THE RELATION OF LOCUS OF CONTROL ORIENTATIONS OF SIXTH- GRADE STUDENTS TO PROBLEM SOLVING PERFORMANCE ON A PHYSICAL SCIENCE LABORATORY TASK

BY

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1990
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by

Edna Dewey Main
Many people have encouraged, supported, and guided my progress through the doctoral program. My doctoral committee chairman, Dr. Mary Budd Rowe, kept me going with her excitement, interest, and guidance. My supervisory committee members, Dr. Patricia Ashton, Dr. Roy Bolduc, Dr. Ruthellen Crews, and Dr. Arthur Newman have been supportive and helpful in reading and responding to my writing. Thanks are expressed to Dr. David Miller for patiently answering my statistics questions and Dr. Linda Crocker for her understanding and concern.

A special note of appreciation is extended to Dr. Paul Eggen of the University of North Florida. He encouraged me to begin my doctoral program and has given me substantial guidance in my educational career. Dr. Royal Van Horn of the University of North Florida faithfully gave me reminders to finish my dissertation asking, "Are you done yet, June?", whenever we talked.

Cindy Holland and I have spent countless hours discussing what we have learned, supporting each other as we worked toward completing our programs. Cindy, Dan
Lofold, Mike Reynolds, Ted Britton, and Kay Sisson were there with timely help and suggestions.

Ralphie Edwards and I share the same vision of what education should be for children. We are growing in understanding of the pathways to get there and enthusiastically plan the next steps, supporting each other along the way.

Ruth Stephens gave me direction and reassurance when they were most needed. She read my dissertation for coherence and cut down on "that" word so frequently used.

Each one in my family has been steadfast in believing that I could and would finish. My daughters, Alison and Sue; son, Steve; sons-in-law, George and Bubba; and brother, Bradford could feel when a hug, an understanding conversation, or a good meal was needed. They were always there . . . with love.
# TABLE OF CONTENTS

ACKNOWLEDGEMENTS ........................................ iii

LIST OF TABLES ............................................. viii

LIST OF FIGURES ........................................... x

ABSTRACT .................................................. xi

CHAPITERS

I  INTRODUCTION ........................................... 1

Rationale .................................................. 1
Intelligence and Problem Solving ......................... 1
Fate Control .............................................. 5
Locus of Control and Fate Control ....................... 8
Locus of Control ......................................... 10
Locus of Control Related to Performance ................. 11

Definition of Terms ...................................... 12

Statement of the Problem ................................ 13

II  REVIEW OF THE LITERATURE ........................... 14

Locus of Control
Cognitive Characteristics ................................ 14
Locus of Control Measures ................................ 16
Factor Analysis of Locus of Control Responses ............ 17
Research on Locus of Control ............................. 18
Locus of Control and Achievement ......................... 19
Locus of Control in the Context of Structure .............. 23

Student-Structured and Teacher-Structured Environments 24

Problem Solving ........................................... 26
Research on Problem Solving .............................. 28
Activity-Based Science Learning .... 28
Problem Solving Strategies ....... 29
Controlling Variables .......... 31
Premature Problem Closure and Hypothesizing .... 37
Effective versus Ineffective Problem Solving .... 38

Summary of Pertinent Research .... 39
Locus of Control .......... 39
Problem Solving .......... 41

Research Hypotheses .......... 42

III METHODOLOGY .......... 44

Background of NIMH Study ....... 45
Sample Population and Design .... 45
Measurement Instruments .... 49
Locus of Control .......... 49
Intelligence .......... 51
Procedures .......... 52
Situational Characteristics .... 54
Cylinder Task .......... 56

Methodology for the Present Study .... 60
Selection of the Sample .......... 62
Data Collection and Display ...... 63
Description and Scoring of Variables .... 70
Rescoring of the Nowicki-Strickland .... 76

Statistical Hypotheses .......... 77

IV RESULTS AND DISCUSSION .......... 79

General Descriptive Data ....... 80
Ravens .......... 80
Nowicki-Strickland .......... 81
Problem Solving Strategy .......... 85
Problem Solving Solutions .......... 87
Predictions .......... 91
Condition of Structure .......... 93

Results of Hypotheses Testing .... 96
Data Analysis for the First Three Hypotheses .... 97
Locus of Control and Strategy .......... 98
Locus of Control and Solutions .......... 100
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1</td>
<td>Eight Subgroups of Like-Sex Sixth-Grade in the NIMH Study</td>
<td>46</td>
</tr>
<tr>
<td>3-2</td>
<td>Population of Students in Subgroups</td>
<td>49</td>
</tr>
<tr>
<td>3-3</td>
<td>Population of Students in Subgroups for this Study</td>
<td>63</td>
</tr>
<tr>
<td>4-1</td>
<td>Descriptive Statistics for the Ravens (Fluid Intelligence)</td>
<td>81</td>
</tr>
<tr>
<td>4-2</td>
<td>Descriptive Statistics for the 40-Item Nowicki-Strickland (Locus of Control)</td>
<td>82</td>
</tr>
<tr>
<td>4-3</td>
<td>Descriptive Statistics for the Six-Item Nowicki-Strickland for the &quot;Science Phenomena Domain&quot;</td>
<td>84</td>
</tr>
<tr>
<td>4-4</td>
<td>Descriptive Statistics for Problem Solving Strategy</td>
<td>86</td>
</tr>
<tr>
<td>4-5</td>
<td>Descriptive Statistics for Problem Solving Solutions</td>
<td>87</td>
</tr>
<tr>
<td>4-6</td>
<td>Correlations between Problem Solving Variables for Subgroups</td>
<td>89</td>
</tr>
<tr>
<td>4-7</td>
<td>Descriptive Statistics for Predictions</td>
<td>92</td>
</tr>
<tr>
<td>4-8</td>
<td>Summary of Anova Results Comparing Mean Scores by Sex between White and Black Student Pairs</td>
<td>93</td>
</tr>
<tr>
<td>4-9</td>
<td>Means and Standard Deviations for Student Pairs by Sex, Race and Condition of Structure</td>
<td>95</td>
</tr>
<tr>
<td>4-10</td>
<td>Dummy Codes for Identification of Race of Student Pairs</td>
<td>96</td>
</tr>
<tr>
<td>4-11</td>
<td>Results of Regression Analysis for Problem Solving Strategy</td>
<td>98</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>The Two Domains of Fate Control</td>
<td>9</td>
</tr>
<tr>
<td>3-1</td>
<td>Cylinder Variables</td>
<td>57</td>
</tr>
<tr>
<td>3-2</td>
<td>Graphic Display for &quot;Tennis Tournament&quot; Strategy</td>
<td>65</td>
</tr>
<tr>
<td>3-3</td>
<td>Graphic Display for &quot;King of the Mountain&quot; Strategy</td>
<td>67</td>
</tr>
<tr>
<td>3-4</td>
<td>Graphic Display for Random Moves</td>
<td>68</td>
</tr>
<tr>
<td>3-5</td>
<td>Effective Problem Solving Process for the Cylinder Task</td>
<td>71</td>
</tr>
<tr>
<td>4-1</td>
<td>Interactions between Ravens and Solutions for Females</td>
<td>104</td>
</tr>
<tr>
<td></td>
<td>(with Nowicki-Strickland Held at Mean) for White Pairs (W/W), Black Pairs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(B/B), and Mixed-Race Pairs (B/W)</td>
<td></td>
</tr>
<tr>
<td>4-2</td>
<td>Interactions between Ravens and Solutions for Males</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>(with Nowicki-Strickland Held at Mean) for White Pairs (W/W), Black Pairs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(B/B), and Mixed-Race Pairs (B/W)</td>
<td></td>
</tr>
<tr>
<td>4-3</td>
<td>Interactions between Ravens and Solutions</td>
<td>106</td>
</tr>
<tr>
<td></td>
<td>(with Nowicki-Strickland Held at Mean) for Male and Female Pairs</td>
<td></td>
</tr>
<tr>
<td>4-4</td>
<td>Interaction between Solutions and Nowicki-Strickland (with Ravens Held at</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td>the Mean) for the Structure of the Task</td>
<td></td>
</tr>
</tbody>
</table>
Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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By

Edna Dewey Main

December, 1990

Chairman: Mary Budd Rowe, Ph.D.
Major Department: Instruction and Curriculum

This study extends the theoretical and empirical differentiation of the locus of control construct in the context of science instruction, investigating the relationship of locus of control orientations and task structure to problem solving performance in science.

Data were gathered on 200 sixth-grade students who had been assessed on locus of control and intelligence. Students were randomly divided into 100 like-sex pairs, matched on locus of control orientation. Pairs performed a four-variable, problem solving task, racing cylinders down a ramp in a series of trials to determine the 3 fastest of 18 different cylinders. The task was completed in one of two treatment conditions: the structured condition with moderate cuing for one cylinder variable and the unstructured condition with minimal cuing. Pairs completed
an after-task assessment, using concrete materials, to measure ability to understand and apply task concepts.

Dependent variables were effectiveness of problem solving strategy, accuracy of task solutions, and accuracy of predictions on the after-task assessment. Independent variables were task structure and individual differences of student pairs: sex, race, intelligence, and locus of control orientation.

The major conclusions were as follows:

1. There was no significant relationship between locus of control orientation and effectiveness of problem solving strategy. A significant main effect was found for intelligence on strategy. Higher intelligence related to more effective strategies.

2. There was a significant relationship between locus of control orientation and task solutions: the more internal the locus of control, the more accurate the solutions. Significant interactions were found between intelligence, race, and sex for solutions.

3. There was a significant relationship between locus of control orientation and accuracy of predictions. Internality was related to higher accuracy.

4. There was no significant relationship between task structure and effectiveness of problem solving strategy. A significant main effect was found for intelligence on strategy.
5. There was a significant relationship between task structure and task solutions. Solutions were more accurate in the unstructured condition. A significant interaction was found between locus of control and structure for solutions. Internality related to more accurate solutions in the unstructured condition.
CHAPTER I
INTRODUCTION

The purpose of this study was to extend the theoretical and empirical differentiation of the locus of control construct in the context of science instruction, investigating the relationship of locus of control orientations and task structure to problem solving performance in science.

Rationale

We live in a world of rapid change, with expanding global communication, travel, and economic production; with unprecedented advancement in science and technology; in a continually changing environment where jobs quickly become obsolete and job requirements are often restructured. To encourage the development of intelligence is this nation’s best hope to be flexible enough to adapt, survive, and grow under these complex conditions. Educational strategies that cultivate intelligence must be identified and implemented.

Intelligence and Problem Solving

Intelligence, wrote John Dewey (1931), gives individuals the power to see the world for what it is and to reflect upon what it might become. Dewey (1930)
believed that acting with intelligence is the "key to freedom" (p. 278). He saw intelligence as converting desire to will, in the spirit of inquiry, by observing, gathering facts, making systematic plans based on accumulated evidence, keeping track of events and analyzing them as they happen, varying plans to change the course of action when necessary, then drawing conclusions and making decisions based on evidence, decisions made with full consideration of values and consequences of particular actions.

Robert Sternberg, a Yale psychologist, has challenged the traditional view of intelligence. He explained his pragmatic theory that focuses on real-life situations in his book, *Beyond IQ: A Triarchic Theory of Human Intelligence* (1984). His Triarchic Theory is an integrated view of intelligence that interrelates the psychometric and cognitive approaches to intelligence in terms of the context in which it occurs. Sternberg defined intelligence as a mental process incorporating three spheres, or subtheories, including contextual, componential, and experiential intelligence.

Contextual intelligence is the mental activity involved in adapting to one's environment, or changing the environment to suit one's needs, or if that is unacceptable, selecting a different environment.
The two spheres of Sternberg's theory of intelligence directly related to this study are componential and experiential intelligence. His componential area of intelligence focuses on the underlying component processes by which intelligent behavior is accomplished. For instance, one would plan an approach to a problem before trying to solve it. Progress in solving the problem would be noted, with formative evaluation being done during the problem solving process. Strategies could then be changed as needed to reach appropriate solutions.

Experiential intelligence is related to experiences confronting people with new situations, facing novel problems needing to be solved. When an appropriate strategy is found to solve a particular problem, this procedural knowledge becomes automatic and can then be applied in solving other novel situations.

Sternberg considers behavior to be proportionately intelligent as it relates to the three spheres of his Triarchic Theory. The focal point of intelligence is not only in a person, or in the person's behavior, or in the context of their behavior, but in the interaction of all three. Sternberg believes that intelligence is essentially a mental process and a person can be taught to be more intelligent, to think more critically.
Development of the ability to think and act with intelligence must be of prime concern in education, from early childhood to college. The Educational Policies Commission (1962) stated in *The Central Purpose of American Education*, "the purpose which runs through and strengthens all other purposes - the common thread of education - is the ability to think" (p. 12). Has the development of the ability to think critically been a priority of education for all students?

In *Education and Learning to Think*, Lauren Resnick (1987), codirector of the Learning Research and Development Center at the University of Pittsburgh, reviewed the history of education in teaching critical thinking skills. She noted these thinking skills have usually been reserved for teaching the elite within highly selective institutions in what she identified as a "high literacy" tradition. Mass education has had a "low literacy" tradition with a goal of producing minimal levels of competence in the general population. Resnick identified the current drive in public education: to prepare the general population of students for "productive participation in an increasingly diversified economic environment" (p. 6). She concluded, "Although it is not new to include thinking, problem solving, and reasoning in *someone’s* school curriculum, it is new to
include it in everyone's curriculum" (p. 7). Resnick referred to cognitive research that suggests failure to cultivate critical thinking skills, even in elementary school, may be the source of major learning difficulties.

If we assume intelligence can be increased, part of this increase may be related to the thinking skills Dewey, Sternberg, and Resnick identify and the user's knowledge of when and how to apply them.

Another ingredient is necessary, however, when accepting that intelligence may be increased by learning critical thinking strategies and enhanced by knowing when and how to use them. Attention to these strategies will not be effective, Resnick claimed in an interview with Ron Brandt (1989), unless learners perceive themselves as being in control.

**Fate Control**

In "Selections from Science Education: A Framework for Decision Makers," Mary Budd Rowe (1983) related a nation's ability to adapt, survive, and grow to the way a nation's people not only understand science and technology, but have an outlook with an orientation of high "fate control." Fate control was explained as a pattern of beliefs about the nature of the world, one's place in this world, and the influence one can have on it. People with high fate control were characterized as
believing they can set goals and plan strategies to positively influence the odds of reaching these goals. They try things and learn from experience; they evaluate outcomes and use the information to adjust strategies; they exhibit adaptive persistence in problem-presenting situations. People with high fate control are not easily influenced, are risk-takers, accept responsibility for their actions, and orient themselves toward the future, participating in long-term plans and projects.

In contrast, people with low fate control were characterized as believing events happen by chance, assuming they cannot influence the odds. People with a low sense of fate control seem to feel they cannot make a difference so there is no reason to try. Responsibility for what happens is placed somewhere other than with themselves. These people seldom evaluate the possible consequences of their actions, have low task persistence and achievement, and are passive and rather easy to influence. The setting of goals is not relevant for those with low fate control. They collapse perspective to the present. They do not perceive the world as patterned, but in more discrete bits.

Rowe (1973) concluded, when we develop a high fate control orientation, we can move in our imagining from what is to what might be and can engineer the route from
"a present reality to a new reality . . . acting as though we believe our fates are mostly under our own direction" (p. 280).

Rowe (1973) stated her belief that education can enhance fate control. She enumerated some of the processes of science which children should experience to develop skills and an experience-based belief in their own ability to control phenomena. These experiences with processing can be incorporated into any science program: manipulating and experimenting with materials, discovering cause and effect relationships, predicting outcomes based on analysis of past and present events, controlling variables so effects can be studied, building arguments on the basis of evidence, exploring and discussing ideas, and solving problems so children can construct their own knowledge of the processes involved in building the content, or product.

These are the processes that develop intelligence (Dewey, 1930; Sternberg, 1984), provide a context for the development and use of critical thinking skills (Resnick, 1987), and enable us to see how the nature of a discipline (e.g., science phenomena) shapes the context of thought.
The "dimension of locus of control involving people and social systems may be distinct from the aspect relating to explanation and control of physical and biological phenomena," explained Rowe (1978, p. 31). The former originates from social learning theory, whereas the latter has its base in the philosophy of science. Rowe believes the common underpinning for both dimensions may be cognitive. See Figure 1-1 for the relationship between fate control and locus of control.

Fate control potentially applies in two domains, the social/political/economic, the left side in Figure 1-1, and what might be called a science phenomenon domain (the right side of the figure). As explained by Rowe (1978), one dimension has to do with what now falls into the locus of control domain of studies: the extent to which people perceive a relationship between the amount, nature, and quality of their actions, and the subsequent yield in social and political effects and extrinsic affect. The second dimension relates to biological and physical phenomena, to technological health, and/or mechanical domains. The two domains of fate control relate and interact in such fields as health and environmental education. Locus of control measures usually tap the social/political/economic domain.
Figure 1-1. The Two Domains of Fate Control.
Locus of Control

Rotter (1982) described the generalized expectancies for internal and external control of events:

An event regarded by some persons as a reward or reinforcement may be differently perceived and reacted to by others. One of the determinants of this reaction is the degree to which the individual perceives that the reward follows from, or is contingent upon, his own behavior or attributes versus the degree to which he feels the reward is controlled by forces outside of himself and may occur independently of his own actions. (p. 171)

When a person has a belief in internal control, an event is perceived as being contingent upon the person’s behavior (e.g., inquisitiveness or task persistence) or attributes (e.g., ability or intelligence). Belief in external control is present when an event is perceived as being primarily contingent upon powerful others, chance, or fate. The perception of a causal relationship can vary in degree on a continuum from external to internal.

There is a question as to the extent a person assessed as being an external would display a successful problem solving strategy. Would the predictive value of a locus of control assessment instrument be affected by personal characteristics, the environmental conditions, or the context?
**Locus of Control Related to Performance**

An essential process in science is identifying patterns and relationships among phenomena. This is a fundamental process in forming concepts, establishing theories from which predictions can be made, adapting behavior, and controlling phenomena. We do not have much knowledge of either the processes and strategies used to construct a concept when latitude is given to solve a novel science problem or the relationship of locus of control orientations to the effectiveness of these processes and strategies.

Joe (1971) reviewed the literature on the relationship of locus of control to strategy preferences and learning. He found the evidence did not unequivocally support the hypothesis that internals perform better than externals in conditions where skill is a factor in the outcome.

Joe suggested a closer examination of the relationship between task characteristics and locus of control orientations be undertaken. A review of recent literature has not resulted in more conclusive evidence.
Definition of Terms

Structured condition. In this condition, students were cued by the observer to experiment with one of the four variables in the science task before beginning the criterion task in order to reduce the complexity of the four-variable criterion task.

Unstructured condition. In this condition, students were presented with objects representing all four variables included in the problem. Then, without being alerted to any one particular variable, they were asked to solve the criterion task.

Statement of the Problem

The purpose of the present study was to investigate the extent to which the generalized locus of control orientations of sixth grade students related to their science problem solving effectiveness in a novel situation where skill, needed to build evidence for the outcome, and the structure of the task condition, were factors.

This researcher used original raw data, sections of which had not been analyzed, gathered during a previously unpublished study by Rowe (1978) to answer the following questions:
1. To what extent did like-sex pairs of sixth grade students, matched for locus of control orientation, with pairs differing on locus of control on a continuum from external to internal, display successful problem solving performances during a complex physical science task?

2. Did the structure of the task situation affect the predictive value of the locus of control assessment instrument?
CHAPTER II
REVIEW OF THE LITERATURE

Locus of Control

Cognitive Characteristics

People with a high degree of fate control were characterized by Rowe (1983) as believing they can set goals and plan strategies intended to positively influence the attainment of their goals. They try things and learn from experience, evaluate outcomes, use information gathered to adjust strategies, and exhibit persistence in problem solving situations. Rowe considered locus of control as a subset of fate control which she explained as being applicable in both the social and science phenomena domain (Figure 1-1, page 9).

The literature on locus of control repeatedly identifies contrasting characteristics of internals and externals confronted with various situations or contexts. Many of these characteristics relate to problem solving behavior and are pertinent to this study; for example, when compared with externals, internals generally tend to more actively seek information to improve their effectiveness (Davis & Phares, 1967)
use a more organized learning strategy (Wolk & DuCette, 1974)

be more attentive to the task (Rotter & Mulry, 1965; Julian & Katz, 1968; Lefcourt, Lewis, & Silverman, 1968)

be more attentive to cues which help to resolve uncertainties (Lefcourt & Wine, 1969)

more quickly note changes in conditions around them and respond to perceptions (Lefcourt, Gronnerud, & McDonald, 1973)

make better use of information gathered when making decisions (Phares, 1968)

spend more time in decision making (Rotter & Mulry, 1965; Julian & Katz, 1968; Lefcourt, Lewis, & Silverman, 1968)

consistently do better on both intentional and incidental learning measures (Wolk & DuCette, 1974)

see relationships more than discrete parts (Wolk & DuCette, 1974)

show more persistence in attempts to solve problems (James, Woodruff & Werner, 1965)

show a higher level of ability in using previously acquired material in a subsequent task (Phares, 1968).

It seems reasonable to assume that a combination of these characteristics, generally descriptive of internals, would be essential for a person to be a successful problem solver in a science context. An external, on the other hand, may "lack the very cognitive processes that would enable him to examine and evaluate his choices and decisions. Unable to scrutinize his own
responses and decisions, he may even fail to see that he has choices available to him" (Lefcourt, 1976, p. 65). According to theory, externals would generally not develop and use organized learning strategies or gather evidence to support hypothesis development and testing or decision making, because they have the belief that what they do does not make a difference in the results.

**Locus of Control Measures**

Several locus of control assessment instruments have been developed to measure the degree to which people in different age groups display a belief in an internal or external locus of control. The Children’s Nowicki-Strickland Internal-External Control measure was developed to assess a general locus of control orientation in children aged 9 to 18. Scores on this instrument have been used to predict behaviors of children in various situations and contexts with varying degrees of success.

Nowicki and Duke (1983) reported acceptable test-retest reliability for the Children’s Nowicki-Strickland for periods of up to a year. In the area of construct validity, studies using the Nowicki-Strickland have found that "externality was more common among children in the lower socio-economic classes and among

Factor Analyses of Locus of Control Responses

In results of factor analysis of 345 South African elementary school children's test responses on the 40-item children's Nowicki-Strickland, Barling (1980) reported that "personal action" was a primary factor, explaining about 70% of the variance. A second factor, luck, accounted for the other 30%.

Allie (1979) used a reduced set of 20 items from the 40-item Nowicki-Strickland in a two-factor solution. He found that "a general feeling of helplessness" accounted for 68.3% of variance in a study with 135 children with adjustment problems who ranged in age from 6 to 15 years. He further separated this factor into two categories: lack of control in interpersonal relationships and lack of control over "things," events, or problems. These two categories relate to the two dimensions of fate control shown in Figure 1-1 on page 9: one dimension involves people and social systems; the other dimension is associated with the explanation and control of physical and biological phenomena.

Three of the seven items on the Children's Nowicki-Strickland found by Allie to pertain to the category of lack of control over things, events, or problems were
18

#1 - "Do you believe that most problems will solve themselves if you just don't fool with them?"

#19 - "Do you feel that one of the best ways to handle most problems is just not to think about them?"

#37 - "Do you usually feel that it's almost useless to try in school because most other children are just plain smarter than you are?"

This dimension of fate control needs further study and is the dimension addressed in the present study involving science inquiry into physical phenomena during a "hands-on" science problem solving task.

Research on Locus of Control

Beck (1979) dealt with concept formation and locus of control in her dissertation. She found that task instructions generally moderated the effects of locus of control on creative problem solving for 178 college freshmen. When task instructions emphasizing the role of chance were given, these instructions minimized the relationship between locus of control orientation and creative problem solving. Significant differences in problem solving performance were found when the role of skill was emphasized for the task. Internals generally performed significantly better than chance-oriented externals. Externals with a powerful others orientation were most influenced by the degree of external evaluation...
provided in task instructions. Students with a powerful others orientation performed better under non-evaluative instructions than internals or those with a chance orientation. Internals performed better than externals under evaluative instructions. Beck appealed for locus of control orientations and creative problem solving to be studied within a person-by-situation framework.

In the present study, locus of control orientations and problem solving were investigated within a two-student team-by-situation framework. The situation was the condition of structure in instruction, either cued or uncued, and its relationship to sixth-grade students' problem solving performance in the context of science.

**Locus of control and achievement**

Evidence of the importance of locus of control in achievement was reported by Coleman, Campbell, Hobson, McPartland, Mood, Weinfeld, and York (1966) in a study, *Equality of Educational Opportunity*, which included information on over 645,000 students. Coleman et al. found that students who assumed they could affect their environment were higher achievers than those who felt that luck, fate, or other uncontrollable factors were responsible for what happened to them. These researchers reported that students' locus of control orientations appeared to have a stronger relationship to achievement
than all school factors combined. Their research results were summarized this way:

For children from advantaged groups, achievement or lack of it appears closely related to their self-concept; what they believe about themselves. For children from disadvantaged groups, achievement or lack of achievement appears closely related to what they believe about their environment; whether they believe the environment will respond to reasonable efforts, or whether they believe it is instead random or immovable . . . children from advantaged groups assume that the environment will respond if they are able enough to affect it; children from disadvantaged groups . . . assume that nothing they will do can affect the environment - it will give benefits or withhold them but not as a consequence of their own action. (p. 321)

Coleman et al. found that, for all groups in their study, a consistent relationship existed between the economic level of a child's home and his or her sense of control over the environment.

Coleman used three statements to which students either agreed or disagreed to measure locus of control:

1. Good luck is more important than hard work for success.
2. Every time I try to get ahead, something or someone stops me.
3. People like me don't have much of a chance to be successful in life.

Joe (1971) summarized his review of research findings on locus of control:

Data are consistent with the theoretical expectation that individuals who are restricted
by environmental barriers and feel subjected to limited material opportunities would develop an externally oriented outlook on life. Also, social class interacts with race so that individuals from the lower classes and minority groups tend to have high expectancies of external control. (p. 635)

Nowicki and Strickland's (1973) locus of control measure for children contains 40 statements to which students either agree or disagree. Since the construction of this measure, "several studies have confirmed that an internal locus of control is related to greater achievement in academic settings" (Nowicki & Duke 1983, p. 24). Most correlations between locus of control and achievement for children were significant but below .50. Research by Brown (1980), Cervantes (1976), McCandless and Rollins (1976), Mount (1975), Nowicki and Walker (1974), Prawatt, Grissom, and Parish (1979), Sherman and Hoffman (1980), and Tesiny, Lefkowitz, and Gordon (1980) supported this position.

Nowicki and Duke (1983) concluded from their review of research findings that locus of control causes academic achievement level. They urged investigators to find more effective educational interventions by studying "ways in which internals and externals differ in their approach to academic achievement situations" (p. 30).
There are conflicting conclusions for the relationship of locus of control to achievement. One problem is in the measurement of achievement. Achievement measures generally used in studies of this type were paper and pencil tests. Several were standardized achievement tests. More than five years after the publication of the results of these studies, researchers analyzed approximately 7,000 items for Stanford Achievement batteries and the California Test of Basic Skills. They found that all test items required lower level thinking skills (e.g., recalling, comparing and contrasting), not the higher level thinking skills necessary for problem solving (Marzano & Costa, 1988). Other achievement measures required reading and writing skills which may or may not have related to the type of achievement measured.

For instance, a paper and pencil assessment requiring lower level thinking would not be an adequate indicator of achievement when measuring science problem solving achievement. This type of assessment may not be able to reveal higher level understandings of the problem processes and solutions specific to the context of the problem, because achievement would depend on the ability of students to read and/or write. Neither does it allow for the individual differences of the learner.
Ronning, McCurdy, and Ballinger (1984) investigated the role of individual differences of junior high students in science problem solving situations. Individual differences included cognitive style, locus of control, attitude toward science, intelligence, and achievement test scores in math, science and vocabulary. Students were asked to "think aloud" as they solved five science problems which involved either manipulation of concrete materials (pendulum and water fountain apparatus), pictorial representations of a problem (lake problem), or the reading of problems (radioactivity and frog problems). Multiple regression analyses indicated the individual differences that were the best predictors of problem solving performance were vocabulary, field dependence/independence, and intelligence. The conclusion drawn by Ronning et al., that locus of control was not found to be a significant predictor of problem solving performance, contradicts the conclusions of previous studies. Most of the previous studies, though, had measured achievement by testing information learned rather than observing, analyzing, and evaluating problem solving performance with a "think aloud" format.

Locus of control in the context of structure

Theory suggests that internals and externals are differentially sensitive to task structure. As reported
in person-by-environment interaction research reviewed by Sandler, Reese, Spencer, and Harpin (1983), internals have been predicted to adapt better in low- than high-controlling environments because of their activity preferences, self-control skills, reactance against loss of freedom, and effective use of situational clues. Externals have been predicted to adapt better in high-controlling situations because of their activity preference, need for explicit cues, low reactance to loss of personal freedom, and poor internal self-regulation skills.

Sandler et al. (1983) stated further, "Externality is found to be adaptive in specified situations" (p. 241). They identified the need for more research in this area.

In the present study this researcher explored the extent to which internals and externals were found to be adaptive in structured versus unstructured situations where the structured condition was more controlled, with cuing for one variable. A more complete explanation of the condition of structure can be found on page 11.

**Student-Structured and Teacher-Structured Environments**

McKee (1978) studied the effects of two different instructional strategies on sixth graders in science classes. The student-structured learning strategy with
minimum restrictions was found to improve student problem solving skills more than the teacher-structured strategy which had moderate restrictions.

In a summary of the results of seven studies done near Florida State University with elementary and junior high students using hands-on science materials, Shymansky and Penick (1981) compared student performance from observations in teacher-structured (TS) and student-structured (SS) activity-centered science classrooms. Students in the SS classrooms were less dependent on the teacher and displayed more productive behavior than students in the TS classrooms. Students in the TS situations behaved as if they thought there was one correct answer to a question, whereas students in SS situations behaved as if they were attacking a problem the way scientists do, with active investigation. When problem solving and creativity tests were compared, SS groups performed as well or better on problem solving tests than TS groups. The low ability students tended to approach the level of high ability students in the SS classrooms. Both groups performed equally as well in verbal creativity, with the SS groups' performance significantly higher on figural creativity than TS groups.
Even though the sample in each of these studies was not assessed for locus of control orientation, the results that relate structure and performance deserve consideration. The mediating variable of structure may cause variance when locus of control is used to predict achievement.

The present study investigated the influence of task structure on internals and externals during a problem solving task, controlling for ability, looking for main effects and interactions between structured and unstructured conditions.

**Problem Solving**

Henri Poincaré emphasized that science is the process that makes sense of the facts. He wrote, "Science is built up with facts, as a house is with stones, but a collection of facts is no more a science than a heap of stones is a house" (Kelly, 1941, p.240). Duane Roller, a science historian, defined science as "the quest for knowledge" (1970, p.23).

John Dewey maintained, "The method of science - problem solving through reflective thinking - should be both the method and valued outcome of science instruction in America's schools" (in Champagne & Klopfer, 1977, p.438). He urged that science teaching and learning be
dynamic and sincerely scientific because, "the understanding of process is at the heart of scientific attitude" (1916, p. 7). Sternberg’s componential sphere of intelligence, which focuses on ongoing reflectivity and formative evaluation during problem solving, parallels Dewey’s problem solving through reflective thinking.

Chi and Glaser (1985) maintained, "Solving problems is a complex cognitive skill that characterizes one of the most intelligent human activities" (p. 227). Sternberg’s assumption, that people can be taught to be more intelligent, supports the contention that people can learn to be better problem solvers.

Resnick (1983) acknowledged that successful problem solving requires a substantial amount of qualitative reasoning to understand the problem situation, to consider the alternative representations, and to consider the relationships among the variables.

Consensus on the nature of learning from cognitive science identifies the potent role learners’ "naive" theories bring to their qualitative understanding of a concept or problem situation. Learners come to science with their own theories about how the world works. Even after much classroom instruction, students still use their prior or "naive" theories to explain a concept or
solve problems. Real understanding of the science concept or problem has not taken place. The students' learning has not been accomplished in a way that allows their classroom knowledge to be accommodated with their understandings learned from everyday experiences.

Research on Problem Solving

Research related to the type of complex problem solving task involved in this study dealt with concept formation and application of specific science phenomena. Literature pertinent to this task was activity-based science learning, effects of the cognitive structure of the task, and development of problem solving strategies: identifying and controlling variables, determining the effect on performance of the number of variables in the task, generating and testing hypotheses, and coming to problem closure on the basis of evidence gathered.

Activity-based science learning

Shymansky, Hedges and Woodworth (1990) conducted a resynthesis of the research comparing student performance in activity-based science curricula of the 1960s and 1970s to traditional textbook programs. The resynthesis generally supported the conclusions drawn in the earlier meta-analysis by Shymansky, Kyle, and Alport (1983). The recent resynthesis also uncovered some notable differences which pertain to this study. In the re-
analysis, mean effect sizes for problem solving and achievement for junior high students were greater in activity-based classrooms than in textbook centered classrooms. The mean effect sizes for process skills, problem solving, and achievement were .39, .23 and .39 respectively, with effect sizes significant at $p<.05$.

A breakdown of student performance by gender showed the problem solving skills of females across all curricula improved significantly in the activity-based programs when compared with traditional textbook programs, whereas males improved significantly in achievement.

**Problem solving strategies**

Rudnitsky and Hunt (1986) conducted an exploratory study to examine and describe the strategies implemented by fifth and sixth grade students to solve complex problems. Four phases in student strategies were identified:

- **Exploration** - "playing around with the environment" to find a sequence of moves that seemed worth following up
- **Patterns** - repeating a move sequence
- **Focusing** - applying a strategy, putting together a combination of moves, pursuing a hunch; critical time for theory building
Hypothesis testing - making and testing a prediction to generate evidence for drawing conclusions.

Results of this study indicated that almost all subjects began with the exploration phase to gather data; some began with random moves or patterns. Subjects next moved to the patterns phase when they identified and repeated patterns found. Moves in this phase were the most prevalent and, according to Rudnitsky and Hunt, reflected the students’ "(perhaps intuitive) appreciation of the need for regularity and predictability as a necessary condition for constructing a theory of the microworld" (p. 462). The exploration and patterns moves led to the more sophisticated phase of focusing when students seemed to be "on to something" and used the data collected to construct a problem representation. Some students were able to turn the data generated into a testable hypothesis and went on to the hypothesis-testing phase; some were unable to do this. Hypothesis testing did not always lead to correct answers or any answers. Hypothesis testing was not always done correctly or completely. Usually when students made one or two hypotheses that were borne out, they used this evidence for drawing conclusions. When hypothesis testing occurred, the researchers noted that it was surprisingly sophisticated.
Rudnitsky and Hunt's study supports the position that theories must be constructed. They do not just exist in nature. Rudnitsky and Hunt stated that "theorizing is more sophisticated when it is operating on theories constructed by the subject rather than theories or hypotheses provided by the researcher" (p. 463). So if we are to guide students to develop problem solving skills, we need to provide them with activities in which they can form and test their own hypotheses.

In the present study, the researcher investigated the ways pairs of like-sex sixth grade students, representing varying locus of control orientations, differed in their development of strategies to find a solution to a complex science problem solving task. Successful problem solving strategies were contrasted with less successful strategies to extend the theoretical and empirical differentiation of the locus of control construct.

Controlling variables

The development of the ability to control variables is an index of intellectual development in general (Inhelder & Piaget, 1958). Essential to what Dewey (1910) called reflective or critical thinking is the concept of a controlled experiment. Formal operations, the most advanced stage of intellectual thought according
to Piaget, contains capabilities such as control of variables and hypothetico-deductive reasoning. The physicist Robert Karplus worked with Piaget on elementary level science curriculum. One of the ways Karplus (1977) characterized the use of formal reasoning patterns was in "recognizing the necessity (of the setting up) of an experimental design that controls all variables but the one being investigated" (p. 170). In conjunction with designing, developing and testing science curriculum, Karplus, Karplus, Formisano, and Paulsen (1975) gave controlling variables problems to 13- and 15-year-olds in seven countries. About 20% of the students used formal operations during controlling-variable tasks.

Levine and Linn (1977) reviewed the research on scientific reasoning ability in adolescence and concluded that an increase in reasoning ability took place around adolescence, but the change was not as complete as suggested by earlier descriptions of formal thought. This review by Levine and Linn indicated performance related to scientific reasoning appeared to be influenced by the number of variables in the task, previous experience with the variables, method of interacting with the materials (free choice or constrained), and the subject matter of the task.
Wozny and Cox (1975) found that the ages of the students in their study interacted with the number of variables in a particular problem. Two variable tasks (e.g., balance beam) were solved by most 12- and 13-year-olds. Tasks with multiple interacting variables (e.g., floating and sinking) were seldom solved even by 16- and 17-year-olds.

Staver (1986) investigated the effects of the number of independent variables and test format on the responses of 548 eighth-grade students to a reasoning problem involving control of variables. To solve the problem, the eighth graders had to separate and control variables to determine the effect of a particular variable on the bending of the rods. There were two levels of independent variables (two-to-three variables and four-to-five variables) and two test formats for response (essay and multiple choice).

Results of the Staver investigation showed test format had no effect on the students' scores. The two-to-three variable versions of the task were significantly less difficult than the four-to-five variable versions. Staver concluded that the results of his investigation indicated, "adding independent variables to a control of variable reasoning problem leads to an overload of working memory, which in turn affects performance" (p.
The achievement measures used by Staver may have limited the assessed outcomes to reading and writing ability, and this raised an important issue. An essay measures the ability to put ideas into writing. This ability may have been a mediating variable, because it measures a different process than the science problem solving process involved in the science task.

Boyer, Chen, and Thier (1976) conducted a study to investigate what sixth-grade students learn about controlling variables in a free-choice, activity-centered environment without direct teacher instruction. They reported that, after autonomous learning in this environment, close to two-thirds of the students seemed to recognize the need to control variables in problem solving tasks. Approximately 10% of the sixth graders could control some variables consistently, and approximately 52% could control variables with less consistency on sphere and balloon tasks involving three variables. Before being exposed to the free-choice learning environment, only 5% of the students controlled variables with consistency.

Lovell (1961) allowed students to experiment freely with pendulum apparatus. He observed that some children who set up controlled experiments drew the wrong conclusions from observed evidence. Even though they had
evidence from their own experimentation that the weight of the bob did not influence the speed of the pendulum, they concluded that weight was important in determining pendulum speed. Lovell inferred that perception interfered with the ability to deduce from observed events. In further study of the pendulum problem with sixth graders, Linn (1977) reported results consistent with those of Lovell. In 86% of the cases, students set up a controlled experiment, then made the erroneous conclusion that the initial position of the pendulum arm made a difference. For the weight variable, 25 of the 63 students were inconsistent. They set up controlled experiments 80% of the time, then concluded incorrectly that weight made a difference. Linn concluded that students interpret their experiments in the direction of their expectations rather than from their observed evidence.

Linn and Swiney (1981) found students were more likely to control those variables they predicted would affect the outcome of the task. Results of their study showed that the variables the experimenter selects for a task may differ from the students' expected variables. The students usually use their expected variables when constructing experiments significantly more often than other variables.
Kuhn and Angelev (1976) reported that giving students practice on a controlling variable problem twice a week for 14 weeks had the same effect as lesser amounts of practice combined with a demonstration of how to design a properly controlled experiment. Kuhn and Angelev concluded that their results indicated that, given the appropriate conditions, students can acquire an advanced cognitive strategy on their own without the need for overt training activities. Linn's study (1980) found 12-year-old subjects were better at planning their own learning experiences when they understood the demands of the task.

When Piaget was asked to comment on the effectiveness of a classroom demonstration of controlling variables, he said, "It would be completely useless, the child must discover it for himself" (reported by Hall, 1970). In their report, Kuhn and Angelev (1976) concluded that exposure to practice in controlling variables was more successful than demonstration.

In a meta-analysis of 65 studies on controlling variables, Ross (1988) concluded that treatments that made the constituent elements of the controlling variable schema explicit to students through a set of overt procedures or salient examples had a greater impact than treatments in which the operations that made up
successful performance were less visible. Linn’s study (1980) supported the conclusions of Ross. One implication suggested in her study was that learning in free-choice programs and informal learning "is far more likely to take place if the learner has been given a general structure or alerted to the salient features of the learning situation" (p. 246).

Premature problem closure and hypothesizing

Wollman, Eylon, and Lawson (1980) cited the ability to avoid premature problem closure as affecting problem solving behavior in science and found that elementary school children seldom demonstrated this ability. The ability to accept lack of closure at certain points in a problem solving task, then successfully propose a strategy to gather more definitive evidence, is necessary when the evidence is not conclusive in a complex problem solving task.

In Lunzer’s (1973) report on the results of his study involving children between the ages of 5 and 15, he suggested the ability to avoid premature closure suddenly developed between 9 and 11 years of age. This corresponded with the ages Piaget proposed children’s formal reasoning begins to develop.

Wollman, Eylon, and Lawson (1980) conducted a study with 141 elementary school children and found the overall
increase in spontaneous avoidance of premature closure, from 5 to 12 years of age, was statistically significant and generally linear. There was no sudden increase shown between the 9- and 11-year-old age groups as suggested by Lunzer. Task complexity, rather than age, seemed to have a greater effect on the ability to avoid closure with insubstantial evidence. The results of this study also indicated the ability to avoid premature closure did not appear to be a fundamental acquisition in the "Piagetian sense" in that its use could be significantly increased by brief cues or by minimal teaching. They further found subjects who were able to spontaneously avoid premature closure were also able to generate hypothetico-deductive strategies, in an if . . . , then . . . , therefore . . . form, to solve the tasks, whereas the nonspontaneous subjects were generally unable to generate strategies to solve the tasks.

Effective versus ineffective problem solvers

Smith and Good (1984) described effective problem solvers as tending to break a problem into a number of parts that they could deal with separately. Ineffective problem solvers try to solve the problem in a single step. According to Smith (1990), the ineffective problem solvers typically use faulty or inexact logic, fail to recognize logical necessity, and do not appear to know
the difference between weakening and falsifying a hypothesis. They tend to make decisions based on inappropriate evidence, instead of upon the relevant evidence that guides effective problem solvers.

Woods (1989) stated, "The top 10 percent of our students seem to be able to cope no matter what we do in the classroom so . . . observations of unsuccessful styles apply to the majority of the students, the other 90 percent" (p. 106).

Summary of Pertinent Research

Locus of Control

Internals performed better than externals when the role of skill was emphasized for a problem solving situation, whereas the performance of some externals exceeded that of internals in a skill situation under non-evaluative instructions (Beck, 1979). Researchers conducting several studies concluded that internality was related to greater academic achievement (Brown, 1980; Coleman et al., 1966; Cervantes, 1976; McCandless & Rollins, 1976; Mount, 1975; Nowicki & Walker, 1974; Prawatt, Grissom, & Parish, 1979; Sherman & Hoffman, 1980; Tesiny, Lefkowitz, & Gordon, 1980). Nowicki and Duke (1983) concluded that locus of control causes achievement.
In contrast, Ronning, McCurdy, and Ballinger (1984) found that locus of control did not appear to be a predictor of science problem solving performance. Vocabulary, field dependence-independence, and intelligence were found to be predictors when individual differences were taken into account for student performance. Beck (1979) reported that task instructions mediated the effects of locus of control on problem solving performance.

Most of these studies relating locus of control and achievement used paper and pencil tests to measure achievement. This type of measure may not reveal subjects' higher level understandings of the problem processes and solutions specific to the science context of a problem.

Internals have been predicted to adapt better than externals in high-controlling environments because of self-control skills and effective use of situational cues. Because externals generally have been found to have a need for explicit cues and have inadequate self-regulation skills, they have been predicted to adapt better in high-controlling situations, although they have been occasionally found to adapt in certain conditions of structure (Sandler et al., 1983). Additional research is needed to investigate the effects of structure on the
ability of internals and externals to adapt in problem solving situations.

Problem Solving

Researchers on cognitive theory contend that learners construct their own knowledge. In support of this theory, it has been found that, when given appropriate learning conditions, students could acquire an advanced cognitive strategy on their own when controlling variables (Kuhn & Angelev, 1976), and when they were alerted to the important features of the situation (Linn, 1980).

The effectiveness of problem solving performance has been found to be influenced by subjects' choice of variables, their own or the experimenter's, with which to experiment (Linn & Swiney, 1981); the number of variables in the task (Staver, 1986; Wozny & Cox, 1975); and the structure of instructional strategies (McKee, 1978; Shymansky & Penick, 1981).

Effective problem solving processes were described in these stages: exploring, discovering patterns, developing a strategy, applying the strategy, making and testing hypotheses, using evidence gathered to draw accurate conclusions. Fifth and sixth graders used more sophisticated processes when they constructed their own
theories when solving complex problems (Rudnitsky & Hunt, 1986).

Problem solving methods characteristic of effective problem solvers have been identified as breaking a problem into a number of parts to be dealt with separately (Smith & Good, 1984); controlling variables with consistency (Boyer, Chen, & Thier, 1976); avoiding premature closure, gathering more definitive evidence when evidence is not conclusive, generating hypothetico-deductive strategies (Wollman, Eylon, & Lawson, 1980) and making decisions based on relevant evidence (Smith, 1989).

Research Hypotheses

On the basis of locus of control and cognitive theory, the following research hypotheses were posed:

A. There will be a significant relationship between locus of control and problem solving performance, given statistical control of aptitude, sex, and race such that, the more external the locus of control orientation score of a student pair,

1. the less effective the problem solving strategy

2. the lower the task solution score

3. the fewer correct predictions made on the after-task assessment.
B. There will be a significant relationship between the condition of structure for the task and problem solving performance, given statistical control of aptitude, sex, race, and locus of control such that, the less structured the task condition,

1. the more effective the problem solving strategy

2. the higher the task solution score.
CHAPTER III
METHODOLOGY

This study was undertaken to investigate the relationship of the locus of control orientations of sixth-grade students and the task structure to the effectiveness of their problem solving performance in a complex science task.

The most extensive study designed to investigate science problem solving in this context was conducted by Mary Budd Rowe (1978). The results of her study have been unpublished except for the final report, presented to the National Institute of Mental Health [NIMH] under Grant number R01MH25229.

The present investigation used original, raw data from Rowe's study, sections of which had not been previously analyzed. These sections of data were analyzed, and other sections of data were reanalyzed and recoded using raw data. This investigation concentrated on students' control over the processes and solutions in one physical science task involving identification and control of variables to find the three fastest cylinders. Pairs of like-sex sixth-grade students, in eight subgroups, were the units of investigation (Table 3-1).
For this investigation, "structure" referred to the mode of entry to the four-variable science problem posed to the student pairs. In the "structured" task condition, students were cued to experiment with one of the four variables in the science task before entering the criterion task. This brought student attention to this particular variable in order to reduce the complexity of the four-variable criterion task. In the "unstructured" condition, students were presented with objects representing all four variables. Then, without being alerted to any one particular variable, they were asked to solve the criterion problem. In this respect, the task was cognitively structured rather than socially structured.

**Background of the NIMH Study**

The purpose of the Rowe's NIMH study was to investigate the relationship of externality to science problem solving performance in three physical science tasks.

**Sample and Design**

A sample of 4800 sixth-grade students was drawn from 105 regular classrooms in 29 schools located in 12 counties in Florida. This sample was representative of sixth-grade students in different types of communities in
Table 3-1

Eight Subgroups of Like-Sex Sixth-Grade Students in the NIMH Study

<table>
<thead>
<tr>
<th>Locus of Control</th>
<th>Male Pairs</th>
<th>Female Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>External</td>
<td>Internal</td>
</tr>
<tr>
<td>* Condition</td>
<td>S</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>U</td>
</tr>
</tbody>
</table>

* S = Structured Condition; U = Unstructured Condition

rural, urban, and suburban areas. It was representative of diverse socioeconomic levels, with the socioeconomic level of students decided upon by Rowe on the basis of student participation in the free lunch program in the schools.

The schools themselves were also representative of different types of school organization: sixth grade as the only grade level in the school (sixth-grade centers), sixth grade as the lowest grade in a school comprising grades six to eight, and sixth grade as the highest grade in kindergarten through sixth-grade schools. Rowe chose sixth-grade students for her study because this age group represents a key transformation time in the development of formal reasoning.
Subjects in this sample of 4800 were administered a locus of control measure, the Children’s Nowicki-Strickland Internal-External Control assessment. They were also given an aptitude measure, the Ravens Progressive Matrices, based on visual analogies.

Rowe chose to use pairs of subjects for the experimentation phase of her study because this type of methodology was conceptually relevant and had the following advantages:

The technique minimized the necessity for direct probes, from the observers, which could have been a source of variation and bias.

Discussion between subjects in a pair was more likely to display the variety and depth of concepts subjects thought would be involved.

At this point, Rowe created an algorithm to be used to randomly form pairs of like-sex subjects, to further control individual differences within teams, for the problem solving phase of the study. Pairs were formed first by sex, then by locus of control orientation. Included in the algorithm was a maximum difference criterion of 5 points on the locus of control measure for each pair of like-sex subjects, so the locus of control orientations of students in each pair were similar. Three hundred like-sex pairs were then randomly formed by computer, using Rowe’s algorithm. Of these preselected
pairs, 247 pairs actually took part in the problem solving phase of this study. The original sample variables, different types of communities and school organizations, and diverse socioeconomic levels of subjects, were spread across this smaller sample so every variable of interest had range. Then, each student pair was given an identification number.

At the time of selection of subjects and assignment of these subjects to pairs, and then to treatment, only the sex and scores on the Nowicki-Strickland and Ravens were known. No prior information on the ethnic distribution of the selected pairs was sought because research (e.g., Coleman et al., 1966) had not indicated conceptually relevant ethnic factors. Locus of control had been related to socioeconomic status rather than ethnic group.

Like-sex pairing of students resulted in six visually identifiable subgroups: female pairs had subgroups of blacks, whites, and mixed-race pairs; male pairs had these same three subgroups. See Table 3-2 for the number of students in each of these subgroups.
Table 3-2

Population of Students in Subgroups

<table>
<thead>
<tr>
<th>Race of Subgroups</th>
<th>Male Pairs N</th>
<th>Female Pairs N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>Mixed Race</td>
<td>43</td>
<td>36</td>
</tr>
<tr>
<td>White</td>
<td>61</td>
<td>66</td>
</tr>
<tr>
<td>Totals</td>
<td>126</td>
<td>121</td>
</tr>
</tbody>
</table>

Measurement Instruments

Locus of control

The Children's Nowicki-Strickland Internal-External Control measure was developed by Nowicki and Strickland (1973) to assess a general locus of control orientation in 9- to 18-year-old children. It is a paper and pencil measure containing 40 questions, each requiring a yes or no answer. Responses on the 40-item children's Nowicki Strickland are scored with 1 point for each response demonstrating an internal orientation and 3 points for each external response. Raw scores are used as each subject's score. The higher the raw score, the more external the assessed orientation of the subject.
In results of extensive sampling of researchers' reports of construct validity for this Nowicki-Strickland measure, it has been reported that the internal consistency and test-retest reliability have both generally been above .60. Test-retest reliabilities were found to be higher over shorter periods of time; however, it has been demonstrated that the Nowicki-Strickland has had acceptable test-retest reliability for periods as long as one year (Nowicki & Duke, 1983).

Sixth-grade students in the NIMH study were given the children's form of the Nowicki-Strickland twice, first as a pretest, then approximately 7 months later, as a posttest, at the time of involvement in the laboratory tasks. Rowe (1978) found the 7-month test-retest reliability was .68 for this measure. She further found that subjects' socioeconomic status, rather than type of school organization, had an effect on student locus of control orientations.

When random samples of approximately 250 tests were drawn from a pool of 4800 tests and analyzed, Rowe found that no compelling factors emerged for the Nowicki-Strickland. She completed an item analysis using the original sample of about 4800 students, the largest sample for which the children's Nowicki-Strickland items had been analyzed. The results of this analysis
indicated that 18 out of 40 items were acceptable discriminators. Items found to be discriminators were item numbers 1, 3, 5, 7, 8, 10, 15-21, 25, 28, 30, 24, 35, 38, and 40.

**Intelligence**

In addition to the children’s Nowicki-Strickland, the Raven Progressive Matrices (Raven, 1938) test was chosen to be administered to the sixth-grade sample in this study. Rowe chose this nonverbal, visual aptitude test, because it was conceptually similar to the problem solving situations to be posed to the subjects in the experimentation phase of her study. Completion of the Ravens did not require the subjects to read. It did require subjects to identify the relationships among the figures used in each item of the test. To complete each item, subjects needed to build the context for the concept being presented for identification as they worked through the item’s visual figures to come to a solution. For each item, a choice needed to be selected as a solution, the choice that was thought to complete a set of figures, a solution resulting from simultaneous changes in figures from two directions.

The Ravens has been generally identified as a measure of "general fluid intelligence" which is defined by Jensen (1971) as "the first principal component of an
indefinitely large number of highly diverse mental tasks" (p. 136). Raven (1966) described his test as "a measure of an individual's capacity, at the time of the test, to apprehend . . . figures presented for his observation, to see the relation between them, to conceive the nature of the figure completing each system of relations presented, and by so doing, to develop a systematic method of reasoning" (p. 1).

According to Cloutier and Goldschmid (1976), the Ravens can also be considered an index of nonverbal convergent thinking. Cloutier and Goldschmid give these arguments in support of this use of the test:

a. no words are involved in the test stimuli
b. all problems are in sight of the subject
c. all questions converge on a single right answer
d. the items involve both generating hypotheses concerning the relations among the stimuli and testing hypotheses in order to select the appropriate answer. (p. 1098)

The 60 problems on the test are divided into 5 sets of 12 items each. Items in each set are progressively more difficult than the items in the previous set. In scoring the Ravens, 1 point is given for each correct response.

Procedures

Rowe chose three physical science tasks for the subjects in the problem solving phase of this study:
a radio task, used as an orientation or calibration problem, and two tasks adapted from two National Science Foundation funded elementary science programs, a cylinder and a spinning table task.

The administration of the tasks and the conditions for this phase were as uniform as possible across school sites. All three tasks were housed in a trailer that was moved to the various school sites in Florida where selected student pairs were to be found. At each school site, students came to the trailer once each day for 3 days. All student pairs at a site performed the radio task on their first visit. This first visit and task also served to familiarize them with the trailer setting and experimental procedures. The order in which each student pair did the next two tasks (the cylinder and spinning table tasks) and the treatment condition (structured or unstructured) for each task had been previously determined by random assignment. For example, some student pairs performed the cylinder task as the second task; some performed the cylinder task as the third task. If the students had been assigned to the structured condition for the second task, they experienced the unstructured condition in the third task.

The observers worked in the middle room of the trailer, and the pairs of students carried out their
tasks in the two end rooms equipped with microphones and one-way windows. Face-to-face exchanges between the students and the experimenters were avoided during the tasks. Directions for task proceedings were given by a tape recording. No praise, criticism, or evaluation of the task results were given to the students. These controls were built in as part of the protocols in order to minimize student attempts to read nonverbal clues from the observers and to minimize any effects of ethnic differences between the students and the task administrators. None of the observers had knowledge of the assessed locus of control orientations or intelligence of students during the experimental phase of the study.

Situational characteristics

Nowicki and Duke (1983) stated that the presence of certain situational characteristics result in a strengthening of the relationship between generalized locus of control expectancies and behavior, a relationship usually found to be low. For this relationship to be strongest, the situation must be novel or ambiguous for subjects.

In Rowe’s NIMH study, these situational characteristics were present. In addition, the components of performance that depended on social context
were distinguished from the intellectual or cognitive characteristics of the task and the setting, as suggested by Joe (1971). In addition, students were placed in a potentially interesting and motivating situation where

a. prior experience with the phenomena of the problem was unlikely

b. students were presented with a problem which had several possible pathways to solution

c. the direction of the solution process was under students' control

d. cue selection, evaluation and use was potentially under the governance of a growing context of meaning

e. the observers were not viewed by the students during the problem solving activities, so cues from outside were not in evidence to students

f. there were no extrinsic rewards given to students

g. students were involved in tasks in both structured and unstructured situations (cued and uncued)

h. the task outcome could be perceived by students as being influenced either by their skill or by chance.

The cylinder task

The science problem solving task that was the focus of the present study was the cylinder task. A description of the radio and spinning table task is in Appendix B.
The cylinder task had a brief pretask familiarization procedure. All subjects practiced racing solid cylinders made of colored wood, a material different from cylinder materials used in the criterion task, to assure understanding of instructions, to allow practice using the starting gate on the ramp, and to establish the predetermined procedures for racing. The wooden cylinders were in different sizes and colors. (Transcriptions of the audiotaped instructions given to all subjects for pretask and task procedures are in Appendix A.)

After student pairs completed the pretask procedures, they were introduced to the main cylinder task. Students had a rack of 18 cylinders, arranged in an ordered array, that differed in material, diameter, length, and type (solid or hollow), Figure 3-1.

Next to the cylinder rack was a ramp, on which to roll the cylinders, that had a starting gate. On the wall in back of the students was a display pegboard with multiple copies of actual size photographs of each cylinder. These pictures of cylinders were orderly arranged in a way that mirrored the ordered array of the cylinders in the rack. There was a second pegboard, called the data display board, on which subjects were to
Figure 3-1. Cylinder Variables.
place pictures of cylinders to show results of their cylinder races.

The criterion cylinder task required students to find the 3 fastest cylinders of the 18 by racing them down the ramp. The cylinders could be raced in pairs or in trios. All cylinders were to be started in motion by lifting a starting gate behind which were the cylinders the student pairs had decided to race. When a race was completed, subjects were to take photographs of the cylinders they had raced off the display board and hang them on the pegboard to show the race results. Pictures were to be hung as the cylinders finished: first, second, and third. As students proceeded to test the combinations of various cylinders, the display on the pegboard expanded. The pictures on this display board were used as a reference to help the students and observers keep track of outcomes of races.

The cylinder task was available in two treatment conditions, structured and unstructured, in which student pairs were randomly placed. In the structured condition students were cued or alerted to one particular cylinder variable to reduce the complexity of the criterion task. This allowed them to build context for the concept, using one less variable than used in the criterion task, and to decide on winners to which they could refer back. In
this condition, students were asked to do two simpler problems: first, to find the fastest hollow (out of 9 hollow cylinders); second, to find the fastest solid (out of 9 solid cylinders). Then they were to find the 3 fastest out of the 18 cylinders, the criterion task.

In the unstructured treatment condition, students went directly into the criterion problem that involved four variables. They were asked to find the 3 fastest cylinders without preliminary cued experimentation with the 18 cylinders.

The data coded by observers and reel-to-reel audiotape recordings of conversations between the observer and students in each pair kept track of student task data: the cylinders raced and the winning cylinder in each trial during the task, the number of cylinders raced during each trial, the extent to which the display board was used, and the student decisions on the three fastest cylinders.

At the conclusion of the criterion task, student pairs applied the concept represented in the cylinder task as an after-task assessment. In one part of the assessment, they were shown various cylindrical objects and were asked to make predictions of the outcomes in proposed races. Next, they did trial races to test their predictions. If a prediction were not confirmed by the
trial race, students were asked to give an explanation of the reason the faster racer won. In the other part of the assessment, the students were verbally given a list of 12 descriptive words (e.g., skinny, fat, long, short, heavy, light) and were asked to tell the observer which three words they would use to describe how they could make a cylinder the fastest racer. There were 10 items to which each student pair responded on this after-task assessment.

During the assessment, the observer coded student predictions, outcomes of races, and student descriptions of the fastest racer. All conversation among the students and the observer was taped on reel-to-reel audiotape. This data, in addition to the data gathered during the cylinder task, pre- and posttests for the Nowicki-Strickland measure, and the Ravens pretest, were kept in packets. There was one packet of data for each student pair that participated in the problem solving portion of the study.

(Background for the NIMH Study was taken from the final report presented to the National Institute of Mental Health [NIMH] by Principal Investigator, Mary Budd Rowe, Grant Number R01MH25229. For additional information, see the report.)

Methodology for the Present Study

The preliminary procedure for the present study was to become immersed in the background of the NIMH study,
the apparatus used for the laboratory phase of the study, and the data collected. Many meetings were held with Mary Budd Rowe to improve contextual understanding of the environment and procedures involved in the study. She gave insight into the procedures used, along with anecdotal comments, which helped this researcher feel as if she were a part of the original study. Additional background was acquired by reviewing the final report of the study made to NIMH (Rowe, 1978) and examining the contents of packets containing data for student pairs.

The cylinders and ramp used in Rowe’s study were cleaned, repaired, set up, and tested. Cylinder task procedures were replicated using the original ramp and cylinders. Pairs of adult volunteers, given instructions for the cylinder task as had the subjects in the original study, worked through the task to find the winning cylinders. This researcher took the part of the observer, completing code sheets to keep track of the task data. This was done to improve understanding of differing problem solving processes, to better comprehend complex coding procedures, and to resolve technical questions.

The reel-to-reel audio and video recordings, taped during the original cylinder tasks, were found to have surface degeneration. These recordings were cleaned, and
the recordings were retaped in more usable formats. The audio recordings were transferred to cassette tapes, and the video recordings were transferred to VHS formatted videotapes. These tapes were reviewed to expand understanding of the proceedings by actually hearing and seeing reactions of the subjects to the cylinder task.

During this time, a considerable amount of reviewing of the literature concerning locus of control and problem solving was accomplished to attempt to integrate the conditions of Rowe’s NIMH study with related theory and the results of research.

**Selection of the Sample**

Next, data packets, of which there was one packet per student pair, were reviewed. Packets that contained full data pertaining to the cylinder task and student pair demographics were identified. One hundred of these packets were retained for use in this investigation. Included in the 100 packets was an oversampling of minority group student pairs. Because the proportion of minority subjects in the Rowe study was rather small in comparison with other subjects, all packets with data for student pairs that contained minority group subjects and included complete data were used for this study. Table 3-3 shows the subgroups for the sample in this study.
Data Collection and Display

Data on observer code sheets for the cylinder task were studied and understanding of student problem solving processes was undertaken. Because the data on the original observer code sheets were not conceptually

Table 3-3
Subgroups of Student Pairs for this Study

<table>
<thead>
<tr>
<th></th>
<th>Male Pairs</th>
<th>Female Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Total Pairs</td>
<td>54</td>
<td>46</td>
</tr>
<tr>
<td>Black Pairs</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>White Pairs</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>Mixed-Race Pairs</td>
<td>16</td>
<td>14</td>
</tr>
</tbody>
</table>

powerful for this researcher to identify the specific problem solving process of each student pair, a new cylinder task data display format was created. Cylinder task data were graphically redisplayed in this new format, with trial races color coded, so processes and strategies used by subjects could be more easily seen and analyzed. Figures 3-2 through 3-4 represent black and white examples of color graphic displays showing specific problem solving strategies used by student pairs.
Figure 3-2 displays the cylinder trials run using the "Tennis Tournament" strategy. A series of races were run across the different cylinder sizes, between cylinders of the same type (solid or hollow) and material (steel, aluminum, or plastic). When these races were completed, the student pair ran the winners of the previous sets of trials to find the three fastest cylinders. In the graphic display, three different types of lines were used. The solid line represents the winning cylinder for each trial; the next two lines represent the other two cylinders raced in the trial. The numbers above the lines show the trial numbers in the sequence they were run. For example, for the first trial, three solid cylinders were run. Following the pathway between variables, these first three were steel cylinders; one was long and fat, one was long and skinny, and one was short and skinny. The largest solid steel cylinder won the race.

The data display shows a balanced and effective "Tennis Tournament" strategy completed in a record eight trial races (which yielded new data) in the unstructured task condition. The students raced all 18 cylinders, mostly in trios, and controlled all variables except 1 in the 8 trials. The observer's notes stated that the pair did not use the data board to keep track of trials.
Figure 3-2. Graphic Data Display for "Tennis Tournament" Strategy.
The student pair accurately chose all 3 winners and had 8 accurate predictions out of the 10 on the after-task assessment. The student pair who accomplished this had a relatively high score on the Ravens and a locus of control orientation assessed as internal.

In comparison to the "Tennis Tournament" strategy, the "King of the Mountain" strategy displayed in Figure 3-3 shows much less balance, with a series of races run with the largest solid steel cylinder. This cylinder was the "King of the Mountain" winner in 10 out of the 11 trials it was raced.

Using this strategy in the unstructured task condition, the student pair completed 12 trial races, raced 11 of the 18 cylinders in duos, and controlled all variables except one in half of the trials. The students did not use the data board to keep track of trial race winners. They accurately chose 2 out of 3 winning racers and had 4 out of 10 predictions correct on the after-task assessment. Students in this pair had above average scores on the Ravens and were assessed as being external.

Figure 3-4 shows no obvious problem solving strategy. The students in this pair did not appear to use a system of choosing cylinders to race. They controlled variables in only one of the trials and raced 13 out of the 18 cylinders in trios.
Figure 3-3. Graphic Data Display for "King of the Mountain" Strategy
Figure 3-4. Graphic Data Display for Random Moves.
The students in this pair appeared to choose the cylinders for their first trial race at random. Their second trial cylinders indicated their beginning hypothesis was that the smaller, solid cylinders were fastest even though the largest aluminum cylinder won the first race. These students ran more trials racing the smallest cylinders than the medium-sized or largest cylinders. This relates to the conclusions reached by Lovell (1961), that student perception interfered with the ability to deduce from observations, Linn (1977), that students interpret their experiments in the direction of their expectations, and Linn and Swiney (1981), that students use their expected variables during experimentation more often than other variables.

None of the correct winners were chosen by this student pair even though two were actual winners in three of their races. They did not avoid premature closure (Wollman et al., 1980). This student pair chose, as their three winners, the same smallest, solid cylinders they had raced in their second trial. They did not use the evidence built from their trials: larger cylinders won every trial race in which they were raced. This relates to conclusions reached by Smith (1990) that ineffective problem solvers make decisions based on inappropriate evidence.
As for predictions on the after-task assessment, they were correct in 7 out of 10 cases. Even though they did not come up with an identifiable strategy, or choose any of the three fastest cylinders, it was interesting to find that their prediction score was relatively high.

Graphic data displays were drawn, using the data on the original observer code sheets, for a large portion of the student pairs. Patterns shown on these data displays were compared, categorized, and evaluated for their importance in the problem solving process. A flow chart of the processes found to be effective was made (Figure 3-5).

Description and Scoring of Variables

The cylinder task was found to be a complex, real-world task that had a natural element of uncertainty built into it. Students needed to organize their experiences and test their ideas concerning the variables to build context for the solution. They needed to turn their beginning state of knowledge into confirming or disconfirming tests as they went through the problem solving process in order to generate their own strategies to find a solution to the task. The cylinder task was such that inferences could be made as to the dominant variables students used and the overall strategy could be contrasted with an optimum strategy. This investigator
SHOWS AWARENESS OF TASK PROBLEM
(Find 3 fastest cylinders)

Begins with own idea of concept
Identifies variables
Makes initial prediction
Tests prediction

FORMS AND TESTS HYPOTHESES
Generates and Tests Problem Solving Strategy
(i.e., tennis tournament)
Separates variables
Races among and across variables
in orderly pattern

Keeps track of race outcomes
(i.e., data board)
Changes one variable at a time
Races all cylinders in duos or trios

Builds concept of cylinder variables contributing to "winning"
based on evidence
Uses evidence to choose cylinders for playoffs
Uses accumulated evidence to choose 3 winning cylinders
Comes to solution of task problem

Figure 3-5. Effective Problem Solving Process for the Cylinder Task
studied student processes of arriving at a decision. The students' problem solving strategies and final decisions were evaluated against the standards of a strategy found to be the most efficient and effective problem solving strategy and the three actually fastest cylinders.

Variables evaluated as being indicative of an effective problem solving process were decided upon, and scoring methods were developed and described for these variables: problem solving strategy, number of trial races, number of cylinder variables crossed, number of trials in which all variable except one were controlled, mode of racing cylinders (in duos or trios), and number of correct solutions. The following is a description of the cylinder task variables and scoring method.

**STRUCTURE**

The cylinder task was administered in two treatment conditions, structured and unstructured. In the structured condition, students were asked to solve two simpler tasks, i.e., to find the fastest of the 9 hollow cylinders, then find the fastest of the 9 solid cylinders before attempting the criterion task of finding the 3 fastest cylinders out of the 18 cylinders. In the unstructured condition, students had only one task: to find the 3 fastest cylinders out of the 18 solid and hollow cylinders.

The structure variable indicated the condition of structure: 0 = structured 1 = unstructured.
Strategies for converging on a solution to the cylinder task were ordered in terms of their effectiveness - potential information yield per move. A hierarchy of strategies was identified with levels ranging from 0 to 4.

(There was a strategy variable in the original NIMH study. For this study student strategies were reevaluated, more definitive scoring protocols were developed, and the strategy used by each student pair was rescored.)

Levels of strategies:

4  Tennis Tournament - series of races run with races between series winners

3  King of the Mountain - ran race, kept winner, added new racers for each successive trial; incomplete Tennis Tournament strategy

2  Mix of strategies: Tennis Tournament, King of the Mountain and/or others with some randomness; not as much evidence used for decision making in strategies; some deteriorated sequences

1  No clearly identifiable strategy; random search; not much evidence used for decision making

0  Made a few moves then stopped; chose arbitrarily with little or no evidence used for decision making

Scoring for strategy:
For unstructured condition - Strategy level X 3.
Scores ranged from 0-12
For structured condition -
Strategy level for Task #1 plus
Strategy level for Task #2 plus
Score for Task #3:

4 - raced winners of Tasks 1 and 2

3 - raced winners and repeated some trials from Tasks 1 and 2; incomplete strategy

2 - raced winners plus other cylinders; repeated many trials run in Task 1 and 2; not as much evidence for decision making

1 - decisions for task winners based on little evidence from Task 1 and 2 or races from Task 3.

Scores ranged from 0-12

SOLUTIONS (0-20)

Outcomes of cylinder races could be very close. Decisions regarding the three fastest cylinders needed to be made. Points were either earned for each correct solution or near alternative. Half the number of points were given for near alternatives as were given for correct decisions.

(SOLUTIONS was comparable to the CORT variable in the original study, but the calculation for SOLUTIONS was different.)

Calculation for SOLUTIONS score:

In the unstructured condition:
4 points each for cylinders: #3, 9, 15
2 points each for cylinders: #2, 6, 18
Calculation: # points for 3 cylinder winners X 1.67

In the structured condition:
Task #1 - Hollow cylinders
4 points for #6 or 18
2 points for #5 or 12

Task #2 - Solid cylinders
4 points for #3, 9, or 15
2 points for #2

Task #3 - 3 winners
4 points for #3, 9, or 15
2 points for #2, 6, or 18

Calculation: Added number of points earned from Task #1, #2, and #3.

Scores ranged from 0-20.

PREDICTIONS (0-10)

PREDICTIONS was a new variable. After student pairs completed the cylinder task, they were asked to predict winners of races using different kinds of cylinders. This was used as a measure of student understanding and ability to apply task concepts. The predictions score was based on the number of predictions found to be accurate as evidenced by these after-task cylinder races.

Scores ranged from 0-10.

(This assessment measure from the original NIMH study had been previously unscored.)

After student pairs completed the criterion cylinder task, they were given oral directions for a hands-on assessment (using concrete objects) of their understanding and ability to apply the concepts involved in the cylinder task. This section of data, gathered by
observers in the original study, had been previously unscored and unanalyzed.

For the present study, this investigator reviewed these data that had been recorded on observers' data sheets. Scores were given for correctly predicted items on the after-task assessment. These scores were used in analyses as an outcome variable.

Rescoring of the Nowicki-Strickland

The Nowicki-Strickland assessment for each student was rescored for this study, using only the 18 items found to discriminate for the original sample in the NIMH study, to obtain a new locus of control orientation score for each subject. A listing of the discriminating items can be found on page 51.

The Nowicki-Strickland was also rescoring another way. Only the six discriminating items that were related to Rowe's "science phenomena domain," control over things, events, or problems, were included. These six item numbers were 1, 7, 16, 19, 28, and 38.

1. Do you believe that most problems will solve themselves if you just don't fool with them?

7. Do you feel that most of the time it doesn't pay to try hard because things never turn out right anyway?

16. Do you feel that when you do something wrong there's very little you can do to make it right?
19. Do you feel that one of the best ways to handle most problems is just not to think about them?

28. Most of the time, do you feel that you can change what might happen tomorrow by what you do today?

38. Are you the kind of person who believes that planning ahead makes things turn out better?

Each of these 6 items was scored either 1 point for an internal response or 3 points for an external response. Raw scores for both of these shorter locus of control measures were used in statistical analyses. Results of the analyses are included in Chapter IV.

Spread sheets were developed and used to record the abundant data on demographics, cylinder task processes and solutions, and assessment scores for subjects in each student pair.

The investigator then used the Statistical Analysis Software (SAS) computer program to run descriptive statistical procedures, analysis of variance, and multiple regression analysis procedures for these data.

**Statistical Hypotheses**

The following statistical hypotheses were tested for the sample of 100 sixth-grade student pairs in this study:
1. There is no statistically significant relationship between locus of control orientation and the effectiveness of problem solving strategies when the variance for sex, race, and intelligence has been partialled out.

2. There is no statistically significant relationship between locus of control orientation and the accuracy of the solutions to the problem solving task when the variance for sex, race, and intelligence has been partialled out.

3. There is no statistically significant relationship between locus of control orientation and the effectiveness of predictions on the after-task assessment when the variance for sex, race, and intelligence has been partialled out.

4. There is no statistically significant relationship between the task structure and the effectiveness of the problem solving strategy when the variance contributed by sex, race, intelligence, and locus of control has been partialled out.

5. There is no statistically significant relationship between the task structure and the accuracy of the task solutions when the variance contributed by sex, race, intelligence, and locus of control has been partialled out.
CHAPTER IV
RESULTS AND DISCUSSION

The purpose of this study was to extend the theoretical and empirical differentiation of the locus of control construct in the context of problem solving in science. The relationship of the locus of control orientations of sixth-grade students to the effectiveness of their problem solving performance was investigated. The effect of the condition of structure for the task on problem solving performance was explored. The following specific questions were asked:

1. Is there a relationship between the locus of control orientation and problem solving performance of sixth-grade student pairs in a complex physical science task?

2. Does the structure of the science task affect the predictive value of the locus of control assessment instrument?

Data were gathered on 200 sixth-grade students who had completed the Nowicki-Strickland locus of control assessment and the Raven Progressive Matrices Test. Students were divided into 100 like-sex pairs, matched on locus of control orientation which met a maximum
difference criterion of five points (i.e., the difference between the student’s locus of control scores in each pair was no more than 5 points). All 100 student pairs performed a science problem solving task and completed an assessment to measure understanding and ability to apply task concepts. The student pair was considered a unit for statistical analyses.

The means, standard deviations, populations, and correlations of scores for sixth-grade student pairs are found in Tables 4-1 through 4-9. Multiple regression analyses and interactions related to the problem solving performance for student pairs are found in Tables 4-11 through 4-15 and Figures 4-1 through 4-4.

**General Descriptive Data**

**Ravens**

Results of data analysis for the Ravens, Table 4-1, show that the overall mean on the Ravens for females (35.37) was higher than the overall mean for males (30.51), with the variance in scores greater for males than for females. Analysis of variance resulted in a significant difference with p<.01 for these mean scores. In general, females were higher than males in fluid intelligence, described by Raven (1966) as "systematic reasoning." This is consistent with results found by
Rowe (1978) for the 247 student pairs included in the original NIMH study.

Table 4-1

Descriptive Statistics for the Ravens (Fluid Intelligence)

<table>
<thead>
<tr>
<th>Student Pairs</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Pairs</td>
<td>100</td>
<td>32.74</td>
<td>9.53</td>
</tr>
<tr>
<td>Female Pairs</td>
<td>46</td>
<td>35.37</td>
<td>8.30</td>
</tr>
<tr>
<td>White Pairs</td>
<td>20</td>
<td>41.00</td>
<td>5.78</td>
</tr>
<tr>
<td>Black Pairs</td>
<td>12</td>
<td>25.83</td>
<td>4.74</td>
</tr>
<tr>
<td>Mixed-Race Pairs</td>
<td>14</td>
<td>35.51</td>
<td>6.15</td>
</tr>
<tr>
<td>Male Pairs</td>
<td>54</td>
<td>30.51</td>
<td>10.00</td>
</tr>
<tr>
<td>White Pairs</td>
<td>24</td>
<td>37.38</td>
<td>6.56</td>
</tr>
<tr>
<td>Black Pairs</td>
<td>14</td>
<td>21.63</td>
<td>6.24</td>
</tr>
<tr>
<td>Mixed-Race Pairs</td>
<td>16</td>
<td>27.97</td>
<td>9.80</td>
</tr>
</tbody>
</table>

Nowicki-Strickland

Locus of control orientation is measured on a continuum from external to internal. The higher scores on the Nowicki-Strickland indicate an external locus of control orientation; lower scores represent internality.

Even though females generally scored higher on the Ravens than males, the locus of control orientations of female pairs were somewhat more external than male pairs (Table 4.2). Analysis of variance procedures resulted in no significant difference between the female and male
mean scores. Comparison of locus of control mean scores (Table 4-8), within groupings for gender and between subgroups, indicated that white females had significantly lower (more internal) mean scores than black females ($p < .05$); white males had significantly lower mean scores than black males ($p < .01$).

Table 4-2

Descriptive Statistics for the 40-Item Nowicki-Strickland (Locus of Control)

<table>
<thead>
<tr>
<th>Student Pairs</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Pairs</td>
<td>100</td>
<td>72.59</td>
<td>10.75</td>
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<tr>
<td>Female Pairs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White Pairs</td>
<td>20</td>
<td>69.73*</td>
<td>10.29</td>
</tr>
<tr>
<td>Black Pairs</td>
<td>12</td>
<td>78.71*</td>
<td>8.35</td>
</tr>
<tr>
<td>Mixed-Race Pairs</td>
<td>14</td>
<td>76.86</td>
<td>7.92</td>
</tr>
<tr>
<td>Male Pairs</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>White Pairs</td>
<td>24</td>
<td>67.56**</td>
<td>12.44</td>
</tr>
<tr>
<td>Black Pairs</td>
<td>14</td>
<td>78.32**</td>
<td>4.83</td>
</tr>
<tr>
<td>Mixed-Race Pairs</td>
<td>16</td>
<td>70.38</td>
<td>11.46</td>
</tr>
</tbody>
</table>

* $p < .05$
** $p < .01$

These results support the consistent finding in literature that U.S. blacks tend to be more external than U.S. whites (Battle & Rotter, 1963; Coleman et al., 1966;

The validity of operationalizing the locus of control construct across cultures has been questioned. For a review of research relating to this question, see Dyal (1984). One way of approaching the problem of whether a locus of control scale is the same or different for blacks and whites is by conducting factor analysis of large samples. Rowe (1978) found that, for the 247 student pairs in the original NIMH study, there was no significant factor structure.

During the present study, the 40-item Nowicki-Strickland was rescored for each subject using only the 18 items found by Rowe to discriminate for the original NIMH population. The 7-month test-retest reliability of this shortened 18-item locus of control measure for the 200 students in this study was .64 in comparison with the test-retest reliability of .68 for the 40-item Nowicki-Strickland reported by Rowe (1978) in her final report to NIMH. The reason for the lower reliability is that the shorter measure had less than half the number of items than the original measure. The correlation between the shortened and original assessment was .93.

A second method was used to rescore the Nowicki-Strickland for the sixth-grade students in this study.
Six of the discriminating items were related to Rowe's "science phenomena domain" (Figure 1-1, page 9) representing control over things, events, or problems. These items were scored with 1 point for each response demonstrating an internal orientation and 3 points for each external response. Raw scores, which ranged from 6 to 18, were used for each subject. The reliability coefficient (Cronbach's Alpha) for this "new" 6-item locus of control measure was .56 for the 200 students in this sample. The correlation between this measure and the 40-item Nowicki-Strickland was .75.

Table 4-3

Descriptive Statistics for the Six-Item Nowicki-Strickland for the "Science Phenomena Domain"

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
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</tr>
<tr>
<td>Females</td>
<td>92</td>
<td>10.97</td>
<td>3.18</td>
</tr>
<tr>
<td>White</td>
<td>54</td>
<td>9.78*</td>
<td>2.95</td>
</tr>
<tr>
<td>Black</td>
<td>38</td>
<td>12.66*</td>
<td>2.73</td>
</tr>
<tr>
<td>Males</td>
<td>108</td>
<td>10.57</td>
<td>3.08</td>
</tr>
<tr>
<td>White</td>
<td>65</td>
<td>10.02**</td>
<td>3.20</td>
</tr>
<tr>
<td>Black</td>
<td>43</td>
<td>11.42**</td>
<td>2.70</td>
</tr>
</tbody>
</table>

*  p<.0001  
** p<.05
Results of analysis of responses on the "new" locus of control measure for the "science phenomena domain" are in Table 4-3.

In general, ANOVA results (Table 4-8) indicated significant differences for subgroups on this "new" measure that were similar to those found for the 40-item Nowicki-Strickland. The difference between the mean scores for the total male and total female groups did not reach significance. Mean scores for white females and black females were significantly different at \( p < .0001 \); scores for white males compared to black males reached significance at \( p < .05 \). These results indicate white sixth graders in this sample of 200 had more internal orientations in the area of control over things, events, or problems than did black sixth graders. It is possible that this shortened, 6-item version of the Nowicki-Strickland could be the beginning of an assessment to measure children's locus of control orientation in the "science phenomena domain."

Problem Solving Strategy

The problem solving strategies employed by student pairs to solve the cylinder task were ordered in terms of effectiveness from a "tennis tournament technique" to random moves. Scores for student pairs on strategy ranged from 2 to 12, the highest possible score. There
were no significant differences between mean scores of subgroups on strategy (Table 4-4).

It is interesting to note that, even though there was a significant difference between the mean scores for the black and the white student pairs for both genders on locus of control, there was not a significant difference between their mean scores on strategy. If the white pairs of both genders had more internal locus of control orientations than the black pairs, theoretically

Table 4-4

Descriptive Statistics for Problem Solving Strategy

<table>
<thead>
<tr>
<th>Student Pairs</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Pairs</td>
<td>100</td>
<td>8.37</td>
<td>2.88</td>
</tr>
<tr>
<td>Female Pairs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White Pairs</td>
<td>46</td>
<td>8.15</td>
<td>2.99</td>
</tr>
<tr>
<td>Black Pairs</td>
<td>20</td>
<td>8.60</td>
<td>2.76</td>
</tr>
<tr>
<td>Mixed-Race Pairs</td>
<td>12</td>
<td>7.67</td>
<td>3.14</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>7.93</td>
<td>3.29</td>
</tr>
<tr>
<td>Male Pairs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White Pairs</td>
<td>54</td>
<td>8.56</td>
<td>2.80</td>
</tr>
<tr>
<td>Black Pairs</td>
<td>24</td>
<td>9.13</td>
<td>2.91</td>
</tr>
<tr>
<td>Mixed-Race Pairs</td>
<td>14</td>
<td>7.50</td>
<td>2.65</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>8.63</td>
<td>2.66</td>
</tr>
</tbody>
</table>

it would follow that their problem solving strategies would be significantly more effective. From the comparisons of mean scores, this was not the case for
student pairs in this sample. Strategy scores possibly could have been affected by a restriction in range.

**Problem Solving Solutions**

During the cylinder task, outcomes for the cylinder races could be rather close. Student pairs needed to make decisions, backed by evidence constructed during cylinder races, regarding the three fastest cylinders to solve the task. Scores on solutions, Table 4-5, reflected the accuracy of these decisions and ranged from 0 to 20, the highest possible score.

<table>
<thead>
<tr>
<th>Table 4-5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Descriptive Statistics for Problem Solving Solutions</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Student Pairs</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Pairs</strong></td>
<td>100</td>
<td>15.74</td>
<td>4.64</td>
</tr>
<tr>
<td><strong>Female Pairs</strong></td>
<td>46</td>
<td>15.01</td>
<td>5.26</td>
</tr>
<tr>
<td>White Pairs</td>
<td>20</td>
<td>17.23*</td>
<td>3.69</td>
</tr>
<tr>
<td>Black Pairs</td>
<td>12</td>
<td>13.40*</td>
<td>5.16</td>
</tr>
<tr>
<td>Mixed-Race Pairs</td>
<td>14</td>
<td>13.21</td>
<td>6.33</td>
</tr>
<tr>
<td><strong>Male Pairs</strong></td>
<td>54</td>
<td>16.36</td>
<td>3.97</td>
</tr>
<tr>
<td>White Pairs</td>
<td>24</td>
<td>17.63**</td>
<td>2.72</td>
</tr>
<tr>
<td>Black Pairs</td>
<td>14</td>
<td>13.39**</td>
<td>4.63</td>
</tr>
<tr>
<td>Mixed-Race Pairs</td>
<td>16</td>
<td>17.06</td>
<td>3.79</td>
</tr>
</tbody>
</table>

* p<.05  
** p<.001
Although there were no significant differences between mean scores of subgroups on strategy, there were statistically significant differences between white and black student pairs on solutions. It would seem that, if there were insignificant differences between the strategies used by student pairs, there would be little difference between scores on solutions. According to the comparison of mean scores, this was not the case.

Analysis of variance results for differences between mean scores on solutions showed significance for white female and black female pairs, with p<.05, and for white male and black male pairs, with p<.001 (Table 4-8).

An inspection of the correlation coefficients (Pearson product-moment) between problem solving variables for subgroups revealed that correlations between strategy and solutions showed a wide range between subgroups (Table 4-6). Significant correlations were shown between strategy and solutions problem solving variables for black male pairs, with a correlation of .58, and white female pairs, .44 correlation. Black female pairs scores correlated at .41. In general, for pairs in these subgroups, as their scores for strategy increased, their scores for solutions increased.

Strategy and solutions scores of white male pairs showed little correlation at .04. Closer analysis of the
raw data for the problem solving performances of these student pairs disclosed two reasons for the low correlations when a good strategy resulted in a low solutions score. One reason was that the pairs developed a good problem solving strategy, finding patterns and manipulating variables, but did not use the evidence

Table 4-6

Correlations between Problem Solving Variables for Subgroups

<table>
<thead>
<tr>
<th>Variables Correlated/Student Pair Groups and Subgroups</th>
<th>N</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategy and Solutions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Group</td>
<td>100</td>
<td>.44</td>
</tr>
<tr>
<td>Mixed-Race Females</td>
<td>14</td>
<td>.76</td>
</tr>
<tr>
<td>Black Males</td>
<td>14</td>
<td>.58</td>
</tr>
<tr>
<td>White Females</td>
<td>20</td>
<td>.44</td>
</tr>
<tr>
<td>Black Females</td>
<td>12</td>
<td>.41</td>
</tr>
<tr>
<td>Mixed-Race Males</td>
<td>16</td>
<td>.06</td>
</tr>
<tr>
<td>White Males</td>
<td>24</td>
<td>.04</td>
</tr>
</tbody>
</table>

| Solutions and Predictions                              |     |                         |
| Total Group                                            | 100 | .37                     |
| Black Males                                            | 14  | .75                     |
| Mixed-Race Females                                     | 14  | .44                     |
| White Females                                          | 20  | .33                     |
| Black Females                                          | 12  | .09                     |
| White Males                                            | 24  | .03                     |
| Mixed-Race Males                                       | 16  | .00                     |
gathered to either form or test hypotheses. The second reason was that the pairs did not base the winners chosen on evidence gathered during cylinder trials. These characteristics of less effective problem solving processes parallel two of those suggested by Rudnitsky and Hunt (1986). The second reason is comparable to the inability to avoid premature closure with insubstantial evidence as described by Wollman et al. (1980).

Generally, these student pairs had been assessed as having an external locus of control orientation and were performing the cylinder task in the unstructured condition. Another reason for the low correlation between strategy and solutions was that 4 of the 24 white male pairs had a lower score than the mean on strategy, but had a perfect score on solutions. These male pairs scored higher than the mean on the Ravens and had been assessed as having an internal locus of control orientation. Three of the four pairs began the task by racing the type of cylinders that finished the task as winners, so their beginning hypothesis was considered to be accurate.

An interesting difference in patterns for scores on solutions was found for mixed-race student pairs (Table 4-5). In the female mixed-race pairs, the black female seemed to have greater input for decisions on solutions
to the cylinder task; in the male mixed-race pairs, the white males appeared to have greater input.

Predictions

All student pairs took an assessment after completing the cylinder task. Each pair was asked to make ten predictions concerning outcomes of posed races using concrete objects. The student pairs then raced the objects to determine the accuracy of their predictions. Scores for predictions were based on the number of predictions made by student pairs and found to be accurate. Actual scores for student pairs on this variable, ranged from 2 to 10.

For predictions, Table 4-7, the mean scores for both white female and white male pairs were significantly higher than for their black counterparts. There were significant differences between scores for male pairs with $p<.001$ and for female pairs with $p<.05$ (Table 4-8).

Based on theory, it would be expected that the more internal the student pair, the greater the ability to use information already acquired. In particular, internals have been reported to show a higher level of ability in using previously acquired material in a subsequent task (Phares, 1968).

The correlation between solutions and predictions, Table 4-6, was significant only for black male pairs with
a correlation coefficient of .75. The solutions and prediction scores of white male student pairs show very little correlation. Since black student pairs had been assessed on the Nowicki-Strickland as generally having external orientations, and white student pairs as having internal orientations, results of this study do not support that theory.

Table 4-7

Descriptive Statistics for Predictions

<table>
<thead>
<tr>
<th>Student Pairs</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Pairs</td>
<td>100</td>
<td>6.89</td>
<td>2.09</td>
</tr>
<tr>
<td>Female Pairs</td>
<td>46</td>
<td>6.74</td>
<td>1.96</td>
</tr>
<tr>
<td>White Pairs</td>
<td>20</td>
<td>7.45*</td>
<td>1.73</td>
</tr>
<tr>
<td>Black Pairs</td>
<td>12</td>
<td>6.00*</td>
<td>1.86</td>
</tr>
<tr>
<td>Mixed-Race Pairs</td>
<td>14</td>
<td>6.36</td>
<td>2.13</td>
</tr>
<tr>
<td>Male Pairs</td>
<td>54</td>
<td>7.02</td>
<td>2.21</td>
</tr>
<tr>
<td>White Pairs</td>
<td>24</td>
<td>8.13**</td>
<td>1.80</td>
</tr>
<tr>
<td>Black Pairs</td>
<td>14</td>
<td>5.79**</td>
<td>1.85</td>
</tr>
<tr>
<td>Mixed-Race Pairs</td>
<td>16</td>
<td>6.44</td>
<td>2.37</td>
</tr>
</tbody>
</table>

* p<.05
** p<.001
Table 4-8

Summary of Anova Results Comparing Mean Scores by Sex between White and Black Student Pairs

<table>
<thead>
<tr>
<th>Variable</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ravens</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female Pairs</td>
<td>1,31</td>
<td>1725.2</td>
<td>58.64</td>
<td>.0001</td>
</tr>
<tr>
<td>Male Pairs</td>
<td>1,37</td>
<td>2192.4</td>
<td>52.76</td>
<td>.0001</td>
</tr>
<tr>
<td>40-Item Nowicki-Strickland</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female Pairs</td>
<td>1,31</td>
<td>605.3</td>
<td>6.54</td>
<td>.05</td>
</tr>
<tr>
<td>Male Pairs</td>
<td>1,37</td>
<td>1023.5</td>
<td>9.54</td>
<td>.01</td>
</tr>
<tr>
<td>6-Item Nowicki-Strickland</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female Pairs</td>
<td>1,31</td>
<td>185.0</td>
<td>22.57</td>
<td>.0001</td>
</tr>
<tr>
<td>Male Pairs</td>
<td>1,37</td>
<td>51.0</td>
<td>5.61</td>
<td>.05</td>
</tr>
<tr>
<td>Strategy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female Pairs</td>
<td>1,31</td>
<td>6.53</td>
<td>0.77</td>
<td>.40</td>
</tr>
<tr>
<td>Male Pairs</td>
<td>1,37</td>
<td>23.35</td>
<td>2.94</td>
<td>.10</td>
</tr>
<tr>
<td>Solutions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female Pairs</td>
<td>1,31</td>
<td>110.02</td>
<td>5.99</td>
<td>.05</td>
</tr>
<tr>
<td>Male Pairs</td>
<td>1,37</td>
<td>159.53</td>
<td>12.79</td>
<td>.001</td>
</tr>
<tr>
<td>Predictions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female Pairs</td>
<td>1,31</td>
<td>15.77</td>
<td>4.98</td>
<td>.05</td>
</tr>
<tr>
<td>Male Pairs</td>
<td>1,37</td>
<td>48.39</td>
<td>14.64</td>
<td>.001</td>
</tr>
</tbody>
</table>

Condition of Structure

One of the purposes of this study was to investigate the relationship between the condition of the structure of the science task, cued or uncued, and problem solving
performance. Student pair subgroup means for each of the two conditions of structure are in Table 4-9.

The scores on strategy for black female student pairs were higher in the unstructured than the structured task condition. The structure of the task did not seem to have an effect on their scores on solutions. For white females, mean scores on strategy were the same for both conditions of structure. Their mean scores on solutions favored the more structured task. The greatest differences between mean scores were found for the mixed-race female student pairs. Both strategy and solutions scores were higher in the structured condition with a significant difference for strategy at p<.05 and for solutions at p<.01. This could indicate a relationship between these scores and the Ravens mean scores for these mixed race pairs. There is a significant difference (p<.01) between their Ravens scores for the condition of structure, with the higher Ravens mean score found in the more structured condition. The higher Ravens scores could have influenced their strategy and solutions scores.

Comparison of mean scores on strategy and solutions for black male pairs favored the structured condition, though the differences were not significant. The
Table 4-9
Means and Standard Deviations for Student Pairs by Sex, Race and Condition of Structure

<table>
<thead>
<tr>
<th></th>
<th>Female Black</th>
<th></th>
<th>Female White</th>
<th></th>
<th>Female Mixed-Race</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Struct</td>
<td>Unst</td>
<td>Struct</td>
<td>Unst</td>
<td>Struct</td>
<td>Unst</td>
</tr>
<tr>
<td></td>
<td>N=7</td>
<td>N=5</td>
<td>N=10</td>
<td>N=10</td>
<td>N=7</td>
<td>N=7</td>
</tr>
<tr>
<td>Ravens</td>
<td>25.14</td>
<td>26.80</td>
<td>39.25</td>
<td>42.75</td>
<td>40.01</td>
<td>31.00</td>
</tr>
<tr>
<td></td>
<td>(4.96)</td>
<td>(4.79)</td>
<td>(5.66)</td>
<td>(5.63)</td>
<td>(2.18)</td>
<td>(5.45)</td>
</tr>
<tr>
<td>LOC</td>
<td>77.36</td>
<td>80.60</td>
<td>69.15</td>
<td>70.30</td>
<td>75.86</td>
<td>77.86</td>
</tr>
<tr>
<td></td>
<td>(10.94)</td>
<td>(2.16)</td>
<td>(11.48)</td>
<td>(9.52)</td>
<td>(10.09)</td>
<td>(5.64)</td>
</tr>
<tr>
<td>Strategy</td>
<td>7.14</td>
<td>8.40</td>
<td>8.60</td>
<td>8.60</td>
<td>9.86</td>
<td>6.00</td>
</tr>
<tr>
<td></td>
<td>(3.18)</td>
<td>(3.27)</td>
<td>(2.55)</td>
<td>(3.10)</td>
<td>(2.41)</td>
<td>(3.00)</td>
</tr>
<tr>
<td>Solutions</td>
<td>13.43</td>
<td>13.36</td>
<td>17.80</td>
<td>16.66</td>
<td>17.14</td>
<td>9.27</td>
</tr>
<tr>
<td></td>
<td>(5.50)</td>
<td>(5.27)</td>
<td>(2.39)</td>
<td>(4.71)</td>
<td>(2.54)</td>
<td>(6.65)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Male Black</th>
<th></th>
<th>Male White</th>
<th></th>
<th>Male Mixed-Race</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Struct</td>
<td>Unst</td>
<td>Struct</td>
<td>Unst</td>
<td>Struct</td>
<td>Unst</td>
</tr>
<tr>
<td></td>
<td>N=7</td>
<td>N=7</td>
<td>N=13</td>
<td>N=12</td>
<td>N=8</td>
<td>N=7</td>
</tr>
<tr>
<td>Ravens</td>
<td>23.34</td>
<td>19.91</td>
<td>36.27</td>
<td>37.46</td>
<td>28.88</td>
<td>27.50</td>
</tr>
<tr>
<td></td>
<td>(7.55)</td>
<td>(4.53)</td>
<td>(8.06)</td>
<td>(5.82)</td>
<td>(9.33)</td>
<td>(11.77)</td>
</tr>
<tr>
<td>LOC</td>
<td>77.64</td>
<td>79.00</td>
<td>68.38</td>
<td>68.13</td>
<td>71.50</td>
<td>67.00</td>
</tr>
<tr>
<td></td>
<td>(4.89)</td>
<td>(5.07)</td>
<td>(12.11)</td>
<td>(13.78)</td>
<td>(11.23)</td>
<td>(11.43)</td>
</tr>
<tr>
<td></td>
<td>(2.48)</td>
<td>(2.85)</td>
<td>(3.09)</td>
<td>(2.70)</td>
<td>(2.03)</td>
<td>(3.46)</td>
</tr>
<tr>
<td>Solutions</td>
<td>14.86</td>
<td>11.91</td>
<td>17.23</td>
<td>17.60</td>
<td>16.63</td>
<td>18.29</td>
</tr>
<tr>
<td></td>
<td>(3.98)</td>
<td>(5.05)</td>
<td>(3.00)</td>
<td>(2.89)</td>
<td>(2.77)</td>
<td>(4.54)</td>
</tr>
</tbody>
</table>

Struct = structured    Unst = unstructured
structure of the task did not appear to make a difference to white male pairs. Mixed race male pairs had higher mean scores for both strategy and solutions in the unstructured condition.

**Results of Hypotheses Testing**

Linear multiple regression procedures were performed using the Statistical Analysis System (SAS) to test the statistical hypotheses for this sample of sixth-grade students. The coding used for the variable of sex was 0 for females pairs and 1 for male pairs. Coding for the structure of the task was 0 for the unstructured condition and 1 for the structured condition. Dummy codes used for identification of the race of student pairs are in Table 4-10.

<table>
<thead>
<tr>
<th>Table 4-10</th>
<th>Dummy Codes for Identification of Race of Student Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>X1</strong></td>
</tr>
<tr>
<td>White Pairs</td>
<td>1</td>
</tr>
<tr>
<td>Black Pairs</td>
<td>0</td>
</tr>
<tr>
<td>Mixed-Race Pairs</td>
<td>0</td>
</tr>
</tbody>
</table>
Data Analysis for the First Three Hypotheses

Regression models suggested by the first three hypotheses were used as basic (reduced) models. These models allowed analysis of partial relationships between two variables, controlling for other regressor variables, as identified in the null hypothesis. Interaction variables were added to the basic models, then these models were employed as full models.

F tests to determine whether or not there were significant differences between the full and reduced models were performed to determine the effect of inclusion of the interaction variables in the models. Full models, including interaction variables, were chosen if they showed a significant difference with \( p < .05 \), when compared to the reduced models, and once interaction variables attained significance. In these cases, the full model was then considered to give a significantly better fit than the reduced model and was preferable in explaining variance. For the first three hypotheses, the same regressor variables, sex, race, Ravens (fluid intelligence), and Nowicki-Strickland (locus of control orientation), were included in the reduced models. Interaction variables were added to the reduced models for the second and third hypotheses.
Locus of control and strategy

First hypothesis: There is no statistically significant relationship between locus of control orientation and the effectiveness of problem solving strategies when the variance for sex, race, and intelligence has been partialled out.

The best fit model had a Prob>F of .05 (Table 4-11), indicating that the regressor variables were

---

Table 4-11

Results of Regression Analysis for Problem Solving Strategy

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Parameter Estimate</th>
<th>T for Ho</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>2.0138</td>
<td>0.627</td>
<td>0.5319</td>
</tr>
<tr>
<td>Sex</td>
<td>1</td>
<td>1.0765</td>
<td>1.735</td>
<td>0.0860</td>
</tr>
<tr>
<td>Race:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White Pairs (X1)</td>
<td>1</td>
<td>-0.2206</td>
<td>-0.300</td>
<td>0.7645</td>
</tr>
<tr>
<td>Black Pairs (X2)</td>
<td>1</td>
<td>0.1055</td>
<td>0.129</td>
<td>0.8977</td>
</tr>
</tbody>
</table>

Test X1-X2=0 with 1 and 94 df, Prob>F = 0.7324 (Black vs. White Pairs)

Ravens (fluid intelligence) 1 0.1218 2.719 0.0078*
Nowicki-Strickland (locus of control) 1 0.0256 0.841 0.4025

Model: R-Square 0.1093, 5 and 94 df, F Value 2.307
Prob>F 0.0499

* p<.01
significantly related to problem solving strategy. When controlling for sex, race and Ravens, locus of control orientation was not a good predictor ($p<.4$) of performance in developing and using an effective problem solving strategy. **The null hypothesis was not rejected.**

Extensive review of the literature on locus of control identified many general characteristics of internals that were related to problem solving, characteristics that were not usually present in externals. When considering strategy, Wolk and DuCette (1974) reported that internals generally tended to use a more organized learning strategy. Other studies have described several general characteristics of internals which would be related to development of an effective problem solving strategy. For example, internals tend to

- more actively seek information to improve their effectiveness (Davis & Phares, 1967)
- be more attentive to cues which help to resolve uncertainties (Lefcourt & Wine, 1969)
- more quickly note changes in conditions around them and respond to perceptions (Lefcourt, Gronnerud, & McDonald, 1973)
- see relationships more than discrete parts (Wolk & DuCette, 1974).

Results of the present study do not support these findings with respect to development of a strategy, using concrete materials, to solve the complex cylinder task,
although a restriction in the range of scores for strategy may have influenced results.

The Ravens scores of student pairs were found to be related to the effectiveness of the problem solving strategy, with $P < .01$, when the variance contributed by sex, race, and locus of control was partialled out. The Ravens, described by its originator as a "measure of an individual's capacity . . . to develop a systematic method of reasoning" (Raven, 1966 p. 1), was the best predictor for the development of an effective problem solving strategy. In general, the higher the score on intelligence the students had achieved, the more effective their strategy to solve the cylinder task.

**Locus of control and solutions**

The second hypothesis was that there is no statistically significant relationship between locus of control orientation and the accuracy of solutions to the problem solving task when the variance for sex, race, and intelligence has been partialled out.

Regression analysis showed the best predictive model for solutions included four interaction variables and had a $\text{Prob}>F$ of .0001. Regressor and interaction variables explained approximately 30% of the variance in scores on solutions, Table 4-12.
Main effects were found for locus of control, Ravens, sex, white student pairs, and black student pairs, with $P<.05$. Significant interaction effects on solutions were found for sex X Ravens and black student pairs X Ravens. Because locus of control orientation attained significance for student pair performance on solutions, the null hypothesis was rejected.

Two general characteristics of internals are related to decision making in a problem solving situation. One concerns the tendency to make better use of information gathered when making decisions (Phares, 1968); the other describes the tendency to show more persistence in attempts to solve problems (James, Woodruff & Werner, 1965).

Because the accuracy with which the three winners were chosen is considered achievement, the rejection of the null hypothesis, in this case, supports the theory that an internal locus of control is related to greater achievement (Brown, 1980; Cervantes, 1976; Coleman et al., 1966; McCandless & Rollins, 1976; Mount, 1975; Nowicki & Duke, 1983; Nowicki & Walker, 1974; Prawatt, Grissom, & Parish, 1974; Sherman & Hoffman, 1980; Tesiny, Lefkowitz, & Gordon, 1980). Achievement in most of the studies listed above was measured by standardized tests.
such as the Stanford Achievement Test, the Metropolitan Achievement Test, and the California Achievement Test. None of the previously mentioned studies used the choice of correct solutions to a complex science problem as the achievement measure. Results of the present study may extend this locus of control theory into the domain

Table 4-12
Results of Regression Analysis for Solutions to the Task

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Parameter Estimate</th>
<th>T for Ho</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>13.9287</td>
<td>2.591</td>
<td>0.0111</td>
</tr>
<tr>
<td>Sex</td>
<td>1</td>
<td>8.8861</td>
<td>2.599</td>
<td>0.0109*</td>
</tr>
<tr>
<td>Race:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White Pairs (X1)</td>
<td>1</td>
<td>10.7882</td>
<td>2.210</td>
<td>0.0296*</td>
</tr>
<tr>
<td>Black Pairs (X2)</td>
<td>1</td>
<td>-8.5347</td>
<td>-1.973</td>
<td>0.0516*</td>
</tr>
</tbody>
</table>

Test X1-X2=0 with 1 and 91 df, Prob>F .0004*
(Black vs. White Pairs)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Parameter Estimate</th>
<th>T for Ho</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ravens</td>
<td>1</td>
<td>0.2268</td>
<td>2.002</td>
<td>0.0483*</td>
</tr>
<tr>
<td>Nowicki-Strickland</td>
<td>1</td>
<td>-0.0987</td>
<td>-2.181</td>
<td>0.0318*</td>
</tr>
</tbody>
</table>

Interactions
<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Parameter Estimate</th>
<th>T for Ho</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex*Ravens</td>
<td>1</td>
<td>-0.2214</td>
<td>-2.269</td>
<td>0.0257*</td>
</tr>
<tr>
<td>Ravens*White Pairs</td>
<td>1</td>
<td>-0.2482</td>
<td>-1.866</td>
<td>0.0652</td>
</tr>
<tr>
<td>Ravens*Black Pairs</td>
<td>1</td>
<td>0.3476</td>
<td>2.139</td>
<td>0.0351*</td>
</tr>
</tbody>
</table>

Model: R-Square 0.2945, 8 and 91 df, F Value 4.749
Prob>F .0001

* p<.05
of achievement for solutions to complex science problems, problems in which student pairs used concrete materials rather than paper and pencil assessments of achievement.

A main effect for the Ravens on solutions was found to be significant at $p<.05$. In general, the Ravens was a good predictor of performance for solutions on this task.

Interactions between the Ravens and solutions were found for student pair subgroups. In general, for black female student pairs (Figure 4-1) and black male pairs (Figure 4-2), as the scores on the Ravens increased, so did the scores on solutions. This relationship was also evident for mixed race female and mixed race male pairs, but to a lesser degree. The Ravens was not a good predictor of scores on solutions for white female pairs in this sample. For white male pairs, it appears that the lower the score on the Ravens, the higher the score on solutions. Even though the Ravens was generally a good predictor of scores on solutions according to multiple regression analysis, it predicted different results on solutions for the various subgroups as summarized in Figure 4-3.
Figure 4-1. Interactions between Ravens and Solutions for Females (with Nowicki-Strickland Held at Mean) for White Pairs (W/W), Black Pairs (B/B), and Mixed-Race Pairs (B/W).
Figure 4-2. Interactions between Ravens and Solutions for Males (with Nowicki-Strickland Held at Mean) for White Pairs (W/W), Black Pairs (B/B), and Mixed-Race Pairs (B/W).
Figure 4-3. Interactions between Ravens and Solutions (with Nowicki-Strickland Held at Mean) for Male and Female Pairs.
Locus of control and predictions

The third hypothesis was that there is no significant relationship between locus of control orientation and the effectiveness of predictions on the after-task assessment when the variance for sex, race, and intelligence has been partialled out.

The regression model for predictions had a Prob>F of .0004 with the regressor and interaction variables in the model explaining approximately 23% of the variance. A significant main effect for predictions was found for locus of control with p<.05 (Table 4-13). In general, the more internal the locus of control orientation of the student pair, the more accurate the predictions on the assessment given after the cylinder task. This assessment showed how well students had accommodated what they had learned during the cylinder task. The theory that internals show a higher level of ability in using previously acquired material in a subsequent task (Phares, 1968) is supported by these results. The null hypothesis was rejected.

Significant main effects for predictions were also found for Ravens, white student pairs, and black versus white student pairs. There was a significant interaction effect for Ravens X Nowicki-Strickland. This indicates that, while prediction scores were lower when scores on the Ravens were high, or scores on the Nowicki-Strickland were
high (indicating external orientation), there was an additional small upward effect in predictions when student pairs were high on both the Ravens and the Nowicki-Strickland (more external).

Table 4-13

Results of Regression Analysis for Predictions

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Parameter Estimate</th>
<th>T for Ho</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>20.576</td>
<td>3.475</td>
<td>0.0008</td>
</tr>
<tr>
<td>Sex</td>
<td>1</td>
<td>0.290</td>
<td>0.686</td>
<td>0.4940</td>
</tr>
<tr>
<td>Race:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White Pairs (X1)</td>
<td>1</td>
<td>1.336</td>
<td>2.669</td>
<td>0.0090*</td>
</tr>
<tr>
<td>Black Pairs (X2)</td>
<td>1</td>
<td>-0.003</td>
<td>-0.006</td>
<td>0.9954</td>
</tr>
</tbody>
</table>

Test X1-X2=0 with 1 and 93 df, Prob>F .0436*  
(Black vs. White Pairs)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Parameter Estimate</th>
<th>T for Ho</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ravens</td>
<td>1</td>
<td>-0.3402</td>
<td>-2.193</td>
<td>0.0308*</td>
</tr>
<tr>
<td>Nowicki-Strickland</td>
<td>1</td>
<td>-0.1997</td>
<td>-2.532</td>
<td>0.0130*</td>
</tr>
</tbody>
</table>

Interaction

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Parameter Estimate</th>
<th>T for Ho</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ravens*Nowicki-Strickland</td>
<td>1</td>
<td>0.0048</td>
<td>2.274</td>
<td>0.0252*</td>
</tr>
</tbody>
</table>

Model: R-Square 0.2290, 6 and 93 df, F Value 4.603  
Prob>F .0004

* p<.05

Data Analysis for the Fourth and Fifth Hypotheses

Results of multiple regression procedures were analyzed for the fourth and fifth hypotheses:
4. There is no statistically significant relationship between the task structure and the effectiveness of the problem solving strategy when the variance contributed by sex, race, intelligence, and locus of control has been partialled out.

5. There is no statistically significant relationship between the task structure and the accuracy of the task solutions when the variance contributed by sex, race, intelligence, and locus of control has been partialled out.

Effect of structure on strategy

There was no significant relationship between the condition of structure and the ability to develop and use an effective problem solving strategy for this sample. This result many have been affected by a restriction of range on the student pair scores for strategy. The null hypothesis for strategy was not rejected.

Multiple regression analysis resulted in only one significant main effect on strategy, for the Ravens, at p<.05 (Table 4-14). Intelligence was shown to be a better predictor than locus of control for the development and use of an effective strategy to solve a complex task (i.e., the higher the intelligence, the more effective the problem solving strategy developed to solve the cylinder problem).
Table 4-14

Results of Regression Analysis of Structure and Other Variables on Problem Solving Strategy

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Parameter Estimate</th>
<th>T for Ho</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>1.8841</td>
<td>0.584</td>
<td>0.5608</td>
</tr>
<tr>
<td>Sex</td>
<td>1</td>
<td>1.0697</td>
<td>1.718</td>
<td>0.0891</td>
</tr>
<tr>
<td>Race:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White Pairs (X1)</td>
<td>1</td>
<td>-0.1967</td>
<td>-0.267</td>
<td>0.7904</td>
</tr>
<tr>
<td>Black Pairs (X2)</td>
<td>1</td>
<td>0.0905</td>
<td>0.110</td>
<td>0.9125</td>
</tr>
</tbody>
</table>

Test X1-X2=0 with 1 and 93 df, Prob>F .7646
(White vs. Black Pairs)

<table>
<thead>
<tr>
<th></th>
<th>df</th>
<th>Parameter Estimate</th>
<th>T for Ho</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ravens</td>
<td>1</td>
<td>0.1202</td>
<td>2.669</td>
<td>0.0090*</td>
</tr>
<tr>
<td>Nowicki-Strickland</td>
<td>1</td>
<td>0.0256</td>
<td>0.841</td>
<td>0.4027</td>
</tr>
<tr>
<td>Structure</td>
<td>1</td>
<td>0.3353</td>
<td>0.597</td>
<td>0.5522</td>
</tr>
</tbody>
</table>

Model: R-Square 0.1127, 6 and 93 df, F Value 1.969
Prob>F .0780

* p<.01

Effect of structure on solutions

A significant main effect, with p<.05, for the condition of the structure of the problem solving task on solutions scores was found (Table 4-15). The null hypothesis relating the structure of the task to performance on solutions was rejected.

Five other significant main effects were found for solutions: locus of control, Ravens, sex, white student
pairs, and black versus white pairs. Three interaction variables reached significance: sex X Ravens, Ravens X black student pairs, and the Nowicki-Strickland X structure.

Table 4-15

Results of Regression Analysis of Structure and Other Variables on Problem Solving Solutions

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Parameter Estimate</th>
<th>T for Ho</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>21.6022</td>
<td>3.664</td>
<td>0.0004</td>
</tr>
<tr>
<td>Sex</td>
<td>1</td>
<td>8.7106</td>
<td>2.652</td>
<td>0.0095*</td>
</tr>
<tr>
<td>Race:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White Pairs (X1)</td>
<td>1</td>
<td>10.5628</td>
<td>2.226</td>
<td>0.0285*</td>
</tr>
<tr>
<td>Black Pairs (X2)</td>
<td>1</td>
<td>-8.7203</td>
<td>-2.098</td>
<td>0.0388*</td>
</tr>
</tbody>
</table>

Test X1-X2=0 with 1 and 89 df, Prob>F 0.0003*  
(White vs. Black Pairs)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Parameter Estimate</th>
<th>T for Ho</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ravens</td>
<td>1</td>
<td>0.2147</td>
<td>1.960</td>
<td>0.0532</td>
</tr>
<tr>
<td>Nowicki-Strickland</td>
<td>1</td>
<td>-0.2074</td>
<td>-3.502</td>
<td>0.0007*</td>
</tr>
<tr>
<td>Structure</td>
<td>1</td>
<td>-13.6369</td>
<td>-2.523</td>
<td>0.0134*</td>
</tr>
</tbody>
</table>

Interactions:

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>Parameter Estimate</th>
<th>T for Ho</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex*Ravens</td>
<td>1</td>
<td>-0.2207</td>
<td>-2.354</td>
<td>0.0208*</td>
</tr>
<tr>
<td>Ravens*White Pairs</td>
<td>1</td>
<td>-0.2361</td>
<td>-1.823</td>
<td>0.0717</td>
</tr>
<tr>
<td>Ravens*Black Pairs</td>
<td>1</td>
<td>0.3597</td>
<td>2.304</td>
<td>0.0236*</td>
</tr>
<tr>
<td>Nowicki-Strickland*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structure</td>
<td>1</td>
<td>0.2031</td>
<td>2.762</td>
<td>0.0070*</td>
</tr>
</tbody>
</table>

Model: R-Square 0.3636, 10 and 89 df, F Value 5.085  
Prob>F .0001

* p<.05
The interaction for structure, Figure 4-4, indicated that, in general, locus of control orientation for the structure of the cylinder task did make a difference in the scores of student pairs on solutions. Within the unstructured task, scores on solutions were significantly higher when locus of control was more internal (lower Nowicki-Strickland score).

Locus of control orientation had little predictive value in the structured condition. The structure of the task appeared to mediate the ability of the Nowicki-Strickland to predict solutions scores.

According to locus of control theory, internals and externals are differentially sensitive to task structure. As reported by Sandler, Reese, Spencer and Harpin (1983), internals are predicted to adapt better in low than high-controlling environments, whereas externals are predicted to adapt better in high-controlling situations. Inferences made from the results of this study are that internals come up with more accurate solutions to problems in unstructured task conditions and the structure of the task does not affect the accuracy of solutions for externals.

A comparison of individual differences of student pairs and problem solving performance between three groups of students is found in Appendix C.
Figure 4-4. Interaction between Solutions and Nowicki-Strickland (with Ravens Held at the Mean) for the Structure of the Task.
Summary of Results of Hypotheses Testing

These were the results of hypothesis testing:

A. There is no statistically significant relationship between locus of control and these problem solving performances when the variance for sex, race, and intelligence has been partialled out:
   1. strategy - not rejected
   2. solutions - rejected at $p < .05$
   3. predictions - rejected at $p < .05$.

B. There is no statistically significant relationship between the condition of structure for the task and these problem solving performances when the variance contributed by sex, race, intelligence, and locus of control have been partialled out:
   1. strategy - not rejected
   2. solutions - rejected at $p < .05$. 
CHAPTER V
CONCLUSIONS AND IMPLICATIONS

Conclusions

Processes of problem solving that have been cited as being important in solving the cylinder task were observing, gathering data, making systematic plans based on accumulated evidence, keeping track of events and analyzing them as they happen, varying plans to change the course of action when necessary, and drawing conclusions (Dewey, 1930; Sternberg, 1984); finding patterns and regularities, generating and testing hypotheses, and using evidence gathered to come to appropriate problem solutions (Rudnitsky & Hunt (1986); and avoiding premature closure (Wollman, Eylon, & Lawson, 1980).

There is evidence that the effective problem solvers in this study did use these processes when they were involved in the cylinder task. A major conclusion drawn from the results of this study was that many of the student pairs in this sample did well on this complex, science problem solving task. The environmental conditions of the task were such that they could use their abilities to build their own context for the
concept involved and use the concrete evidence they had gathered to reach conclusions.

The purpose of this study was to investigate the extent to which the generalized locus of control orientations of sixth-grade student pairs related to their science problem solving effectiveness in a novel situation where skill, needed to build evidence for the outcome, and the structure of the task condition, were factors.

The testing of five null hypotheses by regression analysis resulted in the rejection of three of them:

1. There is no significant relationship between locus of control orientation and problem solving strategy when the variance for sex, race, and intelligence has been partialled out. There was no significant main effect found for scores on the Nowicki-Strickland for problem solving strategy. The locus of control orientation of sixth-grade students was not found to be significantly related to their ability to develop and use an effective problem solving strategy during the cylinder task. The null hypothesis was not rejected. A significant main effect was found for intelligence which indicated that, generally, the more intelligent the student pair, the more effective the strategy they developed to solve the problem.
2. There is no significant relationship between locus of control orientation and problem solving task solutions when the variance for sex, race, and intelligence has been partialled out. There was a significant main effect found for scores on the Nowicki-Strickland on scores for solutions. These results indicated that there was a significant relationship between the locus of control orientation of students and their ability to come up with accurate solutions to the cylinder task. The null hypothesis for solutions was rejected at the $p<.05$ level of confidence.

Interactions were found between intelligence, race and sex for accuracy of solutions to the task. Scores on the Ravens predicted differently for student pair subgroups. In general, for black female student pairs and black male pairs, as the scores on the Ravens increased, so did the scores on solutions. This same relationship was also evident for mixed-race female and mixed-race male pairs, but to a lesser degree. It appeared that scores on the Ravens had little relationship to the accuracy of problem solving solutions for white female or white male pairs.

3. There is no significant relationship between locus of control orientation and predictions when the variance for sex, race and intelligence has been
partialled out. A significant main effect was found for locus of control on predictions. This main effect indicated that there was a relationship between locus of control and the ability of students to predict results of cylinder races on the posttask assessment. The internality of student pairs related to more accurate predictions. The null hypothesis for predictions was rejected at the \( p < .05 \) level of confidence.

There was a significant interaction effect for Ravens X Nowicki-Strickland which indicated that predictions were lower when scores were high either on the Ravens or high (more external) on the Nowicki-Strickland. There was a small upward effect on predictions when scores were high on both the Ravens and the Nowicki-Strickland.

4. There is no significant relationship between the condition of structure for the cylinder task and problem solving strategy when the variance contributed by sex, race, intelligence, and locus of control has been partialled out. There was no significant main effect found for the condition of structure on the problem solving strategies of the 100 student pairs in this sample. The null hypothesis was not rejected. A significant main effect was found for intelligence on
strategy such that, the higher the score on the Ravens, the more effective the problem solving strategy.

5. **There is no significant relationship between the condition of structure for the cylinder task and solutions to the task when the variance contributed by sex, race, intelligence, and locus of control has been partialled out.** A significant main effect was found for the condition of structure for the cylinder task on solutions to the task. This finding indicated that the task structure related to the ability of student pairs to make accurate decisions on solutions to the cylinder task. The null hypothesis was rejected at the .05 level of confidence.

An interaction was found between the structure of the task and the locus of control orientation of student pairs. In general, scores on solutions were significantly higher in the unstructured task condition than in the structured condition such that, the more internal the student pair, the more accurately they made decisions for the solution to the cylinder task. There appeared to be little relationship between locus of control and solutions scores in the more structured condition. The task condition appeared to mediate the ability of the Nowicki-Strickland to predict solutions scores.
Relationship of Conclusions to Previous Research

Researchers have found that the number of variables in a task affects the ability of students to solve science problems: the larger the number of variables, the greater the load on working memory and the more difficult the problem is to solve. For instance, problems with two or three variables were significantly less difficult for students to solve than problems with four or five variables (Staver, 1986). Tasks with more than three interacting variables were seldom solved by senior high students (Wozny & Cox, 1975).

On this basis, the sixth-grade student pairs in the present study did surprisingly well on the complex problem solving task involving four interacting variables. Out of a possible 12 points for strategy, 91% of student pairs scored between 6 and 12 points. 50% of all student pairs scored between 9 and 12 points on strategy. Scores in this range were earned for development of a recognizable strategy (either "Tennis Tournament" or "King of the Mountain"). Out of a possible 20 points for solutions, 92% of student pairs scored between 10 and 20 points. 61% scored between 15 and 20 points.

The results of this study suggest relationships among the results, conclusions, and theories discussed in
Chapter II. Externality was proposed by Sandler et al. (1983) to be adaptive in certain situations. In the present study, the nature of the problem solving situation, a science task to be solved by racing cylinders (using hands-on science materials), possibly influenced external student pairs to be more adaptive in the unstructured task condition. This premise is strengthened by the findings of McKee (1978), Shymansky and Penick (1981) and Shymansky, Hedges and Woodworth (1990).

McKee concluded that student-structured learning strategies with minimum restrictions improved sixth-grade students' science problem solving performance more than teacher-structured strategies with moderate restrictions.

McKee's conclusion was extended by Shymansky and Penick (1981) to activity-based science in which more active, investigative, and productive behavior was displayed by students in student-structured than in teacher-structured situations. This relates to the present study in which student pairs produced more accurate solutions in the unstructured task condition.

The problem solving performance of student pairs in this study may well have been positively influenced by the task situation which involved them in an active science activity, a cooperative task for students in
pairs. They were asked to work together to find the three fastest "racers" by rolling cylinders down a ramp which was complete with a starting gate.

Problem solving performance and achievement have been found to be greater for activity-based science than for traditional science. Increased problem solving ability of females and minorities has been associated with activity-based science. These findings were reported by Shymansky, Hedges and Woodworth (1990) in their resynthesis of the research on activity-based science programs. This promotes the position that the manner in which science concepts are learned affects the performance of students.

Task instructions have been found to mediate the effects of locus of control orientation on problem solving performance (Beck, 1979). The task instructions presented to students in the present study identified the structure (cued or uncued) of the task to be solved; therefore, the structure of the situation, rather than the task instructions, conceivably mediated the effects of locus of control.

The conclusion reached by Levine and Linn (1977), that scientific reasoning appears to be influenced by the number of variables in the task, method of interacting with the materials (free choice or constrained), and the
subject matter of the task favors this supposition. If two-variable, hands-on science tasks are solved by most 12- and 13-year olds, and hands-on science tasks with multiple interacting variables are seldom solved even by 16- and 17-year olds (Wozny & Cox, 1975), then the method of interacting with the variables, free choice or constrained, is plausibly an important variable affecting performance.

In terms of the present study involving complex problem solving, the method of interaction relates to the unstructured and structured condition of the task and is proposed as the mediating variable between locus of control and problem solving performance. Student pairs that had internal locus of control orientations were more accurate on solutions to the problem in the unstructured condition. The structure of the task did not appear to affect the accuracy of solutions for pairs assessed as externals.

Cognitive theorists characterize learners as constructing their own knowledge. This requires critical thinking. Essential to critical thinking in the context of science is the concept of a controlled experiment. The majority of sixth-grade student pairs in this study recognized the need to separate and control variables. They developed and applied complex cognitive strategies
on their own. They used the evidence they had gathered to make decisions to solve the task, decisions which were more accurate in the unstructured task condition.

**Implications**

What implications do these conclusions have for the teaching of problem solving in science? In *Education and Learning to Think*, Resnick (1987) concluded that there is no solid empirical evidence to favor the teaching of problem solving in either separate courses or in a discipline-imbedded approach in traditional school subjects. She supported the discipline-imbedded approach and stressed three of its advantages: It provides a natural knowledge base and environment to practice and develop higher level thinking skills; it provides criteria for what constitutes good thinking and reasoning within the disciplinary tradition; and it ensures that something worthwhile will have been learned even if wide transfer proves unattainable. The last advantage was described as being "profoundly important" (pp. 34-36).

In *Mathematics and Science Learning: A New Conception*, Resnick (1983) summarized the conception of learners and the learning process from cognitive research:

*First, learners construct understanding. They don’t simply mirror what they are told or*
what they read. Learners look for meaning and will try to find regularity and order in the events of the world, even in the absence of complete information. This means that naive theories will always be constructed as part of the learning process.

Second, to understand something is to know relationships. Human knowledge is stored in clusters and organized into schemata that people use both to interpret familiar situations and to reason about new ones. Bits of information isolated from these structures are forgotten or become inaccessible to memory.

Third, all learning depends on prior knowledge. Learners try to link new information to what they already know in order to interpret the new material in terms of established schemata . . .

The science theories that children are being taught in school often cannot compete as reference points for new learning because they are presented quickly and abstractly and so they remain unorganized and unconnected to past experience. (pp. 477-478)

If learners construct their own understanding of concepts, and if the learning of concepts depends on prior knowledge, then the implications are for teachers to identify students' beginning understanding of a science concept, then guide them to extend their understanding. In this way, students have the chance to link new information to what they already know.

One of the ways to do this is to involve students in hands-on, problem solving situations. Then, by observing and analyzing the problem solving processes they display while working on their own, teachers can gain the insight to understand where students are in
performance so that guidance can be given to them to change, adapt, and further develop these processes.

Conclusions drawn from the results of this study show the necessity of taking the individual differences of students into consideration. Some students may require more guidance and encouragement than others in developing and using problem solving strategies, keeping track of accumulated data, formulating and testing hypotheses, and using actual evidence to make decisions.

In this study, students were given the opportunity to become actively involved in problem solving tasks in which they

- explored phenomena with objects and materials
- found patterns and regularities, similarities and differences among variables
- formed beginning hypotheses
- developed their own strategies to solve problems
- tested their hypotheses
- changed or adapted their hypotheses based on the evidence gathered
- observed evidence of the inconsistencies and parameters of concepts
- discovered relationships in and among concepts
- resolved conceptual conflicts
- came up with solutions based on substantial evidence
- applied the processes and content they have learned in other problem solving experiences.
Inferences drawn from the results of this study support providing students with opportunities to be involved in hands-on problem solving experiences in a minimally teacher-structured environment. One of the conclusions of this study was that student pairs in all subgroups did well on this complex problem solving task, a task with four interacting variables. These conclusions differ from those of Wozny and Cox (1975) and Staver (1986) who concluded that the majority of junior high students were unable to correctly solve tasks with four variables.

In comparison, Shymansky and Penick (1981) found that junior high students in student-structured situations performed as well or better on problem solving than students in more teacher-structured situations. Low ability students approached the level of high ability students in the student-structured situations. Shymansky, Kyle, and Alport (1983) and Shymansky, Hedges, and Woodworth (1990) found that female and minority junior high students in activity-based classrooms were significantly higher in problem solving skills when compared with students in classrooms using traditional textbook programs.
If taking part in student-structured, activity-based science can produce these results, especially for female, minority, and low-ability students who, traditionally, either avoid science or have lower achievement than other students, then it is crucial that we provide these kinds of science experiences.

Traditionally, we expose our children to science through processes and materials which have the quality of exporting our science concepts and asking children to contend with them. We seldom find out what they would do if we approached them on their own terms and encouraged them to develop their own processes. David Hawkins (1970) wrote,

[The] pathway into the future is not a ladder, or a highway, but a world of choices. Its choices are not now predetermined or predictable, but will be fixed only by the discoveries it has made, and will yet make, along the way or the lack of them. As we must learn, so we ought to teach. (p. 70)

Two questions arise considering traditional teaching methods. As results of this study have shown, many students are skillful at developing their own effective processes. What would happen if they were in a class where they were taught a systematic, step-by-step, problem solving procedure? Should these students be expected to abandon their own effective processes for the teacher's "correct" procedure?
It is suggested that by observing and assessing student problem solving processes before planning learning experiences, teachers can encourage student-developed processes as long as they are effective. If students are identified as being unable to do the kinds of thinking processes needed, then they can be given assistance in learning workable methods.

This would take more time than the more established approach of telling students what they need to know. It is suggested that the long-range benefits would make it worthwhile. We are not able to tell them, or have them read, all about science, and since science knowledge is continually expanding, students will need to be able to go through the processes to come up with the knowledge on their own. It follows, then, that these processes are as important as the background to understand science outcomes.

When the question arises, "Should we cover more concepts in an area of science or concentrate more on a deeper understanding of fewer concepts?" Research guides us to the later pathway. *Science for All Americans: A Project 2061 Report on Literacy Goals in Science, Mathematics and Technology*, prepared by the American Association for the Advancement of Science (1989), consists of a set of recommendations by the National
Council on Science, Mathematics, and Technology Education to reform science education. In the section on "Principles of Learning", this view is presented,

Learning is not necessarily an outcome of teaching. . . . Cognitive research is revealing that even with what is taken to be good instruction, many students, including academically talented ones, understand less than we think they do. With determination, students taking an examination are commonly able to identify what they have been told or what they have read; careful probing, however, often shows that their understanding is limited or distorted, if not altogether wrong. This finding suggests that parsimony is essential in setting out educational goals: Schools should pick the most important concepts and skills to emphasize so that they can concentrate on the quality of understanding rather than on the quantity of information presented. (p. 145)

The method of testing problem solving achievement deserves consideration. It is suggested that observation of the problem solving process and listening to student discussions during the process may be a more accurate assessment of achievement than a paper and pencil test. A written test may not correspond to the higher level understandings of the problem processes and solutions, the context of the learning (e.g., activity-based science), or the individual differences of students. This type of assessment could also serve a diagnostic purpose because it could better pinpoint the problem solving processes in which students need more guidance and/or practice.
Marzano and Costa (1988) summarized the need for alternative methods to traditional testing,

The need is clear for restructuring and developing alternatives to standardized tests - alternatives that examine the vast array of thinking skills important for the information age. The present system, with its emphasis on factual declarative content, is out of balance. If this imbalance continues, students will enter the information without . . . necessary skills. (p.71)

Effective assessment of achievement, ideally, would more appropriately measure the higher levels of thinking used during the problem solving process and be assessed in a way that is specific to the context of the processes being measured. Marzano and Costa (1988) conclude, "Assessment . . . is an ongoing part of the teaching/learning process. . . . [Testing should be] just one of the pieces used to assess student achievement" (p.70).
APPENDIX A
TRANSCRIPTION OF TAPED INSTRUCTIONS
FOR THE CYLINDER TASK

In Rowe's original study, the administration of the science tasks and the conditions under which the student pairs completed the tasks were kept as uniform as possible. Directions for task procedures were given by means of a tape recording to all student pairs involved in the three science tasks. These are the transcribed instructions for the cylinder task.

"Okay, race fans! You are going to have some time to do some science. There is a ramp over here. Look at the top, over there. You will see a metal bar which is down in the slot. This is the starting gate. Lift it up a couple of times to see how it works. You're going to race some cylinders down the hill by putting them behind the starting gate. Just hold the cylinders on the hill until you're ready to start the race. Then drop the gate into the slot. That starts the race.

(Before task practice race instructions) There are two cylinders, one red and one yellow beside the ramp. For practice, find out which is fastest.
Now you know how to race cylinders. Put the red and yellow cylinders back. They were just for practice.

Look on the wall behind you. You will see a large board with pictures. Pick out the cards for the red and yellow cylinders. Put the picture of the winner on peg number one, and the other picture on peg two or three. You've just finished.

(Instructions for the criterion cylinder task) Look at the board near the hill or ramp that has a lot of cylinders on it. Count them. There should be 18. Your job is to find the three fastest cylinders out of all 18. You should race two or three cylinders at a time, but not more. After each race put the cylinders back in their places on the rack. On the wall there are pictures of these cylinders. You should use these pictures to keep track of what happens as you race cylinders if you want to. If there's a tie, you put both pictures on one peg."
APPENDIX B
DESCRIPTION OF RADIO AND SPINNING TABLE TASKS
IN THE ORIGINAL STUDY

The radio task was the entry task which required no prior knowledge of radio assembly. Students were to follow a set of pictorial directions to construct a radio with materials to be assembled on a board. This task was intended to assess coarse and fine discrimination, ability to follow a set of pictorial directions, and strategies for trouble shooting if the radio did not work after initial assembly. Since each radio had been pretuned to a local station, students could find out if their assembly of parts resulted in hearing the radio work. If the radio worked on the first try, the students had finished with the task. If it did not work, then they were directed by an observer to try to make it work. The processes used by the students were recorded by an observer.

For the spinning table task, two lazy-susan like turntables of different diameters were coupled together by a belt. The smaller table had a handle which allowed it to be turned either clockwise or counter-clockwise at different speeds. The fixed pulley arrangement under the
turntables created a situation in which the ratio of
turns of one table to the other was 3.3:1. There was a
set of 12 test patterns on separate cards. Students were
to tape a piece of paper on the larger turntable, then
turn the smaller table with the handle. As the tables
turned, students were to produce the patterns, one at a
time, on the paper with a felt-tipped pen. The problem
that each pair of students confronted was to bring three
variables under control in order to produce a set of 12
test patterns. The three variables that needed to be
controlled were the speed of the turning table (which
influenced the degree of curvature of the patterns), the
direction in which the table turned (which influenced the
direction the curve of a pattern would open), and the way
the pen was moved on the paper (which interacted with the
other two variables).

The spinning table task was available in two
conditions of structure. The structured condition
provided students with 5 minutes of cued instruction
intended to alert students to the three possible
variables that could be used. The unstructured condition
allowed students 5 minutes of free play with the
apparatus.
APPENDIX C
COMPARISON OF PROBLEM SOLVING PERFORMANCE AND INDIVIDUAL DIFFERENCES IN THREE GROUPINGS

Data concerning individual differences and problem-solving performance of student pairs were further analyzed in a more qualitative manner. The less effective problem-solving strategies of 24 student pairs were compared to the strategies of 12 student pairs that were the most effective to determine similarities and differences among and between strategies. Each of the twelve student pairs with the most effective strategies had received the highest possible score of 12 on strategy and also the highest score of 20 on solutions (HS group).

Two groups of student pairs, each with low scores on strategy, were formed. The pairs in one group (LS) had low scores (from 3 to 6) on strategy and low scores on solutions (from 0 to 10). The pairs in the other group (MD) showed the most disparity in their scores on strategy and solutions. They had low scores (from 2 to 7) on strategy, but had the highest possible score of 20 on solutions. The processes of the two groups of student pairs with the lowest scores on strategy were compared to the processes of the groups with the highest scores.
Table C-1

Comparison of Problem-Solving Performances of Student Pairs with Highest, Lowest and Most Disparate Scores

<table>
<thead>
<tr>
<th>Highest Scores (HS)</th>
<th>Lowest Scores (LS)</th>
<th>Most Disparate (MD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Pairs</td>
<td>N=12</td>
<td>N=12</td>
</tr>
<tr>
<td>Subgroup of Pairs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male White/White</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Female White/White</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Male Black/White</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Female Black/White</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Male Black/Black</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Female Black/Black</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Ravens</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both above mean</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>One above mean</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Both below mean</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Locus of Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>External</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Condition of Structure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structured</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Unstructured</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Problem Solving Strategy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tennis Tournament</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>King of the Mountain</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mix of Strategies</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>No Clear Strategy</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Controlled Variables (percent of trials without retests)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>75-99%</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>50-74%</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>25-49%</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>0-24%</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>
Individual differences of the student pairs in each of the three groups were also classified and compared between groups. Data for the three groups are shown in Table D-1.

According to theory, it would be expected that the student pairs that used the most effective problem solving strategies would have the highest scores on the Ravens and more internal locus of control orientations. This was generally true. Nine of the twelve student pairs in the HS group with the highest scores on strategy had scores on the Ravens which were above the mean for total of 100 teams in this study. Nine of these student pairs were assessed as having internal locus of control orientations, with scores on the Nowicki-Strickland that were above the mean for the total number of teams.

In comparison, seven out of the twelve student pairs in the LS group with the lowest scores on both strategy and solutions had scores on the Ravens which were below the mean. Twelve pairs in this group had locus of control orientations which were assessed as being external. The question then arises, would these student pairs benefit more from a more structured task situation. Student pairs in the MD group with the most disparate strategy and solution scores had a balance of internal and external orientations.
The condition of structure in which most of the student pairs performed the cylinder task was the unstructured condition where they were asked to find the three fastest out of the 18 cylinders without first finding the fastest solid and fastest hollow cylinder. Ten of the student pairs in the HS group, nine of the pairs in the LS group, and seven pairs in the MD group performed the task in the unstructured condition.

All of the twelve student pairs in the HS group with the highest scores used the Tennis Tournament strategy. Of the other two groups, nine of the student pairs in the MD group with disparate scores on strategy and solutions used a mix of strategies, whereas seven student pairs in the LS group with the lowest scores used no clearly identifiable strategy.

It would be expected that the more effective strategies would include a high percentage of trial races in which all cylinder variables except one would be controlled. The most effective strategy was not necessarily to control variables 100% of the time. When the Tennis Tournament strategy was used, all variables except one were usually controlled when racing cylinders across different variables, but this was not always efficient during playoffs between winning cylinders.
When comparisons involving the controlling of variables during cylinder races were made, there were differences between groups. All 12 of the student pairs in the HS group controlled variables in 50 to 100% of the cylinder races, with eight pairs controlling variables more than 75% of the time. Pairs in the other two groups controlled variables less often with seven of the LS group and nine of the MD group controlling variables more than 50% of the time.
REFERENCES


BIOGRAPHICAL SKETCH

Edna "June" Dewey Main was born and raised in Hyannis, Massachusetts, the daughter of Bradford and Edna Dewey. June graduated from Barnstable High School, in Hyannis, in 1958. She received her Associate of Arts degree in fashion merchandising and advertising from Tobé Coburn School in New York City in 1960.

In 1961, June and Don Main were married. They have two daughters, Alison Main Ronzon and Susan Main Leddy, and a son, Steven Main. They were divorced in 1989.

June received her Bachelor of Arts degree in elementary education (1974), Master of Arts in elementary education (1979) and Master of Arts in administration and supervision (1983) from the University of North Florida. In 1986 she entered the doctoral program at the University of Florida. Her specialty area was science education under the guidance of Dr. Mary Budd Rowe.

Her professional experience includes teaching third graders for 13 years, inservice teachers in the Summer Inservice Institute at the University of North Florida for 7 years, and undergraduate education students at the University of Florida for 3 years. She has been a
consultant for the National Science Foundation’s Self Help Elementary Level Science (SHELLS) grant under the directorship of Dr. Mary Budd Rowe. She currently teaches at the University of North Florida.

June’s professional activities include member of the Supervisory Committee for the Educational Community Credit Union, Duval County Teacher Education Council member, teacher representative for President Reagan’s Young Astronaut Program, member of the College of Education Field Services Advisory Council at the University of North Florida, and co-founder and vice president of Quest for Quality in Education.

June was chosen as Teacher of the Year for seven years by the teachers at Holiday Hill Elementary School and was a Duval County Teacher of the Year finalist for two years. She was a recipient of the National Science Teacher Association’s Science Teaching Achievement Recognition (STAR) award. She is recognized in Who’s Who in the South and Southwest, Who’s Who in American Education, and Who’s Who of American Women. Membership in professional societies include Phi Delta Kappa, Delta Kappa Gamma, Phi Kappa Phi, Kappa Delta Pi, the Association for Supervision and Curriculum Development, the National Science Teachers Association, and the Council for Elementary Science Teachers International.
June has written articles for *Science and Children*, an elementary science teaching journal, and has co-authored a book, *Developing Critical Thinking Skills through Science*, with Dr. Paul Eggen of the University of North Florida.
I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Mary Budd Rowe, Chairperson
Professor of Instruction and Curriculum

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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December, 1990

Dean, College of Education

Dean, Graduate School