses by setting one more glass in water and sometimes holding his glasses over the other's. That inspired us to develop the pegboard on which the children can arrange glasses on the pegboard using holders in order to drain and catch water from more than two glasses at the same time.

Curtis and Andrew start with one holder that is already put in the pegboard for each one so that they can have ideas about how to use it. At first, the teacher gives C. a choice among the bottom-hole glasses he used before and he chooses a 15b to put in the holder. He shows his interest as well as difficulty in using holders as new materials. After awhile, A. leaves him and the teacher starts to interact with C. by showing new side-hole glasses, 1MLs, 1Mms, and 1Mhs. Because he has shown interest in the side hole since session one, the teacher offers these glasses to help expand his ideas about the side hole.
T: C., I want to show you something. May I show you something?
The teacher asks permission in a non-authoritarian manner.

C: Yes.

T: I have three different glasses (1Ml, 1Mm, and 1Mh) here. One with a hole there (points to hole near bottom of side) and one with a hole there, (points to hole in middle of the side) and one with a hole there. (points to hole near the top of glass) Which one would you like to use?

C: This one. (Points to one with hole near the bottom and takes it from the teacher.)

He seems to prefer the 1Mls because he knows it empties the most water.

T: Why do you want that one?

The teacher prompts him to think about the reason he wants to use 1Mls.

C: Because it will come out this hole.

He seems to know what will happen to the 1Mls glass but his verbalization is undifferentiated. However, his choice of 1Mls suggests his differentiation regarding the functions of the different positions of the holes.

T: OK. Because it will come out this hole? Why not this one? Why didn’t you choose either of these two (1Mhs and 1Mms)? Can you tell me?

The teacher tries to help him to differentiate his reasoning. Here and in the above, the teacher is using the 'why' question and it works because it matches to C's interest.

C: Um, water will go past there (1Mms) and then it won’t come out of there any more.

He clearly has conceptualized the functional relationship between the positions of the holes and the order of the draining.

T: Oh. When water goes past that hole it won’t come out any more? What about this one (1Mhs)?

C: When it goes past that hole, it won’t come out that hole.

T: Oh, but with this one (1Mls), what will happen?

C: It won’t come past this hole.

T: It won’t go past that hole?

C: (Shakes head.)

T: OK, so you want to try that one (points to the 1Mls)?

C: (Nods.)
Obviously, he knows what will happen to the water in these glasses before he actually acts on them by generalization from his previous experiences with different glasses.

T: OK.

C: (Fills 1Mls with water from the tub, lets it drain into a pitcher sitting in a holder, and watches water come out.)

In this vignette, C. shows that he has perfectly conceptualized the functions, that is, degree of emptying = f (heights of holes) by choosing the 1Mls with his intention to drain from it.

The teacher continues to try to help him to arrange the glasses on the pegboard to drain and catch from one to another. Noticing C.'s uneasiness about doing that, the teacher succeeds in intriguing him to think about catching and draining one into another on the pegboard by demonstrating how to drain the curving stream from one glass to another without any verbal comments (like parallel play among children). The following vignette shows C.'s difficulty in arranging side-hole glasses to catch and drain on the pegboard and the teacher's effective intervention to help him out of his difficulty.

T: Would you like a holder to put that there so it will go into that?

The teacher makes him aware that he can use the holder to put it in.

C: (Tips the 1Mls to empty and fills the pitcher with water, still holding the 1Mls.)

T: I have some more like this. (Shows more glasses which have holes in different places on the side.)

C: (Finds the hole in the 1Mls and positions it over the pitcher that is sitting in a holder on the pegboard. Continues to add water from the other pitcher into the 1Mls in his hand and watches the water drain into the pitcher [see Figure 3.1].)

Figure 3.1. Inventing an arrangement to drain from side-hole glass on the pegboard

It seems hard for him to arrange the side-hole glasses on the pegboard in order to drain or catch. Instead, he holds it up in his hand to do that, inventing the above arrangement. Arranging side-hole glasses on the pegboard to drain or catch from one to another seems to
need more conscious spatial coordination than just intuitively holding a glass. With a bottom hole, it seemed easier than the side hole.

T: (Puts 1Mms in a holder and fills it with water so that the water from the side hole drains into the other glass in holder. Adds more water in the top 1Mms to keep water draining.)

The teacher demonstrates the way to drain the water from the side hole into the other glass. Instead of explaining how to do or forcing him to do it, she prompts him to try by doing it herself with an intention of stimulating his action.

C: (Drops the pitcher he used for pouring and just holds the 1Mls to drain into the other pitcher. Watches the teacher pour water into the 1Mls, then drops the 1Mls. Moves the pitcher (now full) over the 1Mms which the teacher was pouring water in. Emptying the pitcher into the teacher’s 1Mms, watches it drain into glass below it. At first, the water drains into the glass, then the water stream arcs lower and misses the glass [see Figure 3.2].)

![Figure 3.2](image)

Figure 3.2. Engaging in catching curving stream on the pegboard by the teacher’s demonstration and watching water miss the glass when the water stream arcs lower

With the teacher’s intervention, C. finally moves his behavior from just draining the glass in his hand to doing it on the pegboard without feeling forced into it.

T: Hum, I see that we’re not catching that water down there, what do we do about that?

The teacher prompts him to observe the phenomenon and to think about it.

C: (Observing water streaming, continues to pour water into the top 1Mls, turns it a little bit to adjust the position of the hole in the top glass, and adds more water.)
He adjusts the hole as if the problem is in the position of the hole. When he still sees sometimes it does not catch the water, he adds more water to make it drain into the bottom glass.

T: I see sometimes it catches it and sometimes it doesn't. I wonder why sometimes it catches it and sometimes it doesn't?

C: (U)

T: I'm sorry, C., I didn't understand what you told me.

C: When the water goes slower it goes back to this hole (where water came out).

He describes his observation of phenomenon.

T: It goes back to this hole? This (points to water) comes back to this hole. Oh. I wonder if there's a way we can catch it when it comes back?

C: I don't know.

He shows it is a hard task for him to put the glass to catch the curving stream on the pegboard. It is even a harder task than just catching the curving stream from the other. It adds one more variable to the relationship already existing in this situation as shown in Figure 3.2.

T: Do you suppose we could put up two glasses?

C: (Shrugs shoulders.)

T: I wonder what would happen if we put a holder about right here. (Puts holder in the pegboard.)

C: Then the water would come in this hole (means holder).

T: Do you think then it would come here?

C: Uh-huh.

T: Is it OK to try it?

C: (Nods.)

T: OK. Let's see what happens. (Places glass in the holder with the hole facing the teacher)

C: Hole right here. (Turns around the glass so that the hole faces to the right side in order to make water flow into the bottom glass [see Figure 3.3].)

By adjusting the hole, C. anticipates the direction of the stream, showing his practical mastery of this variable.

T: Hole right there. You want it like that? OK.
Figure 3.3. Catching water streams from the side holes on the pegboard by the teacher's intervention

C: (Pours water into the top IMms and watches it drain into the IMms just placed there and then into the bottom one.)
   T: Oh, ho, look what happened there.
   C: Uh-huh.
   His reaction shows that he expected that result.
   T: Ah.
C: (Adds another pitcher of water to the top IMms slowly, watches it drain down, and turns the second glass slightly. As the pressure lowers, the water from the second glass misses the bottom glass.)
   T: How come did you turn that? I noticed that you turned that.
   The teacher tries to prompts him to think about his action.
C: (Pointing to the glass he just adjusted) So that it would come in this one more better.
   T: So it goes in that hole better?
C: (Nods.)
   T: OK. It looks like it is going right over the top of that bottom one. (The water stream from the middle glass misses the bottom glass when the pressure is high.)
   Wonder what we should do about that?
   The teacher tries to prompts him to think about moving the bottom glass in order to catch water in it better.
C: (Pours another pitcher of water in the top IMms and watches it drain in the other ones. Picks up the IMls from water, places it into the holder already put on the pegboard, pours water into it so that the water drains into one of the other glasses [Figure 3.4].)

![Diagram](https://via.placeholder.com/150)

**Figure 3.4. Coordinating all water in one glass**

He does not react to the teacher's question but he **invents an arrangement that has a complex system of relationships by adding one more glass.**

T: Oh, that's a good idea, C. Ah, now you got water coming from two places in that glass, don't you?

C: (Fills two pitchers with water and pours the one in his right hand into the top glass quickly and adds the other one to the other top glass more slowly and watches the water drain from glass to glass.)

It still seems difficult for him to make a relationship between the side-hole glasses to catch water one to another. Catching the curving stream on the pegboard requires consideration of spatial relationships such as distance and angle. Catching the water stream in his hand seems to be perceptible. However, here, **Curtis shows his progress in his logico-mathematical thinking by pouring a pitcher of water in each top glass to make all water from the two ways drain into one. In other words, he coordinates all water trajectories in this complex system of relationships.**

**Session 4: Catching Water on the Pegboard II**

Curtis comes to the water table with Lacy. Three holders are already put into the pegboard in a vertical line for each one in order to provide further experiences for draining and catching from one to another. C. plays at the left and L. plays at the right side of the pegboard. In the following vignette, C. shows how he changes his action and progresses into logico-mathematical knowledge regarding the water trajectories and the speed of the draining. Here, he mostly experiments by himself and the teacher intervenes occasionally.
T: OK, Curtis. Let’s see, here. Here is one. Would you like those? Take a look at those to see if there is one you want. (The teacher finds some glasses and hands them to Curtis.)

The teacher gives him a choice and simultaneously prompts his awareness of the glass he chooses.

C: OK. (Chooses a 1Sb, puts it in the top holder, and pours water into it.)

T: Here are some, here are a couple of more holes. (Gives C. the 1Bb glass.)

C: (Looks at the hole of 1Bb.) I don’t like this hole. (Gives it back to the teacher.)

T: Why don’t you like that one, Curtis?

C: I don’t want big hole.

T: You don’t want big hole? OK. Let’s see. Let me have a look. Here is another big hole. You don’t want that one, either?

C: (Shakes head.)

T: OK, what do you want, can you tell me? (shows glasses with holes)

C: Oh, holes . . . this one.

T: Do you want little holes? That’s going to big hole, too.

C: I want hole on the side.

His interest is clearly still in the side hole. He has been interested in the curving stream since the previous sessions. However, he does not seem to think about draining the water from that side-hole glass of the 1Mms into the other he will put in the bottom holder right below it.

T: You want a hole on the side. OK. Let’s see what I’ve got here.

C: (Takes 1Mms from the teacher, puts it into the middle holder, and pours water into the top 1Sb glass. Continues to pour water in the top until it is full and watches the water flow into the 1Mms [see Figure 4.1].)

T: Why did you want a hole on the side, Curtis?

C: I just did. (Puts water in the top 1Sb and the lower 1Mms )

T: You just did. What happens different when you use a hole on the side than a hole on the bottom?

The teacher prompts him to think about the difference, perhaps the different directions of the water streams between his bottom hole and the side hole because the bottom holder is right below the middle one and he chose the side hole for the middle.
Figure 4. 1. Placing glasses in the holders in a vertical line

C: (Adds water in the 1Mms and points to each glass.) This one comes out on the bottom and that one comes out on the side.

T: (Repeats) This one comes out on the bottom and that one comes out on the side? I see.

C: (Continues to pour water in the top 1Sb and the lower 1Mms.)

T: Did you want another cup? Curtis, would you like another cup?

Noticing another holder left in his line, the teacher encourages him to use another glass for it.

C: (Nods.)

T: What kind of cup would you like to have this time?

C: I want one with a hole on the side.

T: Hole on the side? OK. There's one with a hole on the side. (Hands a 1Mms glass to C.)

C: (Takes the 1Mms and tries to decide where to hang it on the pegboard. Puts it into the bottom holder but takes it out, puts it into the top glass, takes it out again, and holds it for a few seconds, looking at his glasses on the pegboard. Bends down to the bottom holder and stands up, still holding the glass, and then puts it into the top glass. Takes the 1Mms out of the middle holder and puts it into the top glass, too. Pours water in the top which is now a stack of three glasses, one 1Sb and two 1Mms, and turns the stacked glasses around in the holder, looking at the side holes.)

The existing arrangement of holders may constrain his efforts. At first, his interest in the side hole does not seem to allow him to consider catching water from glass to glass in a vertical line. As soon as he puts the 1Mms into the bottom hook, he seems to find that he has a problem in catching the curving stream from the glass above. Even though he
realizes his problem by his action, the solution does not come up right away. In this situation, he needs to think about the relationships in three glasses at the same time. Considering a system of relationships at once seems to be a difficult task for him. That difficulty makes him wander and hesitate so he starts stacking the glasses together. He could move the bottom holder to catch water from the IMms glass above. However, the arrangement of the glass to catch the curving stream seems to be difficult for him. He has three glasses, a 1Sb and two IMms in his stack. Even though the 1Sb blocks the side holes, he looks at the side holes and adjusts them, filling the stack, as if he can make water come out the side holes. He does not coordinate the spatial relations among the holes in the stacked glasses in this situation.

C: (Takes the top 1Mms out of the stack and holds it in his hand, drains it into the pitcher, adds water from the pitcher to it, and tips it over the pitcher until it empties. Puts the empty 1Mms into the middle holder, takes the stack of 1Mms and 1Sb from the top holder, and tries to drain, tipping them over the pitcher. Notices water does not come out, puts them back in the hook, just takes the 1Mms out of the stack, and pours the water from it into the 1Sb in the top hook, puts the empty 1Mms into another 1Mms in the middle hook. Takes the 1Sb out of the top hook and watches the water drain in the pitcher. Rearranges those empty glasses to the original situation [1Sb, 1Mms, and 1Mms from the top], looking at the holes [see Figure 4.2a].) Can I have another... (Takes the 1Mms from the middle hook and places it in the water.)

He seems to verify the relationships between water trajectories and the positions of the holes by draining one by one from the stack.

![Figure 4.2. Exchanging 1Mms for 1Bb to make water go through all three glasses](image)

T: What do you want C.?
C: One more... I found one. (Looks at a glass in the tub.)
T: OK.

C: (Picks up a 1Bb from the tub and puts it into the middle hook [see Figure 4.2b].) Now, he corrects himself by changing a side-hole glass to a bottom-hole glass in the middle hook so he makes the water to drain one into another in the vertical line. Thus, he succeeds in placing the glasses in terms of the water trajectories among all three. Here, he seems to consider the speed of emptying, too, by selecting a big hole for that. However, he does not see the speed of the draining among all three, that is, in a whole relationship. By considering the relationships between only the middle one and the bottom one, he shows his difficulty in reasoning about the relationships among three elements at the same time.

C: (Adds water from the pitcher to the top 1Sb and watches the water drain into the middle 1Bb and the bottom 1Mms. Pours water in the top 1Sb slowly, placing his other hand over the hole in the middle 1Bb. However, the glass is pushed up and it is not plugged very well so it is still leaking [see Figure 4.3a].)

---

Figure 4.3. Trying to make curving stream

Even though he solved the problem between the middle glass and the bottom glass, he still sees another problem in that the curving stream does not come out of the 1Mms. So, he tries to gather the water in the 1Bb by placing his hand over the bottom hole. Perhaps he wants to make a large stream from it into the bottom 1Mms to see the curving stream from it.

C: (Pours water in the middle 1Bb [see Figure 4.3b], and catches curving stream from the bottom 1Mms in his pitcher [see Figure 4.3c]. Recycles the water out of the pitcher into...
the middle 1Bb, reaches down in a hurry, and catches the curving stream into the pitcher again until the 1Mms stops draining.)

Obviously, he wanted to see the curving stream from the bottom 1Mms. When plugging the 1Bb does not make it full, he just puts water in it and catches the curving stream from the bottom 1Mms. He also expects the water to run fast through the 1Bb so he moves down quickly to catch the water from one below it as soon as he pours water in the 1Bb.

C: (Tries to pour the water out of the pitcher into the top 1Sb but stops and looks at the glasses the teacher is holding.) Can I have one with a big hole on the bottom?

Finally, he shows his further progress by considering the relationships among all three glasses regarding the speed of the draining and the water trajectories. Now, by exchanging the top 1Sb to the 1Bb, he makes the large stream go through the middle and then to the bottom so he can see the curving stream from the bottom 1Mms.

T: Sure. (Shows the side-glasses) Here is a big hole on the bottom. Is that what you mean or do you want one even lower than that?

C: I want one with a big one right there. (Points to the bottom.)

T: Oh, big hole on the very bottom? (Gives him a 1Bb.) Like this?

C: (Nods.) Yeah. (Takes the 1Bb from the teacher, replaces the 1Sb in the top hook, and adds water from the pitcher into it. Bends down to fill the pitcher but notices the curving stream from the bottom 1Mms and catches it until it stops [see Figure 4.4]. Fills the pitcher with water from the tub, and pours it into the top 1Bb.)

Figure 4.4. Replacing 1Bb in the top holder to make curving stream from 1Mms
T: (After interacting with L.) What are you doing over, Curtis?

C: (Observing water coming through all three glasses, pours the water from the pitcher to the top 1Bb and bends down quickly to collect water from the bottom glass.)

He seems to be aware of the functions of all of the glasses by moving down quickly to catch water from the bottom 1Mms. A little bit later, the teacher asks him why he wants to have the big hole on the bottom and he reacts “So it would go faster. So it would go out this hole (points to the side hole in the bottom 1Mms) longer.” Obviously, he used the function of the 1Bb to make the curving stream from the bottom 1Mms. In this vignette, he shows how he makes progress by considering the relationships among all three glasses regarding the speed of the draining as well as the water trajectories.

When he experiments on the pegboard, it does not seem to be as easy for him to make relationships as without the pegboard. It seems to be more difficult for him to think about the relationships among three glasses than two and on the pegboard than in his hands. The pegboard allows him to arrange more than three glasses (even though sometimes he caught water using three glasses without pegboard, one was set in water so he could not see the water stream from that) so he needs to think about the relationships not between two but among more than three. Moreover, in a vertical line, he also needed to think about the relationships between the water trajectories and the positions of the holes as well as the relationships between the sizes of the holes and the speed of draining at the same time. In other words, he needed to coordinate between relationships. Thus, even though he showed mastery of the functions in terms of the order of emptying and the water trajectories in the previous sessions, this time he experiences some difficulty in doing that. However, from the observation of his action, he reasons and thinks, and finally progresses.

Later, he puts one more holder in the very top and he tries to put one more glass in there. However, he first chooses the 1Sb glass again and switches to the other and then puts it back into the top, and finally he discards it for a big bottom hole. At this time, the teacher shows him a big-side hole but he here conserves his coordination between two relationships by asking for the big-bottom hole glass. While he pours water in his glasses in a vertical row, the teacher helps him to catch the curving stream on the pegboard by suggesting to him to catch the curving stream. He still has difficulty in arranging the glass to catch the curving stream even though he shows that he coordinates the two different relationships in the above.

C: (Quickly pours three more pitchers of water into the glasses. Adjusts the bottom 1Mms to face its hole to the right side and adds another pitcher of water to the top glass.)

T: I noticed you just turned your cup on the bottom, is there a reason that you did that?

C: So the water would go that way. (Continues to adds water to the glasses.)

T: So the water would go this way over here?

C: (Nods and adds two more pitchers of water to the top glass.)

T: Would you be interested in catching that water?
C: (Pours two more pitchers of water in the top glass.)
   T: If I gave you another thing (finds another hook) could you catch the water that's on
   the bottom? Would you like to?

   Noticing his adjustment of the 1Mms, the teacher takes a chance to suggest he catch
   the curving stream.

C: (Stands up, nods, and takes the hook from the teacher)

T: Where would you put that if you put another one in to catch the bottom one?

C: About here. (Starts to put the hook in the pegboard)

He shows practical mastery of directionality of side hole stream.

   T: Do you think right there?

C: (Nods. Fits the hook in the board and stands up.)

T: OK. What kind of cup do you want in it?

C: Hum.

   T: One with a hole in the side or the bottom?

C: I think this one. (Takes a 1Mls from the teacher.)

   T: You want that one?

C: (Places the glass in the hook that was just hung up. Starts to add water to the glasses
[see Figure 4. 5a])

The teacher prompts him to anticipate before acting on.

C: It's going to go out this hole (in the 1Bb in the second hook) and then this hole (in the
1Mms in the third hook).

   T: And then into that one (the 1Mms in the bottom hook he just put)?

C: (Nods.)

   T: OK. Let's see if...

C: ( Adds water to the glasses.)

   T: Oh, Curtis, you were right.

C: (Adds another pitcher of water to the top and watches the water drain from glass to
glass. Bends down and catches the water draining from the very bottom 1Mms into the
pitcher. Stands up and pours the pitcher of water in the top glass.)

   T: Did it work the way you thought it would, Curtis?
Figure 4. 5. Adding more glasses in the system of draining

T: Now, before you do that can you tell me what's going to happen?

C: (Nods and adds more water to the glasses.)

T: Oh, it sure did. Would you be interested in putting a cup up here? (Points to the top empty hook.)

C: (Nods)

T: What kind of a cup do you want to put there?

C: Is there any more with big holes on the bottom?

T: Are there any more with big holes on the bottom? (Looks for a 1Bb.) Yes, as a matter of fact there are. (Hands the 1Bb to him.)

C: (Takes the glass and puts it in the top hook.)

T: Is that what you want?

C: (Nods.)

T: Why did you want big holes up there?

C: So that it would go fast.
He shows clear evidence of understanding the relation between size of hole and speed of draining.

T: So that it would keep going fast.
C: (Quickly adds water to the top glass several times, observing water coming through quickly [see Figure 4.5b].)
T: Boy, Curtis, you’ve made quite a... What do you have to do to keep it going, Curtis?
C: Keep filling up the bowls.
T: Keep filling up the cups, the bowls.
C: (Nods and continues to add several pitchers of water to the top glass. Adds one more pitcher of water to the glass.)
T: Is there any way to catch that bottom one?
C: (Shakes head and adds two more pitchers of water to the glass) No.
T: You don’t think so?
C: (Shakes head and pours water to the top glass, observing water coming through.)

In this vignette, C. shows that he now considers and simultaneously coordinates both relationships regarding the sizes and the positions of holes in this whole series of draining glasses that actually forms a system.

In the following vignette, the teacher establishes the cooperative atmosphere by inviting C.’s idea to help L. The teacher is trying to help L catch water from the side hole (see Figure 4.6). “Can you make this water (in the IMms) go into here (down side but not close enough to catch it)?” L. pours water in it and sees water does not reach the other glass. However, her observation of the results does not help her to correct herself. Previously during this session, she found that the curving stream went farther when she added more water in the side-hole glass (so her shoes were wet because the hole was facing her). That seems to lead her to false assimilation. As shown in Figure 4.6, the catcher

Figure 4. 6. Lacy’s failure to make curving stream into 1Bb

needs to be moved a little bit closer to the drainer. However, L thinks adding more water will make the water stream reach there so she keeps adding and saying, “It was almost
there. We're going to have to get more.” The teacher decides to invite C. to help L. rather than teaching directly by herself.

T: Do you think it’s going to get there?
L: It was almost there.
T: How can you catch it?
L: We can get more. (Fills the pitcher with water.)
T: We can get more. Curtis?
L: (Puts more water in it and laughs about the water which is missing the glass.)
T: Curtis?
The teacher invites cooperation from C.
C: What?
T: (To Lacy) Can you show Curtis what we were trying to do and see if he can help us? We were trying to get this. . . Can you tell what we were trying to do?
Rather than explaining the problem herself, the teacher asks L. to tell C. so that she can be aware of the problem situation.
L: We're trying to get this water into here. (Puts water into the IMIs to show the curving stream which does not reach to the lower glass.) Like this, like that.
C: I know how you can do it.
T: How can we do it?
C: Move this one (1Bb) closer over here. (Points to the IMIs.)
T: (To L) What do you think?
The teacher protects L’s autonomy by asking if she agrees.
L: (Nods.)
T: He thinks if we moved it over. Do you want to try that? OK. Do you want to take this out? OK. Where should we move it to?
L: (Nods.) Right here.
T: Is that where we should move it to, Curtis? Up here?
C: (Shakes head.)
T: What do you think where we should move it?
L: There (a little bit higher position).
C: Hum, there.
T: Just . . .

C: (Points to the place a little bit lower than where Lacy pointed.) Right there.

T: What do you think, Lacy? Is that OK with you if we move where Curtis says?

The teacher again respectfully asks L's agreement. However, she could have tries it where L suggests.

L: (Nods.)

T: OK. Right there.

C: (Bends down and fills the pitcher with water and pours it in the top glass.)

L: Right there?

T: Yea. That's what Curtis says.

The teacher tries to tell L that the source of the knowledge was not from her, instead, from C. Thus, she attempts to help L. to succeed in draining from the IMls into the IBb in a non-authoritarian manner, that is, with a cooperative attitude.

C: (Adds more water to the glass)

T: OK. Isn't this, is this you want?

L: Uh-hum

T: Should we try it? Thanks for your help, Curtis.

C: (Continues to add several pitchers of water to the top glass at the left of the pegboard.)

L: Right here.

T: You want to try it?

L: ( Watches as the water from the IMls reaches to the IBb) Hey!

She is appreciating the curving stream draining into the other.

T: (Repeats L.) Hey. Curtis, he knows what he is talking about, doesn't he?

Thanks for your help, Curtis.

C: You're welcome.

L: (Still appreciating it) Cool!

T: Cool! Look at that. Ahhh, right. Nifty!

The cooperative intervention from the teacher helps L. to succeed and simultaneously gives C. an opportunity to think about catching the curving stream on the pegboard which is still sometimes a difficult task for him, too. With this intervention, the teacher also establishes the cooperative atmosphere for their experiments.
The following vignette shows shared experiences and negotiation strategies between two children within a cooperative atmosphere established by the teacher in the previous vignette. By C. pouring water in one of L.'s glasses and L. catching water from it, they share their experiences. Then C. moves to his glasses and asks L., "L., do you need some water?" He is negotiating to play together using level 2 negotiation strategy, that is, reciprocal level. When the teacher sees their collaboration, she tries to use it as another chance for them to cooperate by making water draining from two different glasses end up at the same glass. They try once what the teacher suggests but L. moves over to C.'s glasses where she was cooperating with C. before. The teacher does not force them to come back. In other words, she is respecting the children's own agenda and interests. The following vignette shows cooperation between two children.

L: (Pours water in C.'s top 1Bb and bends down to fill the pitcher.)

C: (Bends down to catch water draining from one of L.'s glasses near by his bottom glass.)

C. pours his water into L.'s pitcher and L. laughs.

C: Up high. (Points to his top.)

He asks L. to pour water from her pitcher in the top using level 1 negotiation strategy, that is, unilateral level. Actually, he is saying, "You put water in the top glass; then I will catch it from the bottom glass." He seems to want L. to pour water in the top while he is catching the water from the bottom so that he can see the effect of a group of glasses he put in a relationship.

L: (Stands up to pour water from the pitcher in the top 1Bb.)

C: (Catches the water draining from the bottom 1Mls [see Figure 4. 7].) Do you need some water (when L. empties her pitcher into the top)? (Tries to pour the water from his full pitcher into L.'s.)

L: (Does not realize what he wants and just fills it from the tub, and then pours it in the top.)

T: Looks to me like you are cooperating here, huh? (To C.) She is helping you?

C: (Catches the water from the bottom 1Mls.) She's giving me too much water.

T: She's giving you too much water?

L: (Laughs and continues to add water to the glasses. Takes the 1Mms with water below the hole out of the fourth hook, stands up, and pours water out that makes water splash down to where C. is bending down. Giggles. Puts 1Mms glass back to the holder.) Hey.

C: Hey.

L: (Laughs and pours water in the top glass.) They both continue to pour and catch, often laughing.
They both are sharing experiences sometimes at level 1, giggling, sometimes at level 2, with reciprocity. Later L. starts to catch water from the IMMs in the fourth hook so she stops the flow of water to the bottom glass [see Figure 4.7], joking with C., “You catch it.” This vignette shows that C. and L. use together the functions of the glasses arranged by C. within a cooperative atmosphere. They share the experiences, sometimes joking and using negotiation strategies. In these shared experiences, L. shows her understanding of the functions of all the glasses by stopping water from the fourth glass in order for C. not to get water from the fifth glass. Then, C. shows his level 2 negotiation strategy by asking her to give him water in a persuasive tone.

After having an experience together, L. leaves the water table and the teacher starts to help C. to connect his glasses to L.’s. C. still has difficulty in catching the curving stream on the pegboard. By asking him to rearrange L.’s glasses to catch all of the water with his bottom glass, the teacher tries to encourage him to think more about the curving stream and coordinate all of the draining into one glass.

T: Is there any way to get Lacy’s water to go into your water?

The teacher prompts him to coordinate two systems of draining, his system of draining and L.’s.

C: I don’t know. (Continues pouring water into the top IBb using both pitchers.)
He is aware of fast draining by using both pitchers at once and he seems to focus on only his system of draining. It also seems to be difficult for him to coordinate the two systems. He did it in the previous session but this is a more complex situation.

T: I wonder. Would you be interested in going over there and trying hers and see if you can get hers over into yours? I wonder if you can get hers to fall into any of your cups?

C: (Looks at the glasses which L. was doing.) OK. (Moves over to where L played and takes one of them.)

T: I don't know if you can or not but try pouring water, Curtis, try starting at the top and just pouring some water in it and see where all water goes...

The teacher suggests to him to pour water in L.'s top glass in the hook on the very right side of the pegboard so that he can observe what happens to he water, that is, where the water goes.

C: OK. (Puts the glass back in the holder, fills the pitcher with water and pours it in L.'s top glass to the far right of the pegboard.)

T: And then see if any of it comes into yours and see if you can figure it out to get any of it into yours.

C: (Watches the water drain through the glasses. Fills the pitcher again and pours the water in L.'s top glass [see Figure 4.8a].)

T: I wonder if there is a way to get hers to end up in your bottom cup.

C: (Shakes his head and observes the glasses.) I could . . .

It seems to be hard for him to think about putting one more relationship into a whole system of relationships.

T: Could you rearrange any of it so you can move it so like just bottom one ends up going into that bottom one, into your cup?

C: I don't know.

T: Could you move things around a little bit?

C: (Takes 1Mls-1 out of the hook and then takes that hook out of the pegboard.)

T: (Helps him to take the hook out.) OK, where would you put that one?

C: (Starts to put the hook into the place above and to the right side of his bottom 1Mls.)

He starts to put one into relationship with his bottom glass, using his previous knowledge about the functions he discovered, that is, the water trajectories = f (the positions of the) holes.
Figure 4. 8. Coordinating all water into his bottom glass by rearranging Lacy's glasses

T: (Helps him to put the hook in the pegboard) Then what?
C: (Gets the 1Mls-1 from the tub.) Then we need this. (Puts it into the hook, pours water in it, and watches the water drain. It does not reach his bottom glass.)
(Interrupted by one person)

T: (Turns back to C.) OK, where could you catch this (1Mls) so you make it go into there (C.'s bottom glass)?

C: I don't know.

It shows his difficulty in putting a glass on the pegboard due to the distance and the angle he needs to think about.

T: Hum. Did this one (1Mls) go into your bottom cup?

C: (Shakes his head.)

T: How could you fix it?

C: Put this one higher.

Now, he shows correct anticipation about the spatial relationships by his observation of the result.

T: Do you think higher? Do you want me to help you with that? (Helps him to take the hook out of the pegboard.) Where do you want to put it?

C: (Tries to put it in higher part.)

T: Right there? (Helps him to put it in.) There, is it gonna work? Try.

C: (Puts the 1Mls-1 into the hook and adjusts the hole. Pours water into the glass and adjusts the stream of water so that it flows into his bottom 1Mls.)

T: Wow, alright, that one worked! Now what? What could we get the...

C: Take this one (1Mb-2) and put it right here. (Indicates the spot right above the 1Mls-1' [see Figure 4. 8b])

T: (Helps him to move it) So that one put right here. Where?

C: Right here.

Now, he makes correct anticipation, that indicates construction of spatial relationships, from the previous experience.

T: Right there? OK. (Arranges the hook and glass for him)

C (Pours water into the 1Mb-2' and watches water go through the 1Mls-1' and the very bottom 1Mls.)

T: Oh, that works. Now what?

C: (Takes the 1Mhs-3 with water below the side hole out of the hook and looks for the hole in it.) Is there a hole in this one?
T: Yea, right there. (Shows the high-side hole to Curtis) We could get a different one if you don’t like that one.

C: (Takes the 1Mls-4 from the hook and looks at the hole.)

T: You like that one better?

C: Yea.

Rejecting the 1Mhs and choosing the 1Mls suggests that he has constructed the functions involving the order of emptying according to the heights of the side holes.

T: Where do you want to put . . .

C: Put this here. (Points to the place above and to the right of 1Mb-2").

T: Right there? (helps him to get the hook) Where do you want that one?

C: Here

He indicates a little bit too far to the right side.

T: Here?

C: Yeah

T: (Pushes the hook into the pegboard) What’s gonna happen with that one?

C: Goes into here (1Mb-2").

T: OK.

C: (Pours water into the glass but the water goes in a different direction and then he turns the glass. However the water goes to the 1Mls-1' instead of 1Mb-2'.) It goes down there (1Mls-1').

He anticipates it would drain into the 1Mb-2' however, it does not. At first, he was not aware of the direction of the hole. He adjusts the hole but it goes to the different glass because it was put a little bit too far to the right side. Here, he again shows some difficulty in making a spatial relationship.

T: Yea, it does go in there.

C (Keeps pouring water into the glass he just put in to see where water goes.

T: So, is there a way we could change that so that it would go in here (1Mb-2')?

C: I think we can put that higher.

T: Do you think we can put that higher? OK. Where?

C: Right there. (Shows where to put the hook.)

He makes correct anticipation, this time.
(The hook does not go in that part of the pegboard, so she suggests to put it one row higher and he agrees. She put it into the pegboard to help him.)

T: You want to try that?

C: (Pours water into the 1Mls-4, adjusting the direction of the hole so that it drains into the 1Mb-2'.)

T: Hum. That works. Now where does it go?

C: Here and here. (Points to the 1Mls-1' and the bottom 1Mls.)

T: Ok. Now, anything else?

C: (Shrugs.)

T: You want to use this one up here? This one is a top one. (Points to the 1Mls-5.)

C: (Picks up one more pitcher and fills the both pitchers.) I will (U) (Pours water into both of the top 1Bb and 1Mls-4' at the same time, looking at the very bottom 1Mls where the water ends up [see Figure 4.9].)

![Figure 4.9. Making water from the both systems end up in the bottom 1Mms](image)

Figure 4.9. Making water from the both systems end up in the bottom 1Mms

Now, he coordinates seven glasses so they drain into one. He pours water to see what he expected, in other words, he pours water in both top ones using two pitchers at the same time in order to make water from the both systems end up in the bottom 1Mms.
T: (Back to Curtis's interest) Uh huh, nifty. Look at you. Wow, Curtis! Oh right.
C: (Continues to pour water into both of the top ones again and watches the left glasses empty first as the right glasses are still draining. Adds water to the left top IBb with both pitchers. Alternates to watch the water in both lines and pours the water from both pitchers into the right top 1Mls-4 which is now empty. Fills up the pitchers and pours water in the top and the third glasses of the left line at the same time.)
T: I can pour one while you're pouring one. Would you like me to do that?
C: (Nods)
T: OK. Which one? How about if you stand over there. (Points to the left end of the pegboard) And I could try from here (at the right) and then we could get it on the camera and look at it later. You want to tell me when to go?
C: Go.
T: Go. Is that all going into the same bottom cup?
C: (Points to the bottom glass.)
T: Oh huh. Nifty. Can we do it one more time? You want to tell me when to go?
C: (Watching the teacher's top ones still draining, waits for all the water to drain from it.)
T: Ready? Oh, (He already starts) go. Ok. Is it going? Is it gonna end up in the same cup?
Here, the teacher could have mentioned, "Whose glasses are going to empty first?" "I wonder why my glass are emptying slowly." Since he already knows that all water will end up in the same glass, she could have prompted him to compare the functions of the different sizes of the holes.
C: Uh-huh. (they watch the water drain into the same cup)
They continue to pour water into the glasses and watch the water drain from both sides in the same glass for awhile.
T: You know I notice that I don't have to fill mine as often as you have to fill yours. Have you noticed that? Did you notice that? How come do you suppose that is?
Now, the teacher is trying to make him notice the differences in the two systems due to the hole sizes.
C: (Adds more water to the left top glass as the teacher adds it to the right top glass and watches it drain.)

T: (Interrupted by somebody and then comes back to C.) Did you notice C., you have to fill yours more often than I have to fill mine?

C: Yea.

T: I wonder why that is? Do you have any idea?

C: No. (He just fills his pitcher.)

It is not as simple a task as comparing just two glasses, for example, a 1Bb and a 1Mb. This is a situation in which he must compare the two groups of glasses with several relationships. In these two systems, he needs to think about the complex relationships such as the number of glasses, the water trajectories, and the sizes of the holes. At this time, he does not seem to be able to consider all relationships at the same time. He may not know the holes are smaller in the right system.

T: Hum. Hum. I wonder if we looked at it if we could figure it out. Do you think we can figure it out? Is there any thing different about mine and yours? That you can think of that would make mine, that I wouldn’t have to fill mine as often as yours?

C: (Shrugs and shakes his head)

T: If you looked at it?

C: (Looks at the glasses on the pegboard.)

T: I think part of it might be that this top cup stays full longer.

C: (Looks at the teacher’s top 1Mls.)

T: Let’s look at, try it and see. I think maybe my top cup stays full longer.

C: (Gets ready to pour water in his top.) One two three.

He seems to be interested in only making water run through the glasses. It seems to be too difficult a problem or he might be too worn out to reason and to think because he has stayed for over an hour by now.

T: OK. (both pour the water into the glasses) Is my top cup staying full longer?

C: Yea.

He observes the phenomenon but he does not seem to want to think about it.

T: Hum. I wonder why.

The teacher tries to prompt him to think about it for a little more but the does not. In this vignette, C. shows progress in coordinating all water draining from the two
systems of glasses at the practical level. In other words, he constructs the water trajectories in the two systems of glasses. However, he does not coordinate the order of emptying in them. It seems to be too difficult a task for him to think about.

Session 5: Water Movement in tubes I

In this session, the activity moves to the water movement in tubes due to decreasing interest in the activities on draining. Curtis and Andrew are at the water table. The materials being used at the beginning of the activity are a reservoir attached to a valve, a piece of tube, and a pitcher (see Figure 5.1). Curtis pours water in the reservoir and lets it go through the tube that is inserted into the reservoir. He turns the valve on and off to make water flow. Sometimes he catches water from the tube in his pitcher. The teacher lets him play with these new materials for awhile so that he can be familiar with using this apparatus. After awhile, the teacher comes over and shows more tubes and asks him, “Are you interested in hooking on more tubes?” By this intervention, the teacher tries to expand C.’s activity to the water movement in tubes. However, he does not seem to be ready to use more tubes and seems to be interested in just pouring and catching water. For him, it seems to be an extension of draining from glasses with holes. The teacher just withdraws her suggestion, respecting his interest. The teacher lets him play with the reservoir for a little longer and comes back.

T: (Shows the holders for the tubes) You know that we got these things that you can hook in here. (Places a hook in the top of the board) Did you see that C.?

The teacher tries to expand his action once again.

C: (Pours more water in the reservoir and turns to look at the hook.)

T: You can make the hose go down in it if you want to.

C: (Takes the free end of tube from A. and looks at the hook and the tube.) Make it (U). (Points to just below the hook)

He seems to think that the tube is too short to be put through the hook but he does not ask for more tubing.

T: You want it to go through there? (Replaces the hook a little bit lower.)

This time, the teacher could have asked why he wants to put it lower or she could have suggested that he use more tubes.

C: (Nods and adds several more pitchers of water to the reservoir.)

Teacher leaves the water table.

. . . .

The teacher is still busy with the other activities and C. is pouring water in the reservoir and letting it go through the tube. Now, C. is playing alone without A. I come over and put two hooks up on the right side of the pegboard and place a glass in each hook to prompt C. to think about using more tubes.
C: (Watches the glasses being placed in the holders, pours water into the reservoir, holds up the free end of the tube that is attached to the reservoir, and asks me to make the tube longer.) Could you make this longer?

Finally, his interest moves to using more tubes to make the water go through the tubes into the glass.

T: (Comes back to him) C., now sometimes if you hook these together you can make it go other places. Would you be interested in that?

The teacher did not hear what he asked and tries again to make him aware that more tubes are available to use.

C: (Nods and adds water to the reservoir.)

T: (Gives him a piece of tube attached to a connector.)

C: (Connects one into the other and hooks the tubes in the small hook near the top of the board placed by the teacher previously.)

T: If you want to make it longer than that, there are other hoses over there.

C: I am going to put like this, to make the trickle go in here. (Points to the glass placed by me.)

T: Oh, are you going to make it go into that glass? Is that what you're doing?

C: (Nods.)

T: That will be interesting. Think it will go?

C: (Nods and turns the water on. Watches the water flow into the glass [Figure 5.1].)

Figure 5.1. Making water flow from reservoir into glass

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
T: Wow, look at you, C.

C: (Watches as the water fills the glass and adjusts the flow into the glass. Pours water in the reservoir, seeing the water level in it is going down. Turns the water off and catches the water from the 1Mls glass in the pitcher.)

T: I wonder why the tube isn’t getting empty.

C: (Continues to collect water from the 1Mls glass and add it to the reservoir. Fills the pitcher with water and adds it to the reservoir.)

T: Did you notice that the water stopped in here? (Points to the tube.)

C: (Nods and adjusts the tube.)

T: I wonder why it stopped going out of the tube?

C: Cause I made it stop here.

T: Oh, you made it stop over there?

C: (Nods and turns the water on so that it trickles out.)

T: Look, now it’s coming.

C: (Turns the water on faster and looks at the tube.) Uh, now it’s going.

T: Oh, now it’s going.

C: (Pours water in the reservoir and watches the water flow into the tube. Tries to adjust the tube so that the water drains into the glass from the tube.)

T: C., we have more of these. (Picks up a hook)

C: OK. (Takes a hook from the teacher and hooks it to the pegboard to attach the free end of the tube so that it points to the glass.)

The teacher leaves the water table after helping him to hook it. C. fills the reservoir with water and turns water on to let it go into the glass for awhile. The glass and the tubes are placed lower than the reservoir so he always gets water in it, so I (R) try to give a situation in which he can confront a contradiction.

R: (Places another hook and glass near the top center of the board.) Can you make water go in here? (Points to the new glass in the top center, shown in Figure 5.2.)

By this intervention, I try to give him a situation in which he can feel contradiction when he confronts the phenomenon that the water does not come out of the tube even though he fills the reservoir.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Figure 5. 2. The situation that gave Curtis contradiction

C: (Removes the tube from the hook and attaches it to the higher place in the pegboard so the tube will stay over the glass.)

R: (Helps him to replace the free end of the tube in the pegboard but the tube does not stay very well.)

C: (Turns the water on and watches a little water flow from the tube into the glass and then stop [see Figure 5. 2]. Alternates to look at the end of the tube and the valve when the water stops. Looks at the water in the reservoir which is full and tries to turn the valve on perfectly, looking at the end of the tube. Goes over to the end of the tube and bends it downward so that the water starts to flow into the glass and holds it there for several seconds. Lets go of the tube and moves back to the reservoir, seeing water come out of the tube. However, the end goes back up and the water stops again. Tries to adjust the reservoir and the valve, looking at the end of the tube. Goes back over and holds the end of the tube down and the water starts to flow again.)

Here, he shows that he feels contradiction when water stops by checking to see if the valve is on and looking at the water inside the reservoir.

R: Maybe you can make it longer. (Finds some more tube and tries to help him to extend the tube.)

At that time, I do not see that he has a contradiction because I was finding a way to fix the unstable end of the tube. I thought that making the tube longer might solve the problem. I should have asked him, “What happened to the water? I wonder why it stops.”

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
C: OK.

By my intervention, he has a contradiction, here, between his expectation of water coming out of the end of the tube and the result of the action. However, he might have thought that the problem was in the end of the tube because he could not attach it in the pegboard well.

The teacher just comes back and helps him to extend the tube. C. shows interesting reaction with the extended tube. He wants to put the free end of the tube into the reservoir, expecting the water to recycle. Previous experience shown in Figure 5. 2 might make him further experiment to see what will happen in this situation.

T: (Comes back to him.) Are you having trouble getting this through? (Takes the tube and attaches a connector to it.) Did you decide you wanted to make it longer, is that it? Sorry, I was busy.)

C: (Nods.)

T: What do you want on it? Do you want that on it? (Gives him a piece of tube.)

C: (Nods. Tries to attach the other tube to the one already there.)

T: (Helps him to attach.)

C: (Looks at the end of the tube.) Could we try the other side after you hook them?

T: What? Are you going to try the other side?

C: (Nods)

T: What other side are you going to try?

C: (Takes the tube and puts the end of it in the reservoir.) . . . in there.

It is interesting that he wants to try to put the end of the tube in the reservoir. Perhaps the previous contradiction makes him want to try it. He experienced previously that the water did not come out of the end of the tube when it was high as shown in Figure 5. 2. That might create challenge in the different situation to see ‘What will happen when I hold the end of the tube over the reservoir up high?’ In other words, that might make him erase his own question by himself.

T: Oh, you are going to try and put it in there?

C: (Nods)

T: That will be interesting. What do you think will happen?

The teacher makes him to anticipate before he experiments.

C: It will go back in there. (Points to the reservoir.)

He predicts that water will go up in this situation, that is, without pressure.
Figure 5.3. Experiencing contradiction by trying to recycle water and then watching water come out when he put the end of tube down lower.

T: Oh, it will go back in there? Can you show me with your finger how it will go back in there?
C: (Uses his finger to demonstrate what he means) It will go in like that and like that.

T: OK, let's watch it.

C: (Turns water on and watches, nothing happens [Figure 5.3a]. Touches the valve to check if it is on and looks at the end of the tube in the reservoir.)

He obviously feels a contradiction, here. Probably, his previous experience with the water from the faucet makes him feel conflict. He experienced that water just came out from the faucet when he turned it on, no matter where the hose was located.

T: Did you turn it on?

C: Uh-huh. (Nods. Still holding the free end of the tube in the reservoir and watches the water level in the tube, pushes the tube down as shown in Figure 5.3b. Continues to push it down as far as he can, seeing water move up. However, the water level in the tube is always the same as the water level in the reservoir. He checks the valve again and finally takes the end of the tube out of the reservoir, and then bends it downward so that the water comes out. Attaches the end of the tube to the pegboard using the hook [Figure 5.3c].)

From his thinking, the water should come up through the tube so he tries to make it by checking the valve and pushing the tube down in order to make water come up. Finally, he makes water come out by putting it downward that was accidental success. However, his contradiction seems to still remain in his mind. In this vignette, he asks his own question and tests his hypothesis.

The teacher leaves him in response to another and comes back and tries to know what was his thinking in the previous situation by demonstrating what he did. Thus, the teacher engages in the problem as a companion who shares his objectives. C. still expects water to come out of the end of the tube into the reservoir. Here, he seems to conclude that it is easier for the water to come down than to go up high.

C: (Turns off the valve and pours water in the reservoir then turns it on. Repeats this for awhile.)

T: (Comes back to the water table while C. is watching water drain.) Now, I wanted to ask you a question, C. Everyone has been asking for me. Now, I wanted to ask, I see it going now, is that right?

C: (Nods and watches water still come out of the tube.)

T: But when you had it going in here (points to the reservoir), it didn't go, is that right? Could I try it?

C: (Nods)
T: (Takes the tube and puts the end over the reservoir and the water stops.) Hum, I see. (Puts the tube back down and all of the water drains from the reservoir and tube) Could we fill it up and try it again?

When the teacher holds the end of the tube over the reservoir, the reservoir was almost empty so she thinks that might affect C.'s thought so she asks him to try it again after filling it up.

C: (Nods and hooks the end of the tube on the pegboard as shown in Figure 5.3c.)

T: With it filled up? Would that be OK?

C: (Nods)

T: (Shuts off the water) I'll turn it off and help you fill it up, would that be all right? (Adjusts the tube)

C: It doesn't matter if it is on or off.

T: It doesn't matter if it's on or off? Which do you want, on or off?

C: On.

T: On. (Turns the water back on) OK, it's on. Do you want me to help you fill it?

C: Hum, yea.

T: If we fill it, will water go through it now, do you think? (Fills the reservoir with water.)

C: (Nods and adds water to the reservoir. Watches water come out of the end of the tube that was put downward.) It's going.

T: It's going? OK, now, can I see if it will go in here? (Points to the reservoir. Removes the tube from the hook and puts it over the reservoir and the water stops.)

C: (Looks at the end of the tube in the reservoir and the water moving back to the same level as that in the reservoir.)

He still looks at the end of the tube in the reservoir as if he is expecting water to come out this time. He might have thought that more water would make it go up. However, he does not look at the water level in the reservoir and focuses only on the water inside the tube. He does not think of the water level in the tube in relation to the water level of the reservoir yet. His pre-operational cognitive structure does not let him think about this relation.

T: Huh? (Lowers the tube and the water flows.) Well, that's interesting. You put it through there (places the tube on the hook) and it flows.
C: (Observes water coming out of the tube now.) I know what, because that shorter and that higher.

T: (Holds it back over the reservoir and water stops.) What did you say? (Puts it back downward.)

C: When it’s this way, it’s shorter (points to the tube bent downward) but when it’s the other way, it’s higher (when it is held over the reservoir) and so it’s hard for the water to get up high.

He does not use the word, lower, instead, uses ‘shorter.’ Perceptually, when the tube is bent down, it seems to look shorter than the tube unfolded. This may suggest that he does not have conservation of length. He might think the water needs to travel longer in the tube unfolded. However, he also uses the word, “higher” so he uses two different dimensions, the length and the height. Nevertheless, now, he seems to think that it is hard for water to go up “higher.” He corrects his own theory that water will go up, from the observation of his action. It is progress in his reasoning.

T: Oh, because this is shorter and this is higher, it’s harder for the water to get up in here.

If the teacher asked him, “Do you think it is shorter than the other way?” and “Do you think the water travels longer in the other way?” she could have known more detail about what he thinks.

C: (Nods.)

T: Oh, that’s interesting. Look at there. (Touches the tube.) Because it is going now, isn’t it?

C: (Nods and fills up the pitcher with water.)

In this vignette, he shows a little progress. When he put the end of the tube into the reservoir, he thought that water would go up but from the observation of the result of his action, he now thinks it is easier for water to go downward.

After that, he extends the tube with another piece and that allows him to make a more complex arrangement. This causes an air problem in the tube that the teacher and I did not anticipate [Figure 5. 4a]. When the air pockets are built in the tube, the water flows part way in it and drips from the end of the tube. He touches the valve to check if it is on and adjust and places the end of the tube lower on the board and watches the water flow from the tube into the glass [Figure 5. 4b]. From now on, he often gets the air problem in the tube which could hardly be understood by means of pre-operational reasoning. The air problem makes it difficult for him to construct the knowledge about the water level because even though the tubes are lower than the water level in the reservoir, the water just trickles from the end of the tube. That seems to reinforce his false assimilation that since it is easy for the water to go down, the tube needs to be put in the low position, instead of lower than...
the water level in the reservoir. Thus, whenever he gets the air problem back, he just put the tube lower than where it was and adds more water in the reservoir.

T: Curtis, is there any way you can get the water into this glass (in the top of the pegboard as shown in Figure 5.2), do you think?

C: (Looks at the tubes, and glass for several seconds and shakes his head)

T: Why not?

C: (Shrugs.) I don’t know. Just don’t.

He is showing his practical knowledge. He knows the water will not come out of the tube in that height from the previous experience but does not know why.

T: You don’t think it will go into here? (Points to the glass at the top of the board)

C: (Shakes head.) Uh-huh.

T: Could I try? Do you care if I try? Could I just try and see what happens if I put it in here? (Points to top glass)

C: OK.

T: (Takes the end of the tube and holds it over the glass and the water stops flowing) You’re right, it won’t go in there. Do you have any idea why?

C: Because that’s too high.
He describes the situation but does not show conceptual understanding about the water level.

T: Because that’s too high. I need to put it back to here, don’t I? Because it’s too high. If I lower this, do you think it will go in this cup (lower glass)?

C: I don’t know.

In the previous experience, even though he put the tube lower, he could not get water from the tube because of the air problem. It seems to affect his thought. However, he is sure the water does not go up high, even though he does not consider ‘higher than what.’

T: (Leaves him.)

C: ( Watches as the water drains from the end of the tube into the reservoir. Turns the water off and picks up another piece of tube. Attaches it to the tube already hanging from the board and hooks it in a very low position of the pegboard. Turns the water on and watches the water flow from the reservoir to the tube. Adds water to the reservoir.)

T: ( Comes back to the water table and watches round tubes he arranged and water come out of the end of it.) What did you make, C.? Oh, I see you made it go all of the way around.

C: ( Nods)

The teacher and Curtis watch the water go through the tube for awhile.

C: ( Turns the water off and adds water in the reservoir. Watches the air pockets established in parts of the tube when he turned water off. He turns water on and watches water drain slowly while the air pockets are being pushed out and then water come out fast.)

Teacher leaves the water table and Curtis is alone again.

C: ( Adds water to the reservoir and turns water on and watches the reservoir get empty. Puts his finger on the top of reservoir and moves it gradually down following the way the water was moving down. Watches the small amount of water left in the reservoir as it drains quickly from the reservoir and the water and the air pockets stay in the tube.)

He shows his consciousness of phenomenon of decreasing water level by following it with his finger.
C: (Adds water in the reservoir and watches water come out very slowly and the air pockets move out then water comes out faster. Gets one more piece of the tube to connect it to the tubes already there.)

He seems to like being challenged by another situation. Now, he has no problem making the water go through the tube he arranged, so he wants to change the feature of the tubes to see what will happen with the new situation.

T: (Comes back to the water table.) Curtis, Curtis.

C: What?

T: Can we make the tube up this high (holds hand near the top of the board) and see what happens? Would it be OK if we lifted this (points to the first hunched part of the tube he arranged) up to about here (points to top of the board) and see what happens?

The teacher tries to give him a situation in which he cannot make water go through the tube so that he can think about the water levels in both the reservoir and the tube. However, in this situation, it does not help him at all because of air problem.

C: (Nods and starts to move it up to the place where the teacher suggested it be.)

T: (Helps him to attach the tube higher on the board) Let’s put it right here. OK?

C: (Nods)

T: All right. There you go.

C: I’ll put this into here. (Bends down to hook another piece of the tube to the ones already there.)

T: What? Put that one on?

C: (Hooks it onto the end of the tube and lets it down the tube [Figure 5.5].)

T: Oooh, are you going to have it go clear down there?

C: (Nods and starts to turn on the small amount of water which is small left in the reservoir.)

T: Before we start could we fill the water clear up, could I help you fill it with water?

C: (Nods and adds water to the reservoir with the teacher.) It’s higher enough.

T: It’s higher enough? OK.

C: (Turns the water on. Watches water move slowly because of the air pockets.)
T: Is it on? Is it coming out?
C: (Checks the reservoir and the water is on. Looks at the end of the tube.)
T: Is it on?
C: Yes. (Checks the reservoir again.)
T: (Adjusts the tube.)
C: (Watches the water gradually move out.) It’s coming out again.
T: Is it coming out again?
C: (Nods. Puts the pitcher in the reservoir and pushes on it.)

C.’s action of pushing down on the water leads to the assumption that he has a primitive idea of pressure (pressure makes water go faster). In this new situation, C. challenges himself and acts to solve his problem.

T: Why did you put the pitcher in there?
C: Trying to make it go faster.
T: Oh, you were trying to push it down and make it go faster?
C: (Nods.)

Another child comes over to the water table.
Co: (Comes over the water table.) How does the water go up? (Draws the line up following the first circle of the tube (see the arrow 1 in Figure 5.5) which is full of water.)

T: He wants to know how does the water go up?

C: It comes down through there (see the arrow 2 in Figure 5.5) and tries to go up.

It is interesting that he uses the words, 'tries to go up.' He seems to think that if the tube is put too high, it cannot go up even though it tries to.

T: You mean it tries to go up?

C: (Nods.)

T: Why do you think it’s not going faster?

The teacher could have asked, “How high can it go up?”

C: Cause it won’t go through there. (points to the first bend in the tube)

T: Cause it won’t go through there?

C: (Nods)

All three look at the apparatus for a few seconds. In this vignette, C. shows again his undifferentiated thought about the water level. He does not know yet that the water can go up in the tube only until it is the same level as in the reservoir. However, he progresses in his reasoning of water movement, that is, it is hard for water to go up high.

Session 6: Water Movement in Tubes II

The equipment being used are a reservoir with no tube attached, a backwards J-shaped tube, and a funnel that is in the top end of the tube (see Figure 6.1). Curtis spends the whole morning activity time with this activity and comes back with Nathan at afternoon activity time. The teacher and I learned this morning that the more complex the feature of the tube is, the more air pockets the tube gets. Thus, this time we gave him a simple J-shaped tube hooked in the pegboard, expecting that he will experiment with it so that he can become aware of the water levels of both side of the tube.
However, N. starts with this tube and extends it with several more tubes. attaches some more pieces of the tubes to the short end of the J-shaped tube before C. experiments with that and C. just pours water in the reservoir and lets it go and sometimes catches it in the pitcher. C. wants to put tube into the reservoir soon. “Could you give me some hoses? I don’t have mine. The teacher attaches one piece of the tube to the reservoir for C. and leaves him to find some more tubes.

C. starts to negotiate with N. to play together, perhaps to hook his tube to N.’s. They are very close friends and both are the all-day children in this classroom. By hooking together, C. hypothesizes that the water from the reservoir will come out of the funnel that is in the top end of the tube. When the result does not match his expectation, he says, “I got an idea” and puts the free end of the tube downward so that water come out of it. Their collaborations give them a context to think about the water movement in the tube together. Following vignette shows that happening.

C: (Fills up the pitcher and then pours the water back in the tub.) N., N., need some water? Get water from here. (Holds up the end of the tube for N. to get water from it.)
He tries to cooperate with N., for later negotiation.
N: (Does not react to him. Goes to get a pitcher and fills it from the tub.)
C: N., don’t get it from down, put that down, OK? (Helps N. dump the water back into the tub.) Get the water from here. Come on. (Grabs the end of the tube for N. to catch water in his pitcher.)
He is asserting his own idea but checking N’s agreement at level 2 negotiation strategies and physically forcing him to do what he wants at level 0 negotiation strategies.
N: (Picks up the pitcher and puts it near the end of the tube C. is holding)
Now, he is responding to C.
C: (Aims the end of the tube in N.’s pitcher and turns the water valve on. The water flows into N.’s pitcher.)
N: (Continues to catch water from the tube hooked to the reservoir.)
C: ( Watches N.’s pitcher fill with water and shuts the valve off when the pitcher is full.)
You can pour it down in yours. (Points to the funnel that is in the top end of the tube.)
N: (Pours some of the water in the funnel and watches the water go through some of the tube and stop before it gets to the end.)
C: N., (U) N. Can we take this out? (Tries to take the funnel out of the top end of the tube.)
Now, he negotiates more directly to connect his tube to N.’s by asking permission from N. at level 2 negotiation strategies.
N: Yea.
C: Hu . . . We don’t have to.

He seemed to want to connect his tube to the top end of N.’s tube, at first, but changes his mind.

N: (Starts to add water to the funnel but stops. Readjusts the tubes)

C: N., N., let me put this one (takes a hold of the end of N.’s tube) on mine. OK? (tries to hook his tube to N.’s tube.) . . . try to hook it on. And it will come out, my water, then it will go in here (touches the funnel) and come out (touches the pegboard down below of the funnel) (see Figure 6. 2).

![Diagram of tube arrangement](image)

**Figure 6.2. Attaching his tube to Nathan’s to see water come out of funnel**

He is checking N.’s agreement and also explaining the reason for his demands at level 2 negotiation strategies. In this cooperative context, he shows his hypothesis before pouring water in the tube.

C. attaches the tubes together and N. smiles, watching C.’s actions.

T: (Comes back with more tubes.) Are you trying to hook together here?

C: Yea. It will come out. . . . It will go (touches the reservoir) then here (points to the tubes) then come out from there (points the the funnel).

He expects that the water will come out the funnel. Actually, if there is no air problem, the water will come out in this arrangement when he adds more water in the reservoir. However, there is no evidence that he considers the water level in the reservoir.

T: It will go in there and come out from there?

C: (Nods.)

T: OK, I’d like to see that happen.
C: (To N.) Let's turn it on, OK? (Turns the water valve on and the water does not move right away. Fills the pitcher with water to add it to the reservoir.)

As soon as he observes that the water does not move, he tries to add more water in the reservoir. He seems to think that adding more water will make it come out.

T: Can I watch?

C: Yea. (Adds water to the reservoir. Watches to see if the water moves through the tube.)

T: Is it turned it on? Did you guys connect together?

The teacher makes sure if the water is on and the tubes are connected.

C: Uh-huh. (Continues to add water to the reservoir.)

T: It's not coming out? Ah, it's coming.

C: A little.

T: It's coming out a little. Is it open or shut?

C: (Watches the water slowly move up the tube. Pushes the water down in the reservoir using the bottom of the pitcher and the water overspills from it.)

He again presses the water to make it go through fast.

T: Are you trying to press it down again?

C: (Nods.) Hm. (Adjusts the valve.)

T: OK. Well, that's interesting.

C: It won't come out here (points to the funnel).

T: It won't come out here.

All three watch the reservoir, water, and tube, trying to figure out why the water is just sitting in the tube.

C: I got an idea.

T: What's your idea?

C: (Sets the pitcher down in the reservoir.) Take this out. (Tries to take the end of the tube out of the hook.)

T: OK. We can do this. (Helps him to remove the hook.)

C: (Tips the funnel upside down and lets the water drain from it.) And put it like that. ( Places the funnel and tube down lower on the pegboard [see Figure 6.3].)
T: Oh, is it coming now?
C: Yeah. I'll put that right here.
T: Where do you want it?
C: Right here.
T: Right there?
C: Yea.
T: Is it coming, now?
C: Yea. (Bends down and fills the pitcher from the reservoir and adds it to the pitcher.)
Hey, Nathan, let's fill this up. (Continues to fill up the reservoir with N., watching the water flow from the reservoir out the tubes and funnel.)
T: C., can you explain your idea to me? What were you thinking when you decide to change the funnel?
C: I don't know.
T: Why did you decide to put that way, instead of up here? (Points to where he has moved the funnel.) It was right here, why did you put it down there?
C: Then the water would go down easier. (Points to the place where the funnel is now.)
He goes back to his previous idea that water flows down easier. C. is exercising his practical intelligence.
T: Why would the water go down easier, do you think?
C: Cause it would go, starts from here (points to the reservoir) and it would go up there and go like that and that and that. (Points to the different pieces of tube the water flows through as shown in Figure 6. 3.)

T: And then go down?

C: Uh-huh. (Nods. Fills the pitcher with water and adds it to the reservoir.)

T: OK. And when it was up, How about when it was up?

C: (Continues to add several pitchers of water to the reservoir) Hm, I thought it would come out like that but . . .

T: But it . . . what? I'm sorry I interrupted you. You thought it would come out like that? (Points to the water flowing from the reservoir.)

C: (Nods)

T: But it didn't? Is that what you mean?

C: (Nods. Continues to add water to the reservoir.)

T: Why do you think it didn't?

C: (Shrugs.) I don't know. (Continues to add water to the reservoir.)

T: You are not sure?

C: I am not sure. (Bends down and picks up a funnel from the tub.)

T: I think you must have thought of some reason because you changed it. What was the reason that you changed it?

The teacher seems to press him too long here.

C: I don't know. (Puts the funnel in the reservoir.)

In this vignette, he seems to confirm his own logic, that is, water go down easier than up. Again, the air pockets interrupt his reasoning. However, he shows his primitive beginnings of idea of pressure by pushing down the water in the reservoir when he gets air pockets in the tubes.

Session 7: Water Movement in Tubes III

Attached to the reservoir are some tubes that have been hooked to the pegboard by Curtis and Nathan [Figure 7. 1]. In this session, Curtis continues to have the air problem. From the observation of the results, C. has confidence how to handle this problem. He lowers the tube whenever he gets the air problem. However, in this session, he once again shows his erroneous idea by putting the free end of the tube into the reservoir. When they turn the spigot on, water goes slowly and bubbles are built in the tube.
N: C., we need more hose.

He seems to think if they attach more tubing, the problem will be solved.

C: That's because you made it go wrong. (Takes the upper circle of hose and moves it lower on the pegboard.)

However, C. knows how to solve the problem by lowering the higher part of the tube.

N: Hey, C., (U). (Tries to hook more pieces of the tube.)

C: Let's hook it there. (Continues to change the tube around.) Just need to make one more.

He seems to know that extending the tube makes a problem so he wants to attach just one more piece. He continues to lower the tubes on the pegboard and holds the free end of the tube that is sitting in the tub.

In the following example, he again puts the end of the tube in the reservoir. After making water flow, he holds the end of the tube up as high as where the reservoir is. When he still sees water come out, he puts it into the reservoir. Since he does not construct the knowledge about the water level and thinks simply that it is hard for the water to come up high, he seems to think that he might also get water over the reservoir because he gets water in a pretty high position.

C: Turn it on.

N: (Turns on the water.) Now it's working.

C: (Holds the free end of the tube and watches it drain into the tub for several seconds and then puts it in the reservoir.)

He seems to still think that water may come up and out the end of the tube when he holds it in the reservoir.
N: (Helps C. to hold the tube over the reservoir.)
Both boys watch water stop flowing out of the tube into the reservoir.
N: Hum.
C: (Takes the tube out of the reservoir soon and puts it down lower. Watches it start to
drain again.) Needs to be hung lower on the wall.

However, he does not show the same behaviors as he did in session 5, such as checking
the valve on and pushing down the tube to make water to come up. As if he expected that
water might not come out, he just takes it out of the reservoir and puts it downward.
From the observation of the result of his action, he seems to conclude the
tube needs to be put lower and puts the free end lower than the reservoir.
However, he does not say 'lower than what.' Thus he succeeds in doing that at proactical
level.

In the pre-operational stage, it is a hard task for him to think about For the
knowledge about water level, the air problem is an obstacle to his reasoning. From the
three sessions involving the water movement in tubes, the teacher and the researcher think
the simple shape of the tube without the reservoir will help the child to think about the
water level better. This activity should have been before the activities of the water
movement in tubes.

Session 8: J- and S- shaped Tubes on the Pegboard

In complex arrangements, it is more difficult for the children to observe regularities, so we
used simpler J- and S-shaped tubes in this session. Curtis is playing with Tyler at the
water table with the pegboard on which J- and S- shaped tubes are fixed by the teacher.
Before coming to this activity, C. was in a group time talk about these shapes of the tube.
The teacher asks the children “What will happen to water in this tube (J-shaped tube) when
you put water in here (the long end of it)?” C. does not react to the question but when the
other children say that water will come out of the short end and go up to the top of the
pegboard and then will go into the left end of the S-shaped tube that is to the right side of
it, he disagrees. At the water table, C. starts to pour water into the J-shaped tube with Ty.
In this session, C. stays 10 minutes without the teacher and does not play with the S-
shaped tube. He shows that it is a hard task for him to consider the water levels in both
sides of the tube at the same time.

C: (Pours a pitcher of water in the funnel that is put into the long end of the J-shaped tube
and watches it shoot out the short end of it [see Figure 8.1].)
Ty: (Adds water to the long end of the J-shaped tube and moves over to the S-shaped
tube.)
C: (Adds water to the long end and watches again as the water shoots out the short end
then watches water level in the long end. Slowly adds a pitcher of water to the funnel and
watches as the water comes out of the short end slower. Adds more water to the funnel,
slower than the last one and watches as the water shoots from the short end of the tube.
Repeats this some more times, watching the water come out of the short end.)
He does not seem to think about the relationship between the water level in both of the ends of the J-shaped tube. At first, he observes the water shooting out of the short end when he pours water in the long end and then, he pours water in the long end slowly. He might have thought that the water will not come out the short end when he pours carefully in the long end. However, when he sees it still come out, he just pours the water quickly. He once again observes the water level in the long end of the J-shaped tube after looking at the water coming out the short end but does not alternate to look at both levels again. He seems to think about each one separately, that is, reason by empirical abstraction not by reflective abstraction. When he observes water coming out of the short end, he constructs the physical knowledge by empirical abstraction about two phenomena that are not related to one another yet, one is "the water comes out the short end when I put water in the long end" and the other is "the water stays in the low position in the long end or the long end does not get full when I put water in the long end of the J-shaped tube." They are not related yet by reflective abstraction in his mind, that is, it is not logico-mathematical knowledge yet.

The following vignette shows that cooperation between children is important in their cognitive development.

C: (Adds more water to the long end and watches the water shoot from the short end of the tube. Goes to get another piece of tube. Tries to hook another piece to the two pieces, J- and S-shaped tubes on the pegboard.) Let's put this right there [see Figure 8. 2].

Ty: (Just glances at it and starts a kind of pretend play with a circled tube, making sounds.)

He is not cooperating with C. He notices what C. is trying to do but does not seem to be interested and ignores it by engaging in his own pretend play.

C: (Tries to hook it to the J- and S-shaped tube once again but gives it up and removes it.)
He fails to get a collaboration from Ty and does not try to negotiate with him again. Thus, C. does not succeed in connecting the J- and S-shaped tube and does not have a situation in which he could think about the relationships between the water level in both ends of the tube. They are not very close friend so the lack of cooperation might affect their interaction. If it was, the social-cooperative context seems to be important for their cognitive development.

Later, they cooperate with the J-shaped tube by pouring and catching water.

Ty: (Adds water to the long end of the J-shaped tube and watches the water shoot out the short end of it. Takes the short end of the J-shaped tube out of the hook and holds it in a 2Mdsdh glass in a holder. Watches water come out of it.)

C: (Pours water in the long end and watches the water flow into the glass from the short end Ty is holding.)

Ty: (Watches water come out of the two holes of the 2Mdsdh.) Hey, it has two.

C: (Adds more water and watches it flow through the tube into the 2Mdsdh.)

Ty: (Watches the two water streams and laughs.)

C: Hey, you can fill yours up (hands Ty a pitcher and places it next to a hole in the glass) right here when I pour [see Figure 8. 3].

By cooperating with Ty's interest, C. coordinates the movement of the water from his pitcher through the tube and the glass into Ty's pitcher.

Ty: OK.

C: (Adds more water to the long end as T. catches water in the pitcher.) I'll fill yours up.

(Adds another pitcher of water.) Is it filled up?
Figure 8.3. Cooperating with Tyler to pour and catch water

Ty: (Nods. Pours the water back into the glass from his pitcher and catches more as C. adds water to the long end.)

C: (Fills the pitcher.) Hey, Ty, do you need some water?

He tries to cooperate with Ty again by using level 2 negotiation strategy.

Ty: Yeah.

C: Get some from there. (Points to the glass)

Ty: (Puts pitcher under the glass.)

C: Look how full this is.

Ty: (Nods.)

C: (Adds water to the long end and Ty catches some in the pitcher.)

Ty: I need some more than that. Come on. Come on, let's fill it up.

C: (Slowly adds water to the long end.)


C: (Laughs and adds more water to the long end.)

Ty: More. (Takes pitcher and stirs water with a holder while C. pours water in.)

This vignette shows that this material can become a cooperative context in which children can share their experiences and experiment together.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Session 9: Making Fountains I

Curtis comes to the water table after having group time about making fountains. At the group time, the teacher shows the children the fountain by videotape (because the field trip was not available) to prompt them to make fountains. He starts playing with a big plastic glass which has two thin tubes inserted in two bottom holes. This apparatus was provided to inspire the children to make fountains inside the big glass by squeezing the baster attached to those tubes or just blowing in those tubes. C. is joined by Spencer soon. Curtis has to quit this activity after 25 minutes because of clean-up time and wants to save the fountains he made for the next time. After pouring some water in the container and watching water come through the thin tubes, he soon starts to use another glass to make fountains. He makes relationships by making water flow from one to another through the tubes. In the course of making fountains, he tries one more time to recycle by putting the free end of the tube from the big glass into it.

C: (Adds enough water to fill the big glass.) Here, I have an idea. (Takes a glass from the tub. Takes the holder, places closer to the big glass, and places the glass in it. Tries to get the free end of tube that is attached to the big glass.) (U) (Takes one piece of the tubes from S.) (U) I kind of like this. (Puts it in the glass he just set [see Figure 9.1].) (U) then it (water) will go out this hole. (Points to the hole of the 1Mls)

Figure 9.1. Making fountains

He takes one of the tubes from S. and seems to explain why he needs that. He succeeds in making water flow from the big glass to the 1Mls by putting it lower than the big glass.

S: (Looks at what C. points to.)

C: (Holds another big glass under the 1Mls to catch water from its hole, holding the small tube in the 1Mls in his other hand.)

S: (Fills the baster with water and adds it to the 1Mls from which C. catches the water.)

C’s experiment is interrupted as S and C’s interest moves to using a baster. After awhile, he starts to make his fountains again.

T: (Comes over the water table.) What are you guys doing over here?

C: (Takes the end of the tube that fell out of the 1Mls and holds it back in the 1Mls.}

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
Watches water drain in the glass, moves the free end of the tube in the big glass, holds it there for a couple of seconds, and then takes it out. Holds it down and watches water come out, then puts it in the 1Mls. Looks at the water coming out of the tube in the glass, takes a holder, and hooks the tube in the pegboard [see Figure 9.2]. Then, adds water in the big glass.

He repeats the same behavior once again by putting the end of the tube hanging from the container back in it. However, this time, he takes the end of the tube out of the big glass soon as if he expected that the water might not come out then holds it down to make water come out of it.

![Diagram showing the process](image)

Figure 9.2. Trying to recycle again

C: (Watches the water flow from the big glass through the tube to the 1Mls and does more adjusting with the tubing. Watches small amount of water drip from the side hole, fills two basters with water, and adds it to the 1Mls. Picks up a pitcher full of water, pours it in the 1Mls, and watches the curving stream from the side hole. Plugs up the hole of the 1Mls to collect the water in it when the curving stream stops. Then, removes hand from the glass and watches the curving stream come out of it.)

S: (Takes the other tube out of the big glass so the water drains from the hole of it.)

C: (Watches the water come out and catches it in the pitcher. Puts the pitcher down, picks up a 1Mms glass with water in it, holds it under the big glass from which the water is draining. Picks another one up and looks at the several holes in it ('fountain glass'), drops the 1Mms, and places the 'fountain' glass under the big glass using a holder [Figure 9.3]. Adds water to the big glass.)

By putting one more glass under the big glass, he makes one system of fountains.
Figure 9.3. Adding a “fountain” glass to his fountains

T: Did you guys try to make a fountain there?

C: (Adds more water to the big glass.) I’m making two fountains.

T: You made two fountains? Wow! How are you doing that, C.? I can’t see from over here.

C: (Shows water path with hand) This one comes down from here (the big glass) into there (the ‘fountain’ glass) and this one comes down here and goes in here (the hole of 1Mls).

T: Wow, what a great fountain!

C: (Adds another pitcher of water to the big glass.)

T: And then I see it’s fountaining down into the water table, too.

C: Uh-huh. (Pours more water into the big glass, picks up another big glass, and looks at the hole, and holds it over the big glass that’s already there.)

T: How do you like the glasses with lots of holes instead of one hole?

Curtis tries the other glass with lots of holes in it in response to the teacher’s suggestion and he says that he likes it. After that, he tries to put another big glass over the big glass already in his fountains. However, he is not allowed to do that because there are no more holders to use. In this session, he synthesizes his knowledge about the draining and the water movement in the tubes by making a relationship between glasses using the tube. He puts tubes low according to his logic he constructed in the previous sessions and arranges the glasses according to the water trajectories. He shows his construction of the relationships between the order of emptying and the heights of the holes by choosing the 1Mls and the fountain glass that has holes in the low position to make his fountains go longer. In this session, he once again shows he did not construct the knowledge about water level by putting the free end of the tube from the big glass into it. However, he quickly takes it out and puts it back to the glass shown in Figure 9.3.
Session 10: Making Fountains II

Curtis comes back for the fountains he made in the last session. This time, the reservoir and one more fountain glass are also hooked up in the left side of his fountains (see Figure 10. 1 and 10. 2) to give him more opportunities to experiment with the water movement in the tube. His interest soon moves to combine the reservoir with his fountain but not with the other fountain glass until later. The following vignette shows he succeeds at the practical level in making the water go through the tube into the big glass.

C: (Adds water to the big glass of his fountains in the center of the pegboard and watches the water flow through the tube and glasses. Sometimes adds water to the fountain glass and the 1Mls and watches water go further from the holes. Looks at the tube and reservoir which are placed at the left side of his fountains. Picks up the tube that is hooked on the reservoir and places in the big glass of his fountains. Adjusts the reservoir and that makes the tube fall out of the big glass.)

R: There are some more tubes.

C: (Finds another piece of the tube and hooks it to the one attached to the reservoir. Places the free end of the tube in the top of the big glass. Adds water from the pitcher to the reservoir and watches it drain in the big glass. Shuts the water off and adjusts the tube in the big glass and the tube falls out of it. Looks things over for awhile, separates the two pieces of tubes, and hooks a new piece of the tube onto the one attached to the reservoir. Puts the free end of the tube in the big glass [Figure 10. 1].

Figure 10. 1. Putting the end of tube into his fountains
T: (Comes over.) Tell me what you are doing, C. Did you change things from the last time?

C: (Nods and turns the water back on.)

T: How did you change them? (Watching water stop in the tube as shown in Figure 10. 1.) Hum.

The teacher tries to make him aware of the water stopped in the tube even though he turned the water on.

C: (Adds water to the reservoir and watches the water level increase each time when the pitcher of full water is added. Watches as the third pitcher of water makes some water go through the hunched part of the tube and drain in the big glass. Adds more water to it.)

He seems to think that the empty reservoir needs to be filled to make water go through the tube into the big glass. When he observes that water goes up and up and goes through the hunched part of the tube by pouring more water, he seems to assimilate it to his existing cognitive structure, that is, adding scheme. However, in this situation, he is right. This experience seems to make him reinforce his false assimilation in the situation in which the reservoir (or the glass) is lower than the end of the tube. Here, we should have suggested to him to put the reservoir lower than his fountains or we could have arranged it lower before he started this activity.

T: C., I see that it is flowing now, and it wasn’t before.

She tries one more time to make him aware of the phenomenon.

C: ( Adds a pitcher of water to the reservoir.)

T: Can you tell me what you did to make it go different and where it was before?

C: I put water in here (points to the reservoir) and then this one in here (points to the big glass).

He means he puts water in the reservoir and then that makes water come out of the tube. He shows that his thought is undifferentiated regarding the water level. Thus, he seems to conclude simply that adding more water makes it go through the hunched part of the tube and come out of the tube. His reasoning is not yet related to any knowledge of the water level.

T: Boy, I see it’s going all different ways (points to water draining out of the bottom ‘fountain’ glass) And there’s water flowing down from that one (points to the big glass) down to that one (points to the fountain glass) and through the tube and into that one (points to the 1Mls) and it to that one (points to the fountain glass). Man, you really have a great fountain going. C., now I want to know why it was . . .
C: (Turns water off before the reservoir gets less than the half of water.)

T: Oh, you turned it off?

C: (Nods and adds more water to the reservoir.)

T: I'm curious about why it was going before and why it's not now. I know it's not going now because you shut it off, right?

C: (Nods.)

T: Why did you turn it off before it got completely empty?

C: It needed more water. (Adds a pitcher of water to the reservoir.)

Obviously, he thinks the water needs to be added to the reservoir to make water go through the tube.

T: It needed more water?

C: (Nods and adds a pitcher of water to the reservoir till it overflows and adjusts the water flowing from the reservoir. Watches the water flow for several seconds and adds the rest of the water from the pitcher to the reservoir.)

T: Boy, it's really going neat.

C: (Watches the water drain from the tube in the big glass and then in the other two glasses of his fountains.)

T: I'm glad we left it for you.

C: (Nods and turns off the flow of water draining from the reservoir.)

T: Why are you shutting it off before it gets to the bottom, C.?

C: (Looks at the water in the tube.) Cause it's almost going to the top.

He means that he turns water off when it gets almost in the top of the hunched part of the tube. Thus, he shows some consciousness of relationship between fullness of reservoir and flow through tube.

T: Cause it's almost to the top, oh, because that's almost to the top. Oh, OK.

C: (Adds water to the reservoir and watches the water drain from place to place, then shuts it off again.)

From his observation, he knows the water will stop coming out when it goes back up to the top of the tube so he turns it off before it gets there and adds more water in it. He knows how to succeed but does not know why yet. Nevertheless, there is some consciousness of relationships between fullness of reservoir and flow through tube. This may be a step toward consciousness of water level.
Later, C. is joined by Co. who shows his interest in using the baster. Both boys fill up the basters and squirt them into the reservoir and giggle and laugh. However, C. often returns back to his fountains, pours water in the reservoir, and watches his fountain go. Occasionally, he pours water in another fountain glass left alone in between the reservoir and his fountains. I intervene to connect that glass to his fountain and he shows again his erroneous idea about the water level (see Figure 10.2).

![Figure 10.2. Trying to send water through tube from lower glass to higher glass](image)

C: (Switches the 1Mls of his fountains to another ‘fountain glass’ that was hanging alone and pours water in the 1Mls. Watches water come out of the hole, holds the baster onto the hole, and catches water coming out of it at the same time adds more water to the 1Mls from a pitcher.)

R: C., I wonder if you put the hose in there, what is going to happen?

C: (Picks up one piece of the tube from the tub, hooks one end of the tube into the hole of 1Mls, and puts the other end in the big glass, then pours water in the 1Mls [see Figure 10.2]. Watches the water drain into the tube and tries to pour one more pitcher of water but interrupted by Co.)

He seems to think water will go up into the big glass.

Co: (Squirts the baster toward C.)

C.'s experiment is interrupted by Co.'s behavior. They squirt basters at each other and giggle and laugh.

Co: Don't.

C: Oh, ya?

Co: Oh, ya. (Fills baster and squirts it at C.)
C: (Holds the pitcher and catches the water from Co.'s baster from which Co is squirting.)

Thanks for giving me more water. (Laughs.)

Co: (Laughs and continues to squirt water at C.)

C: (Tries to pour the water from his pitcher to Co.'s baster and laughs.)

They are sharing the experience, even joking.

C: (Starts again to add water to the 1Mls where the piece of tube is placed to overflowing as shown in Figure 10.2. Watches the water level in the other side of the tube. Fills the pitcher again and pours it in the glass even though the glass is full and overflows, watching the water level in the other side of the tube. Adds one more pitcher of water and then pulls the tube out of the 1Mls. Watches water come out of the end of the tube and the hole in the glass when it is taken out and tries to catch water from the hole into the tube, and then blows in the end of it so the water sprays into the big glass [Figure 10.3].)

Figure 10.3. Blowing into tube when water did not go up from lower glass to higher glass

He seems to feel contradiction, here. In the previous experience with the tube from the reservoir into the big glass, he observed water goes up each time when he adds more water to the reservoir. However, here, water does not increase. At first he seems to negate and distort what he observes because he thinks the water will go up. Thus, even though the glass overflows he keeps adding water to it, expecting the water will go up in the other side of the tube. Finally, he seems to give it up, and invents new action to see what will happen, then sees the result of his action by blowing through the tube. He accidentally invents idea of pressure. This idea of pressure might be from previous using of baster.

C: (Puts the end of the tube back into the hole of the 1Mls, pours water in it, still watches the water level in the other side of the tube, pulls the tube out of it, watches the water come
out of the tube and the hole, and tries to catch water from the hole in the tube, and then
blows it. Repeats these steps.)

Now, he does this action to make the effect of blowing. In other words, he creates desired
effect.

C: (Often pours water in the reservoir to make his fountains go and watches water go up in
the other side of the tube.)

He seems to affirm his false assimilation, that is, when the water is added, it will go up.

. . . .

Later, the teacher comes over and asks about what happened to the new connection.

T: Tell me what happened when you connected from there to there.

C: (Catches the water draining from the glass into the pitcher) When I blew through the
pipe it came.

T: When you blew through the pipe it came?

C: (Nods.)

T: Oh, why did you blow?

C: Because I wanted to. I wanted to make it go. (Picks up another pitcher of water and
pours it in the glass and catches the water in the other pitcher.)

T: Because you wanted to make it go? Did you know that if you blew, you would
make it go?

The question, “How did you know that if you blow, you would make it go?”
might be better to know about what his reasoning was.

C: (Nods and adds water to the glass from the pitcher that was catching water from the
glass.

T: Oh, you knew that?

C: (Nods.)

T: That was a good idea.

C: (Nods and adds more water to the large container until it overflows, then adds a pitcher
of water to the glass. Turns the water off at the reservoir and watches the water in the
tubing and the containers.)
In this vignette, he shows again the erroneous idea about the water level; however, this time, he solves the problem by blowing in the tube to make water go up. Later, this will develop into the conceptualization of pressure.

Session 11: Water Squirter with a Target

The water table is outside. The reservoir attached to the Y-shaped valve is placed in a low position on the pegboard. Two basters are attached to tubes that are hooked onto the Y-shaped valve so that these two can get water through the tubes from the reservoir at the same time. There are also pop bags as targets at which the children squirt with the basters. This activity is provided for them to think more about the water level within their interests in using basters. With the intention of setting the stage for contradictions, the reservoir is arranged low on the pegboard. Curtis comes out first and starts this activity with Nathan before the teacher comes outside.

At first, C. is very excited about using basters to squirt so he does not even think about turning water on and just tries to squirt. In other words, his mind is centered on only the baster. The teacher asks them if the water is turned on. The following vignette shows how he decenters from thinking only about the baster and differentiates his action to accommodate to the new materials. At first, he does not succeed in getting water in the baster and in the course of decentering, he falls back on his previous logic, that is, 'It is easy for the water to go down,' then succeeds in spraying water at the target. At first, they have some troubles with the materials themselves so the teacher fixes it for them in the sitting position and gives one to N first. Nathan just sits down on the ground as the teacher did but he does not seem aware of the relationships concerning water level.

N: (Sits down on the ground and successfully squirts the baster at the pop bag.)
C: (Starts squeezing the baster at the targets in the standing position and sees no water in the baster [see Figure 11.1]. Bends down to siphon water from the tub into the baster and returns to the standing position. Squirts a little water but not all of the time or very much. Tries hard to squirt it.)

Here, he does not succeed in practice to get water in the squirter. He does not think to check the water level in the reservoir at all and just tries hard to squirt the baster as if he can get water when he does that. He does not think about getting water through the tube and just puts the baster in the tube in order to get water in it. This is assimilation to previous use of baster when he experimented with making fountains so he is using his previous knowledge in this situation. He is so engaged in using the baster itself, he can not think about anything else at the same time, that is, he cannot decenter from the baster itself.

T: Why do you think that N.’s is working and yours isn’t? Hum?

The teacher tries to make him to decenter so that he can be aware of the difference in the positions.

N: Mine is working real good.

T: Yeah, N.’s is going really good. (Adds more water to the reservoir.) Why do you suppose that is?
The teacher is adding water in the reservoir because she thinks that he might think that happened because of the empty reservoir when he turns and looks at it. Thus, she facilitates experimentation with baster without the children having to worry about reservoir.

C: (Shrugs and continues to try to squirt the baster still in a standing position.) He still thinks only about the baster.

N: Because C. is standing.

This seems to be a conclusion that is merely descriptive. It is not clear that he understands the spatial relations.

C: (Lowers the baster, squirts it, and water shoots out.) Mine's too. Now, it's coming out. (Reaches over and moves a target closer. Continues to spray the target with water.) He seems to be aware of his position by N.'s comments and accommodates his action by lowering it. The teacher's intervention makes N. to help C. to decenter from the baster. However, this seems to be an imposition from outside rather than by his own reasoning.

T: (Fills the reservoir full of water.)

C: (Returns to the standing position and sees no water come out. Lowers the baster again and water comes out.) Mine is only (U) (Continues to spray the target, bending over. The
water in the reservoir almost gets to the same level as the heights of their basters. Puts a finger over the opening of the baster and lowers it again to collect more water in it.)

Now, he is differentiating his action to accommodate to the properties of the objects by himself, instead of by other's imposition. He seems to forget about his standing position. However, when he does not see the water come out, then he realizes it and lowers his position himself. Then, he seems to conclude that he needs to lower the baster to get water in it.

N: (Still sitting on the ground) Mine is not fast. (As water level gets lower in the reservoir, the water in his baster is decreasing.)
Here, he shows the lack of consolidation of water level even though he was sitting on the ground to hit the target.

T: Your is not fast any more?
C: Put it down low.
Now, he gets water in the baster from the reservoir, in other words, he knows how to succeed at the practical level.

T: C., says to put it down low. And see if it makes a difference.
N: (Lowers the baster and the water goes farther.)
C: (Sees no water come out.) Turns and checks the water level in the reservoir and lowers the baster with finger still on the opening of the baster. Removes finger and sprays the target again.)
Here, he accommodates his action more to the objects, that is, he starts to check the water in the reservoir and lowers the baster when it does not spray well. He seems to assimilate this situation to his existing logic, that is, it is easier for the water to go down than up. Thus he shows progress by taking reservoir into account. He gets engaged in hitting the target when the baster sprays water easily and often forgets his logic. Sometimes when the baster does not work very well, he moves the target closer and closer to himself as if the distance between the reservoir and the target is one of the factors that causes the problem. When he forgets and stands so the water does not come out of the baster, he again reminds himself of his logic and lowers it. He once again gives a tip to N., saying, “Get down like this (bends low),” when N. asks him, “C., I'm having trouble.”

Later, by holding up the reservoir, the teacher tries to make him aware that he can get water when the water level in the reservoir is higher than the position of his baster. However, he just gets engaged in hitting the target when he keeps getting water in his baster by the teacher’s action. The teacher takes the reservoir out of the holder and moves to the place where the children can see the water level in the reservoir (Figure 11.2). The pop bags are placed on the milk crates because they are shaken well on it when they are hit by water. It also gives them a situation in which they can make a spatial relationship between the height of the baster and the heights of the targets.
In the following vignette, C. shows more decentering and starts to think that the reservoir needs to be held up high by help from the other child who has been observing this activity.

T: (Holds the reservoir on the ground.)

Recognizing that they are not conscious of the water level in the reservoir, the teacher holds the reservoir on the ground in order to give them a situation in which they cannot get water in their basters so they can become aware of the relationship about the water level.

C: (Tries to spray the targets but no water comes into the baster) Turn it on.

T: I turned it on.

C: (Lowers the baster until the baster gets water in it and then holds it up to hit the target sitting on the milk crate. A little bit of water sprays but the water in the baster goes back down to the tube so no more water comes out.)

He shows that he has no idea of height of reservoir in relation to holding baster to hit the target. He lowers the baster to get water in it and expects the water to stay in it in the standing position.

A: (Being around them and observing their actions) You need to lift it (points at the reservoir) up like you did before. You lifted it up and the water came out.

T: (To A) Do you think if I lifted it up, then the water would come out?

A: (Nods)

T: A., says that maybe I should lift it up, if I lift it up maybe the water will come out. Should I try that A.?
C: (Cries) Yeah, yeah.

T: (Stands up and lifts the reservoir and the water starts to flow in the tube.)

The teacher helps the children observe a regularity that is necessary to constructing a relationship. In other words, she tries to make them aware that when the reservoir is high, they can get water in the baster and when the reservoir is low, they cannot.

C: (Squeezes the baster in the standing position and the water sprays out and hits the target that it is aimed at.) I'm squirting it. It's coming out. See.

A: I know, you turn it on and the water just comes out. That would happen (U).

C: (Continues to squeeze the baster and hits the target sitting on the milk crate. Sprays the water close to the target and the target starts to tip over.) I almost got him down.

(Continues to spray the target and after several shots and hits with the baster, knocks the target to the ground) I got him down.

After filling the reservoir, the teacher again holds it on the ground and the two boys are not concerned about the position of the reservoir and just try to squirt by lowering their basters.

A. again suggests the teacher to hold up the reservoir and C. gets water in the baster.

C: (Tries to squirt the water in the standing position and nothing happens, leans down. Places finger over the tip of the baster until it fills with water and holds it a little bit higher to squirt the target sitting on the milk crate but sees the water goes down so lowers it back, still putting his finger over the opening of the baster. Then, stands up and squirts the baster. The water squirts out till it's empty again. Looks at the water way down in the tube and puts the baster down lower. Seeing water come out, holds the baster up toward the target sitting on the milk crate but the water stops.)

He still often goes back to the standing position so he does not seem to make the relationship between standing position and lack of flow and sitting position or leaning over and flow. However, he is self correcting. In the beginning of this activity, the teacher once tried to make him aware of his standing position, comparing N.'s sitting position. The teacher could have called his attention to this again here. He might not want to sit on the ground.

A: Mrs. S., he can't get no water.

C: (U) (Puts the pop bag down on the ground from the milk crate and sits down and tries to squirt the baster at it.)
Now, he seems to think about his logic that it is hard for water to go up. He puts the target lower from the crate to the ground and lowers himself to get water in the baster at the practical level. Now, he takes another variable into account by lowering the target.

T: He can't get any water. Is that what you said?
A: Yes.
T: (Still holding the reservoir on the ground) What do you think we should do so that he can get water?
C: (Continues to squirt and it works.) Now I can.
T: Now you can?
C: (Continues to spray the target and the baster gets less water because the water level gets lower in the reservoir sitting on the ground.)
T: A., A., what do you think I should do so that they can get more water?
A: Turn it on.
N: It's on already.
A: How about lift the thing up?
T: Lift the thing up?
A: Yeah.
T: All right, I could try that. (Lifts the reservoir and the water starts flowing into the tubing)
C: (Continues to squeeze the baster in the sitting position and the baster hits the target.)
T: What do you think, N., does that make a difference?
N: (Nods.)
T: C., does that make a difference when I lift it up?
The teacher tries to make C. conscious of regularity that the reservoir needs to be in the high position.
C: (Nods and watches the water squirt further. Puts the target back on the milk crate and returns to the sitting position and squirts it with water. Puts finger over the end of the baster until it fills with water and watches Nathan as he squirts the target in the standing position. Stands up, removes finger, and squirts water at the target. Still gets water because of the reservoir in a high position.)
This experience gets him to think about the reservoir as one of the factors he needs to consider to get water in the baster. The question, “Is reservoir higher than your baster?” or “Do you think water will go up through the tube when you hold it up higher than the water in reservoir?” might have been helpful for them to think about the position of the baster in relate to the water level in the reservoir.

C. finally asks the teacher to lift up the reservoir in the following vignette, showing he has constructed the regularity that the reservoir needs to be in the high position to get water through tube.

C: (Adds water to the reservoir the teacher is holding on the ground.)
N: Turn mine on.
T: OK.
C: Turn mine on, too. Turn mine on.
T: All right. (Turns the water back on to both basters.) It’s turned on.
C: (Squeezes the baster in the standing position and tries to lower it and at the same time looks at the reservoir.) Lift it up.
T: Lift it up?
C: (Nods.)
T: (Lifts up the reservoir a little.)
C: (Tries to spray the target, nothing happens.) Higher.
T: Lift it higher? (Lifts it a little higher.)
C: (Nods.)
T: Higher? (Lifts it some more.)

Both boys start spraying the targets
C: (Continues to spray the target but moves closer and tries to knock it off the milk crate.
The target tips but does not fall. Continues to spray the target to knock it over) I knocked it down twice.
T: You knocked it down twice?
C: (Continues to squirt the target with water.)

Finally, he thinks the reservoir needs to be lifted up even though “high” position of reservoir is not differentiated to relate to height of water in tube. He always lowered the baster to get water in it and at first he tries to put it a little bit lower but stops and asks the teacher to lift it up. He added water to the reservoir to fill it but this does not work. From his existing scheme, he can get water in the baster when he adds water to the reservoir or puts the baster lower. However, now, he decenters from that thinking and expands it to
consider the position of the reservoir as well. **Even though it is at the practical level, he progresses in knowing two ways to know how to get water in the baster: one is lowering his baster and the other is lifting the reservoir.** It is remarkable how long he persists to succeed. He shows his autonomy of thinking by decentering from the baster itself and constructing two schema, that is, lowering the baster and lifting the reservoir.
CHAPTER 5
SUMMARY AND DISCUSSION

The purpose of the current study was to understand changes in a child's reasoning in a series of water activities that were developed in this study. With this purpose in mind, this study focused on how the child progresses in his reasoning about water phenomena, what kinds of water activities promote the child's reasoning, and what kinds of teacher's interventions help the child's progress in children's reasoning and knowledge. According to Duckworth (1987), "the having of wonderful ideas" (p. 13) is "the essence of intellectual development" (p. 13). Duckworth continues to emphasize two aspects of occasions that lead to wonderful ideas: accepting children's ideas and providing a setting that suggests wonderful ideas to children. The study pursued exactly what Duckworth says and examines how the child progresses in situations having these characteristics.

In this study, the situations provided inspired the child's reasoning, that is, "wonderful ideas." The child showed progress in his reasoning about the water draining and water movement in tubes and also progress in developing his intelligence in the course of trying out his wonderful ideas through a series of constructive water activities within a cooperative context. The water draining and the water movement in tubes gave the child contents to act on and think about. The study focused on one child, interpreting progress in his reasoning in the course of his participating in water activities. Teaching strategies and the activities were also evaluated in terms of progress in his reasoning.

Progress in the Child's Reasoning over a Series of Water Activities

The target child constructed physical knowledge, including causal relationships about water draining and water movement in tubes. The child also revealed his active constructive process in the course of construction of water knowledge, including hypotheses and experimentation that reflect equilibration, contradictions, and reequilibration. In this process, the child constructed regularities by empirical abstraction through physical experiences with water and relationships by reflective abstraction through logico-mathematical experiences. Here, I summarize the results of his progress and limitations in his reasoning.
Curtis’s Structure of Water Knowledge and Limitations in Structure of Reasoning

In the case of water draining, Curtis showed his construction of the following regularities and relationships:

- The regularity of water running out of holes
- The regularity of complete emptying of bottom-hole glasses and incomplete emptying of side-hole (except 2Mbs) glasses
- The relationships between the sizes of holes and the temporal order of emptying
- The relationships between the positions of the holes and the direction of water stream or the order of cessation of leaking
- The relationships between the water level in the glass and the arc of the water spout
- The coordination of two relationships: one between the order of emptying and the sizes of the holes and the other between the water trajectories and the positions of the holes.

In the case of water movement in tubes, Curtis showed his construction of the following regularities and relationships in this study:

- The regularity that water moves easily down a tube but not so easily up a tube
- The regularity that when the reservoir is in the high position, the baster gets water in it through the tubes attached to the reservoir
- The regularity that water overflows from the short end when water is put in the tall end of the J-shaped tube
- The regularity between draining/not draining and the on/off positions of the valve
- The relationship between adding more water in the reservoir and increasing water level in the tubes.

Curtis showed limitations in constructing regularities and relationships by failing to construct the following:

- The regularity that water will not fill the S-shaped tube but will stay in the tube at the same level in the left and right ends of the first half of the S when water is continuously poured into the left end
- The regularity that to make water go through in the S-shaped tube, either the left end needs to be made higher than the hunched part of the S, or the hunched part needs to be made lower than the left end
- The relationship between the water level in the reservoir and water level in the tube
The coordination of three different relationships between the number of glasses and the order of emptying, the size of holes and the order of emptying, and the position of holes and the water trajectories in two systems of glasses.

Curtis's Constructive Process during Water Activities

The following discussion will review how he revealed his intellectual efforts in the course of constructing his water knowledge about draining and water movement in tubes. Action plays an important role in his reasoning. During the water activities involving draining, we can see Curtis progress by reciprocal effects between actions and reasoning. At first, Curtis's immediate actions (holding one glass above another) led him to reasoning and thinking (comparing the order of emptying) and then that led him to differentiation of his action (holding two glasses side by side to compare). According to Piaget (1974/1978), when conceptualization and action begin to have reciprocal effects upon each other, the situation changes markedly from simple material action. In other words, the child begins to move from material action to coordination of relations by reflective abstraction. At first, the child made relationships between the sizes of the holes and the order of the emptying with the three different sized holes on the bottom in glasses. Here, he found the dependency of the order of the emptying, that is, the order of the emptying = f (the sizes of the holes). This discovery of a function led to reflection and the structure of seriated correspondences.

Another example showed the important role of action in constructing knowledge at the practical level. When Curtis tried to drain water through three glasses in a vertical line, he chose a 1Sb for the top holder, a 1Mms for the middle, and another 1Mms for the bottom.. However, as soon as he put the 1Mms in the bottom holder, he found that he had a problem in catching the curving stream from the glass above. He quickly took it out, thought about it, put it back, then exchanged the middle 1Mms for a 1Bb. He corrected himself by his action and that led him to practical coordination of the relation involving the water trajectories of all three glasses. This result showed how children need to act on objects to construct their physical-knowledge as well as logico-mathematical knowledge as Piaget (1970b/1972) emphasized. Therefore, it seems clear that inferential coordinations originate in the child's own reasoning that derives more or less directly from the general coordinations of his own actions.
Curtis shows his erroneous ideas and tries to explore them. Curtis showed his erroneous and wonderful ideas during the water activities. When he stacked the side-hole glass into the bottom-hole glass, he tried to drain them from the side hole that was blocked by the bottom-hole glass. Even though that showed his failure to consider both glasses at once, that exploration later led him to the action of matching the holes and to the simultaneous consideration of two glasses.

Taking another example of an erroneous idea, we can see his intellectual effort to try out his idea. When the tubes attached to the reservoir were extended, he came up with an idea to recycle the water in the reservoir through the tube. He tried out this idea two more times. At other times, however, his expectation was changing. First, he tried really hard to make water come up through the tube but later he just held the free end of the tube into the reservoir for a second to watch and confirm the previous result. From this observation of the result, he drew the conclusion: 'it is hard for water to go up high.' In the other case, he tried to send the water from the lower glass to the higher glass through the tube attached to the lower one, pouring water in the lower one. When it did not work, he thought of the wonderful idea of blowing water in the tube. Actually his erroneous ideas were ideas as wonderful as correct ideas. Inspired by erroneous ideas to try something else, Curtis had more wonderful ideas. Thus, trying out his erroneous ideas, which are also wonderful ideas, was the sources of his progress.

Overcoming his contradiction between his expectation and the results, Curtis equilibrates his structures. Curtis's initial understanding of side holes was based on a general undifferentiated concept that water will come out of a hole. At first, he showed surprise and feelings of contradiction in terms of the water trajectory and the water stopping below the side hole. Overcoming the contradictions between his expectations and the results of the actions, he equilibrated his cognitive structure regarding water draining from the side hole and then conserved it. When the water stopped below the side hole, he accommodated his action by tipping it and also assimilated the side hole into the cognitive structure of the bottom hole by putting the water over the side hole. In the course of these experiences, the child constructed the function: the nature of draining = f (the positions of the holes). Thus, he constructed the relationships between the positions of the holes and...
the nature of the draining. When the child moved to the activity involving catching water on the pegboard, he showed progress by considering at the same time and coordinating two relationships involving the order of the emptying and the water trajectories. In the case of water movement in tubes, he experienced a contradiction when he tried to send the water through the tube from the reservoir to the glass held at almost the same height as the reservoir. His effort to overcome that contradiction led him to another trial involving recycling and finally to constructing the regularity, ‘It is hard for water to go up high.’ Thus, the experiences of contradiction can lead to progress.

He is gradually conscious of his actions and the properties of the objects. However, conceptualization still lags behind his action. Whenever the child was provided with a new glass, he showed his knowledge at the practical level. At first, he was at level 1A, that is, concentrated on the result of his action, and then moved to level 1B, that is, began drawing conceptualization and action together. In other words, at level 1A, most of the time when he was presented with a new glass, he drained another glass into the new one several times to observe water coming out of it. At level 1B, he began drawing a connection between action and conception by making correspondences between the sizes of the holes and the order of emptying, and the positions of the holes and the nature of the draining. According to Piaget (1974/1978), the children at level 1 still focus on their action and conceptualization lags behind their actions. When the child was presented with 2Mdsdh after acting on 2Mbms, he did not generalize the concept that the lower hole leaks longer. However, after acting on different glasses with holes, he showed his cognizance at level 2A by the correct anticipation. That is, he anticipated correctly when the teacher asked him about which hole of 2Mdsdh glass drains the longest. Later, by choosing always the side hole in the low position before acting on it, he showed his conceptualization at level 2A.

When he moved to the activities involving catching water on the pegboard, at the action level, initial reactions with catching and draining on the pegboard consisted in proceeding through isolated assimilation schemes, concerning water trajectory and order of emptying. There was an attempt to link these to his activity and his progress consisted in coordinations by reciprocal assimilations of these schemes in use. Certainly, this was also
a process leading from the periphery to the center. However, it did not become general and independent of the elements; in other words, there was a limitation in his ability to simultaneously coordinate the three relationships (between the number of glasses and the order of emptying, the sizes of holes and the order of emptying, and the positions of holes and the water trajectories). That is, he did not coordinate the order of emptying in the two systems of draining that had three elements to think about (the number of glasses, the sizes of holes, and the positions of holes).

Through experimenting with water movement in tubes attached to the reservoir, the child made his own intuitive theory: it is hard for the water to go up high. When he experimented with the reservoir and the fountains he made, he always succeeded in sending water into the fountains from the reservoir whenever he added more water to it since it was in a higher position than his fountains. Here, he constructed the adding schema and applied it to another situation.

However, thinking about adding water to the reservoir interferes with thinking about the position of the baster in the activity involving water squirter. That is, Curtis’s false assimilation to the adding scheme (adding more water to the reservoir will make water come out the end of the tube or the baster) was an obstacle for him to accommodate his action (lowering his baster) to the new situation (the reservoir in the low position) so when he did not get water in the baster, he added more water to the reservoir. This was an attempt to accommodate his action to the goal of making water squirt out of the baster. However, when it did not work even though he added more water, he lowered the baster. Thus, he alternated between two hypotheses: adding water to the reservoir and lowering the baster.

The hypothesis involving the adding scheme was partly verified because when he poured water in the reservoir, he sometimes saw the water rise in the tube, due to two causal aspects. When he poured water in the reservoir, the rise in level there was accompanied by a corresponding rise in level in the tube. In addition, he sometimes unconsciously lowered the tube in his hand, causing a rise in level in the tube. Proof of the failure to construct the equality relation between the levels of water in the reservoir and the tube is seen in the fact that he followed the observation of water rising in the tube by
standing up to hit the target and causing the tube to be higher than the water level in the reservoir.

Later, he considered the water in the reservoir to make water come out of the free end of the tube by asking the teacher to lift it up high. However, he had not yet construct the knowledge that the water is always at the same level in both the reservoir and the tube. The contradiction between two schema, adding water to the reservoir and lowering the baster seems to delay the construction of the relationship. According to Piaget (1974/1978), the contradiction between schemas remains unconscious for a long time. That is, the child has to construct the coordination of two schema internally within a wider referential system for transcendence. In short, the child’s false assimilation, adding water, caused his unconsciousness of equality of levels in baster and reservoir.

This contrasts with the progress Curtis made in water draining. Whereas the child showed progress at the conceptual level for water draining, he showed only progress at the practical level for water movement in tubes. The results of this study confirm the previous study by Kwak (1993). Even though his progress in water movement in tubes was made only at the action level, this is viewed as an abundant and necessary source of future progress in conceptualization.

**Evaluation of Teacher’s Interventions**

Now, I turn to consideration of the relation between Curtis’s progress and the teacher’s intervention. In this study, Curtis progressed in his reasoning about the water dynamics by the teacher’s cooperative interventions that promote his empirical and reflective abstractions. Here, I will discuss what seems to be the teacher’s effective interventions and non-productive interventions to promote Curtis’s reasoning about water dynamics.

**Prompt the Child’s Reasoning by Engaging in his Problem as a Companion.**

This study shows that when the teacher engaged in Curtis’s problem as a companion, he tried to reason and find the solutions. With that intervention, the teacher reduced her authority and promoted the child’s autonomy. For example, she experimented along with children and called attention to difficulties, in a manner that had the effect of reducing her exercise of authority. When the teacher said, “Mine’s only coming out of this
side, too. I wonder why. Whoop! Now it’s coming out of both sides. Whoop! Now it’s only coming out of one side. I can’t figure it out,” he reacted, “I know. This is the lowest and this is the highest.” It is a striking contrast to his reaction, “I don’t know,” when the teacher asked, “Why did it quit?” In another instance, when C. tried to recycle the water into the reservoir, the teacher engaged in his problem as a companion who shared his objective by repeating his action and saying “Could I try it?” This intervention made him elaborate his reasoning and conclude “It’s hard for the water to get up high.” In the other case, when Curtis had a difficult time in draining from the side hole into another on the pegboard, the teacher decided to show him a model. She arranged glasses to catch the water from the side hole and poured water in the top glass to demonstrate it rather than questioning him or asking him to do it. That intrigued him to try it and go on to make a relationship between the water trajectories and the side hole on the glass. Thus, this suggests that the teacher’s egalitarian attitude works effectively. It is more effective to engage in the child’s problem as a companion than an authority.

Foster Observation and Construction of Regularities

If the children fail in constructing the regularities by empirical abstraction, they cannot construct the relationships by reflective abstraction. In this study, the teacher helped Curtis to observe the phenomena and to construct the regularities by using appropriate questions. According to Kamii and DeVries (1978/1993), the question “What is happening?” can lead the child to observation of the phenomena. This question led Curtis to observe the results of reaction and encourage his empirical abstraction so that he could construct regularities from the phenomena he observed. By constructing the regularities, the child lays the foundation for making relationships. Sometimes, the teacher called attention to results of his actions to make him conscious of them. For example, when Curtis was watching water streaming from a 1Sb, the teacher drew attention to the resulting action of the 1Sb, saying “That one’s taking a really long time, isn’t it?” However, it is more effective to use the question, “What is happening?” than the just illustration of the results.
Encourage Hypotheses and Testing Hypotheses

Piaget (1972) emphasized that children need to do their own research and experiment with their own problem. In this study, when Curtis tried to recycle water from the end of the tube into the reservoir with a hypothesis that the water will go up and back to the reservoir, the teacher encouraged him by saying, “That will be interesting. What do you think will happen?” and “Can you show me with your finger how it will go back in there?” Even though it was erroneous idea, the teacher encouraged him to test the hypothesis. Children’s hypotheses do not have to be right ideas. They can be erroneous ideas, that is, wrong ideas from the adults’s perspective.

Foster Comparison and Construction of Relationships

According to Piaget (1972), intellectual development is promoted by teaching strategies which make reflective abstraction possible for children. When Curtis observed two different sized bottom-hole glasses, the teacher prompted him to compare them by asking “Which is going to empty first of those two?” so that he could think about the relationship between the sizes of holes and the order of emptying. In another case, the teacher expanded his reasoning to facilitate his coordination of two relationships between the sizes of holes and the order of emptying and between the positions of holes and the water trajectories.

Promote Consciousness of Actions

The question “How did you do that?” or “What did you do?” made the child conscious of his actions and prompted causal relationships. For example, when Curtis tipped the side-hole glass to make water come out, the teacher made him aware of his action by asking “What did you do?” Curtis answered “I just put the water over the hole and it came out here.” By that intervention, the teacher inspired him to conceptualize the nature of the water draining from the side hole. In addition, the question “Does it make any difference?” prompted the child to be aware of the result. When Curtis was not conscious of the reservoir in the activity involving the water squirter, the teacher made him aware of it by lifting it up and putting it down with that question.
**Promote Interchange of Ideas among Children**

The teacher established the cooperative atmosphere between the children by inviting Curtis to help another child with her problem. With this intervention, the teacher tried to communicate that the source of the knowledge was not from her but from Curtis. This gave them a foundation to cooperate with each other sharing experiences and negotiating.

In another instance, when the other child suggested to the teacher to lift up the reservoir in the activity involving the water squirter, she asked Curtis what he thought about the other’s idea and if he wanted to try it. That led them to interchange their ideas.

**Foster Consciousness of Contradictions**

In this study, Curtis is provided with situations in which he could make hypotheses and experiment on them. During his experiment, he encountered contradictions and tried to overcome them. For example, when Curtis experimented with a side-hole glass after using bottom-hole glasses, the teacher fostered his consciousness of contradiction between the expectation and the result regarding the cessation of water from the side hole by saying, “Oh, mine is quit, I wonder why?” That led him to consciousness of his contradiction between the expectation and the result.

**Foster Predictions**

The teacher, in this study, fostered Curtis to predict before he acted on objects, using the question “What will happen if...” This question made Curtis anticipate the results and encouraged him to experiment and observe the phenomena. For example, when the teacher gave him a new glass, she asked, “Can you tell me what’s going to happen if you put water in there?”

**Foster Causal Reasoning**

The teacher helped his causal reasoning in this study by using the question, “Can you...?” or “Why...?” According to Kamii and DeVries (1978/1993), the teacher can use the first question to help children to act on objects at a practical level and the latter question to prompt children to think about it at a conceptual level. In this study, the question “Can you...?” made the child try out and experiment with his idea or a desired effect. However, the idea suggested or the question asked should match his interest and agenda. The question “Why...?” made him think about the reason for the phenomena he
observed so that he could think about the relationships. Kamii and DeVries (1978/1993) indicate that the "Why" question is somewhat dangerous to use for young children and suggest using it in relation to an action such as "Why does not the block move?" However, this study shows that if the 'why' question directly matched as the child's interest, he tried to reason and answer it and if it did not, the child ignored it and did not try to reason and think. Thus, it is important that the questions match the child's interest and agenda.

Non-Effective Interventions: Different Agenda or Interest from the Child's

One of the most important things to keep in mind for the constructivist teacher is always to think about what the child thinks and reasons during his or her activity. When the teacher misses this point, the teacher cannot promote and expand the child's ideas and cognitive structures and sometimes interrupts the child's experiment. For example, when Curtis was engaged in making a curving stream from the side hole, holding the big-bottom-hole glass above it, the teacher mentioned the phenomenon of the tornado she saw from the bottom hole. The child did not answer because his interest was not in that. In another case, when Curtis was interested in the water trajectories, the teacher failed in intervention by posing her agenda about the size of the hole. When the child's agenda seems to be different than the teacher's, it is better to withdraw and to match the child's topic.

In the case of the activity involving water squirter, the teacher failed in introducing the child to the activity so at first, the child often went to the tub to siphon with the baster rather than trying to get water through the tube. The teacher could have introduced the activity by asking, "Can you make water come out of your baster through the tube from the pop bottle (reservoir)?" This shows the importance of introduction of new activities or materials.

Evaluation of Water Activities

In this study, a series of constructivist water activities was developed in order to try to promote the child's reasoning and knowledge regarding the water draining and the water movement in tubes. Curtis certainly knew at the end more about water phenomena than he knew before and he certainly reasoned in ways he did not reason in the beginning of the project! Here I briefly review how the activities produced these positive results.
The Activities Gave the Child Opportunities to Act on Objects and Observe the Results

The transparent materials and colored water led him to observe the water movement inside of the glasses and the tubes, making the construction of regularities and relationships easier. Different sizes and positions of the holes inspired him to compare and to make relationships involving the order of emptying and the nature of draining. In the activity involving catching water on the pegboard, varying the heights of the side holes in the glasses gave him opportunity to engage in his interest in the curving streams from the side holes. In the activity involving the water squirter, he did not decenter from the baster itself because of his interest in squirting it. However, his purpose of hitting the target led him to decenter from his narrow interest and consider the water in the reservoir. These activities engaged his interest and purposes enough that he could spend more than one hour in each of three sessions and more than 30 minutes in each of four sessions. For the rest, mostly his activities were stopped by the transition time.

The Activities Inspired the Child to Make Hypotheses and Test Them

In the activities involving water movement in tubes, Curtis showed his hypotheses numerous times. For example, when he experimented with Nathan’s tube, he connected his tube attached to the reservoir to Nathan’s and anticipated water would come up to the funnel attached to Nathan’s tube that was almost at the same level as the reservoir. Whenever he did not have any problem, he made further problems by changing his arrangement of tubes or exchanging one glass for another. Then, he tried them out to see the results of his expectations.

The Activities Inspired Experiences that led to Contradictions between Expectations and Results

Curtis’s numerous erroneous ideas led to contradictions between his expectations and results and inspired him to try to overcome them.

The Activities gave the Child Opportunities to Cooperate with Others

These activities engaged the children in cooperative efforts to create effects they did not or could not achieve alone. The activities were an effective context for construction of regularities and relationships.
There were Limitations of the Activities: Building Air Pockets in Tubes

The activities involving water movement in tubes had limitation in building air pockets that could hardly be understood by means of pre-operational reasoning. Extending tubes caused an air problem in the tube that the teacher and I did not anticipate. The air problem made it difficult for Curtis to construct knowledge about the water level because even when the tubes were lower than the water level in the reservoir, the water just trickled from the end of the tube. That seemed to reinforce the false assimilation that since it is easy for the water to go down, the tube needs to be put in the low position, instead of lower than the water level in the reservoir. Thus I suggest giving the children only two or three tubes for simple arrangement of tubes.
CHAPTER 6
CONCLUSION

This study provides insights into what and how a child reasons and thinks about draining and water movement in tubes within a cooperative context. As Duckworth (1987) mentions, working with one child at a time enables a teacher to figure out what is in a child’s mind and to observe how he corrects himself and progresses. However, this study does not necessarily imply that this is what ought to happen in every class for every child. This would obviously be impractical. Nevertheless, it is practical for the teacher to be on the lookout for the kinds of progress and opportunities for the effective teacher interventions described in this study. This study provides the teachers with practical instances that match the theoretical foundation in which they can have detailed insights into how children learn and how teachers can promote the children’s reasoning.

It is useful for teachers to have a theoretical background to figure out what is really in a child’s mind. Piaget (1969/1972) emphasized that “without an adequate knowledge of child psychology, the teacher cannot properly understand the students’ spontaneous procedures” (p. 69). In other words, without a theoretical background, the teacher fails to take advantage of significant reactions from the child and fails in expanding the child’s further reasoning.

This study also demonstrates that it is essential to provide the cooperative context in the course of children’s construction of knowledge. By accepting and respecting children’s erroneous ideas and by allowing them to test their hypotheses even though they are wrong ideas, teachers can provide children with situations in which they can reason and construct their own knowledge. This cannot occur within the teachers’ authoritarian interventions such as direct teaching and forcing their agendas on children instead of following the children’s agendas.

The study is important in providing an analysis that demonstrates that children in water activities are not “just playing,” but that when materials and interventions challenge children’s reasoning, they do in fact, make progress in knowledge and increase their intelligence. In fact, the children in this study played with water from their perspective, however, they “did science” from the teacher’s perspective. The water activities were
"play" in that the children were engaged in their purposes and interests, and their behaviors were creative, spontaneous, and pleasurable. However, they were "science" in that the children explored water phenomena with the materials, formed hypotheses and tested them, drew conclusions, and communicated and cooperated with peers.

Sometimes, water play is rejected by adults in schools because it causes a mess (Goldhaber, 1994). However, if it is clear what children learn when they play with water, that problem with water can be overcome as Goldhaber (1994) indicates. Moreover, if teachers have clear ideas about how water activities can be developed and what kinds of materials and situations can be provided for children's learning about water phenomena, water activities will be considered as excellent classroom activities. This study provides solutions by showing: (1) progress in the child's construction of the regularities and relationships regarding his actions and the results, and the properties of materials; in other words, he learned "science;" (2) kinds of activities and situations that helped the child to construct knowledge; and (3) kinds of teacher's interventions that promoted progress in the child's reasoning in the course of his activities.

This study also challenges the traditional approaches in science education that focus on the acquisition of scientific concepts. The traditional approaches in science education fail to change children's misconceptions by trying to teach the bits of knowledge directly. Contrasting with that, the water activities, as good physical-knowledge activities, in this study focus on children's mental structure and constructive process that shows how they change their existing structures by making sense of the world. In short, this study shows how children can construct their logico-mathematical knowledge as well as physical knowledge in the course of acting on water with other materials and how teachers can help them, as young scientists, construct knowledge and intelligence when they engage in water activities with experimentation, interest, and cooperation with others.
References


Goldhaber, J. (1994). If we call it science, then can we let the children play? *Childhood Education*, 71 (1), 24-27.


Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.


