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ELIMINATING EXTRAMISSION BELIEFS ABOUT VISION:
THE EFFECTS OF INSTRUCTION

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

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*****

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To Matt and My Mother
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# TABLE OF CONTENTS

DEDICATION............................................................................................................ ii
ACKNOWLEDGMENTS................................................................................................. iii
VITA........................................................................................................................... iv
LIST OF TABLES....................................................................................................... viii
LIST OF FIGURES.................................................................................................... x
INTRODUCTION......................................................................................................... 1

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. LITERATURE REVIEW</td>
<td>5</td>
</tr>
<tr>
<td>Theories of Vision: Historical and Developmental Trends</td>
<td>5</td>
</tr>
<tr>
<td>Misconceptions in Science</td>
<td>15</td>
</tr>
<tr>
<td>Light and Vision in Science Education</td>
<td>24</td>
</tr>
<tr>
<td>Hypotheses</td>
<td>30</td>
</tr>
<tr>
<td>II. METHOD</td>
<td>32</td>
</tr>
<tr>
<td>Testing Time One</td>
<td>32</td>
</tr>
<tr>
<td>Testing Time Two</td>
<td>39</td>
</tr>
<tr>
<td>III. RESULTS</td>
<td>42</td>
</tr>
<tr>
<td>IV. DISCUSSION</td>
<td>65</td>
</tr>
</tbody>
</table>

APPENDICES

A. Scripts.................................................................................................................. 75
B. Eight Main Questions: Times One and Two, Orders 1-4.................. 86
C. Information Questions, Times One and Two................................. 99
D. Open-Ended Questions, Time 2 ......................................................101

LIST OF REFERENCES ...........................................................................103
# LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Description of Four Question Presentation Orders</td>
<td>36</td>
</tr>
<tr>
<td>2. Sequence of Seven Computer Items and Final Verbal Item Used for Main Test Questions, Proceeding from the Most Complex Computer Question to the Least Complex</td>
<td>38</td>
</tr>
<tr>
<td>3. Repeated Measures Analysis of Variance Summary of Total Number of Intromission Responses by Condition, Grade, Sex, and Inorder</td>
<td>44</td>
</tr>
<tr>
<td>4. Frequency of Subjects Showing Perfect versus Imperfect Responses as a Function of Condition during Time One</td>
<td>49</td>
</tr>
<tr>
<td>5. Frequency of Subjects Showing Perfect versus Imperfect Responses as a Function of Condition during Time Two</td>
<td>49</td>
</tr>
<tr>
<td>6. Frequency of Subjects Giving Intromission versus Extramission Responses as a Function of Condition (Time One)</td>
<td>51</td>
</tr>
<tr>
<td>7. Frequency of Subjects Giving Intromission versus Extramission Responses as a Function of Condition (Time Two)</td>
<td>52</td>
</tr>
<tr>
<td>8. Repeated Measures Analysis of Variance Summary of Total Number of Correct Responses on Information Questions by Condition, Grade, and Sex</td>
<td>55</td>
</tr>
<tr>
<td>9. Frequency and Percentage of Subjects' Answers to Open-Ended Question One by Perfect versus Imperfect on Eight Main Questions during Time One</td>
<td>61</td>
</tr>
<tr>
<td>10. Frequency and Percentage of Subjects' Answers to Open-Ended Question Two by Perfect versus Imperfect on Eight Main Questions during Time One</td>
<td>61</td>
</tr>
<tr>
<td>11. Frequency and Percentage of Subjects' Answers to Open-Ended Question One by Perfect versus Imperfect on Eight Main Questions during Time Two</td>
<td>62</td>
</tr>
</tbody>
</table>
12. Frequency and Percentage of Subjects' Answers to Open-Ended Question Two by Perfect versus Imperfect on Eight Main Questions during Time Two

..............................................................62
# LIST OF FIGURES

**FIGURE** | **PAGE**
---|---
1. Graph of Subjects' Mean Scores on Eight Main Questions at Time One and Time Two as a Function of Condition | 45
2. Graph of Subjects' Mean Scores on Eight Main Questions as a Function of Grade | 46
3. Graph of Percentage of Subjects Scoring Perfectly on the Eight Main Questions as a Function of Condition | 50
4. Graph of Percentage of Subjects having Correct Performance on the Two Choice Question at Times One and Two as a Function of Condition | 52
5. Graph of Subjects' Means on Five Information Questions as a Function of Grade and Sex | 56
INTRODUCTION

Piaget (1929) observed that children believe there are emissions from the eyes during the process of seeing and that people's looks can mix. As Piaget noted, these beliefs are similar to some ancient beliefs about visual perception, collectively known as extramission theories of perception. These ancient theories suggest that emissions from the eyes are what allow people to see (see Lindberg, 1976, 1992; Meyering, 1989 for reviews). Piaget (1974) further investigated the existence of extramission beliefs in children, and he found that virtually all young children espouse extramission beliefs. Piaget (1929) suggested that the presence of extramission beliefs indicates an inability to discriminate between self and other.

Although Piaget first made his observations during the early part of the twentieth century, little was made of these findings. Recent evidence confirms the presence of extramission beliefs in children (e.g., Cottrell & Winer, 1994; Karrqvist & Andersson, 1983; Guesne, 1985), although some researchers question the authenticity of extramission beliefs (Guesne, 1985).

While it is possible that methodological artifacts account for some extramission responses, it is unlikely that these types of explanations account for the developmental trends associated with extramission beliefs. Studies show that extramission beliefs decline with age and are replaced with the belief that something enters the eye during the visual process (i.e., intromission beliefs; Cottrell & Winer, 1994; Winer, Cottrell, Karefilaki, & Gregg, 1995). The
beliefs; Cottrell & Winer, 1994; Winer, Cottrell, Karefilaki, & Gregg, 1995). The developmental progression from extramission to intromission beliefs has been likened to the paradigm shift which occurred in scientific theories of visual perception (see Carey, 1985; T. Kuhn, 1962 for related information).

Although the production of extramission beliefs generally declines with age, a subset of older children and adults continue to give extramission responses. In fact, a surprising number of college students produce extramission responses to questions about vision (Cottrell & Winer, 1994; Winer, Cottrell, Karefilaki, & Gregg, 1995). These findings have implications for cognitive development and for the development of the understanding of perception.

In addition to the developmental significance of extramission beliefs, there are educational implications as well. Misconceptions about science topics tend to be resistant to instruction and are, therefore, of interest to educators (Champagne, Klopfer, & Gunstone, 1982). Extramission beliefs are particularly interesting because of their apparent simplicity and because of their persistence into adulthood. Pilot studies show that some college students continue to produce extramission responses after exposure to a section on visual perception in an introductory psychology course, and these results remain even when college students read a passage about visual perception immediately before answering questions about extramissions from the eye.

An explanation for the resistance of misconceptions to instruction and their persistence into adulthood is that the information presented in the classroom does not completely expunge misconceptions. When children learn about physics principles, for example, the information presented in the classroom
does not replace prior misconceptions but rather new, accurate information is integrated with faulty, preexisting theories (Carey, 1986; Chinn & Brewer, 1993; Gardner, 1991). While students may produce more accurate responses immediately following instruction, as the memory for the newly acquired (i.e., accurate) information wanes, students may revert to prior (i.e., inaccurate) beliefs. It is still a mystery, however, why students retain such misconceptions even after receiving instruction to the contrary several times (i.e., grade school, junior high/high school, college). The persistence of these beliefs in the face of contrary information has ramifications for both cognitive psychology and education.

An awareness of common misconceptions may enhance the instructional process and help eliminate misconceptions. Chinn and Brewer (1993) agree that confronting contradictory beliefs can be helpful in teaching scientific concepts, but instructors must anticipate and address students' beliefs. In one study, merely addressing children's common misconceptions about light increased students' correct responses to subsequent questions (Anderson & Smith, 1986). The duration of these effects was not determined, however, so it is impossible to determine if misconceptions would have resurfaced later. If directly confronting misconceptions while presenting accepted scientific explanations would allow students to eliminate their preconceptions, long term effects rather than more temporary changes in responses would result.

Misconceptions about emissions from the eyes are not usually addressed in science classes or units about visual perceptions; a perusal of the sensation and perception chapters in several current introductory psychology
books failed to find one that contained either a description of ancient extramission theories or addressed extramission as an incorrect belief. Most books include thorough descriptions of light and its role in vision, but, as suggested by previous studies this information is not adequate to eliminate beliefs in emissions from the eyes.

The purpose of this study was to determine the effectiveness of traditional instruction, i.e., instruction that presents correct information only versus counter-teaching, i.e., instruction directly confronting incorrect misconceptions in eliminating extramission beliefs. It was expected that the direct contradiction of extramission beliefs would reduce the presence of these beliefs in all age groups tested. While traditional instruction was expected to cause some immediate increase in intromission responses, the effects were expected to be of shorter duration than instruction directly addressing misconceptions.
CHAPTER I

LITERATURE REVIEW

Theories of Vision: Historical and Developmental Trends.

Although it is widely accepted today that light must enter the eyes in order for a person to see, some ancient philosophers and scientists believed that emissions from the eyes allowed visual experiences to occur. These ancient theories, which proposed that there are emissions from the eyes that produce visual experiences, are known collectively as extramission theories of vision (see Lindberg, 1976, 1992; Meyering, 1989). The Pythagoreans, such as Archytas, believed that an invisible fire was projected from the eye, and the fire exposed the color and shape of the object. Similarly, Euclid believed that the eyes emit rays that travel in a straight line from the eye to the object that is seen. He believed that if an object was not seen, it was because the rays emitted from the eyes did not reach the object. Ptolemy's conceptualization of vision was very similar to Euclid's with the exception that Ptolemy believed visual rays were bound together in a cone shaped projection rather than a series of discrete rays as suggested by Euclid. In a still slightly different conceptualization, Plato suggested that fire flowed from the eyes to combine with light rays, forming an intermediary between the object and the eyes. Many extramission theorists suggested that the protruding form of the eye was indicative of its emitting nature, while the ear, which is hollow in form, was
a receiving organ. Extramissionist views such as the ones presented here may be appealing because of the active, direction-oriented nature of the eyes—in order to focus on an object the looker must direct her eyes toward the object.

Although extramission beliefs about vision were fairly widespread among early thinkers, others believed that the object's image only must be projected into (rather than out of) the eye for vision to occur. Theories which propose that something (light, the object, or something else) enters the eyes are known as intromission theories. Many of the intromission theories (and the extramission theories as well) were attempts to discover the mediator between the object and the eye; it was believed that some material must directly connect the object to the eyes. The Atomists, for example, felt that atoms emanate from the object and enter the eyes. Aristotle, on the other hand, suggested that a transparent medium, such as air or water, allows properties of the object, such as color, to be communicated to the eyes. A move toward the modern view of vision was achieved when Alhazen rejected the idea of a projection of visual rays from the eyes, arguing that hypothesized output of rays would lead to no further understanding of the visual process. Alhazen did not deny the possibility that rays were projected from the eyes, but he was attempting to produce a more efficient model of vision which included only those ideas necessary to explain the phenomena. Alhazen also made strides in illustrating the anatomical and physiological properties of the eyes, something that had been largely ignored by extramission theorists. With increases in the understanding of the eye, light and its properties, Kepler finally developed the modern theory of the retinal image which is accepted today (Lindberg, 1976).
While the controversy about whether vision is better described as a process of intromission or extramission was largely resolved in the seventeenth century, remnants of extramission theories are still apparent in children's and even adults' answers to questions about vision. Interestingly, Piaget (1929) noted the similarity between children's beliefs about vision and ancient extramission theories when he observed that some children believe that their looks can mix and that emissions from the eye allow them to see. Although Piaget found that virtually all young children have extramission beliefs, these results were apparently never published in English (Piaget, 1974). Piaget (1929) concluded from his observations that young children demonstrate extramission beliefs because of their inability to discriminate between internal and external experiences. As children develop the ability to distinguish between self and other, extramission beliefs about vision are replaced with a more accurate, intromission-based understanding of the visual process.

More recently, the existence of extramission beliefs in school-aged children was confirmed (Karrqvist & Andersson, 1983; Guesne, 1985; Cottrell & Winer, 1994). Karrqvist and Andersson (1983) examined beliefs about light and its properties in a sample of twelve to fifteen year olds to determine if the understanding of light had an impact on their understanding of vision. Using an interview technique, children were given scenarios demonstrating various principles of light, and the answers were then categorized according to response-type. Some students expressed extramission beliefs on the questions they were asked about vision, replying that rays, impulses or something else are projected from the eyes to the object. Other students believed that rays or something else were sent out of the eyes to the object and then reentered the
eyes. Although only 55 out of 631 students (approximately 9%) gave answers indicating extramissions, the number may be depressed somewhat because of the nature of the question; students were asked what the link between the object and the eye is, and the majority of students gave answers indicating that light links the object to the eye. In the initial categorization of the answer, the direction in which light traveled was omitted. Indeed, when answers that did include directionality in the response were broken into subcategories (i.e., into the eye, out of the eye, no direction implied), all three types of answers were evident. When answers to the question were broken into subcategories, 67 students gave answers containing extramission beliefs, compared to 15 students who gave answers containing intromission beliefs and 74 students who did not discuss directionality in their responses. Extramission beliefs were present in responses even when students were answering questions about such abstract principles as reflection and refraction of light: "When you look down into the water, your sight is bent at an angle so you can see it" (p. 46). While it appears that children know that light is necessary in order to see, the role of light in the visual process is unclear or misunderstood by many of them.

Guesne (1985) also used the interview technique to investigate thirteen- and fourteen-year-old students' ideas about light and vision. As with the Karrqvist & Andersson (1983) study, Guesne found that most children realized that light plays a role in the process of vision. Children seldom understood, however, that light reaches the eye. Many children in the study assigned the eyes an active role in vision, with some children suggesting that something (often undefined) leaves the eyes so that the person could "look at" the object. Guesne drew the association between these responses and the extramission
theories of early philosophers and scientists; she was quick to mention, however, that only a few children in her study gave extramissionist answers. She asserted that, quantitatively speaking, the existence of these beliefs was not very important, and she cautioned against "...the temptation that always exists to find historical parallels" (p. 189). While this may be a valid reminder, it also denies a potentially interesting finding without adequate exploration. In addition to the fact that Guesne studied a small number of children, the number of subjects who might have provided extramission or intromission answers if probed is unknown since most of the children interviewed did not indicate any link between the eye and the object. Considering the small number of children in the study (N=30), it seems reasonable to allow that these ideas may exist and to determine the prevalence of these beliefs. Several studies, like the one by Karrqvist & Andersson (1983) and others to be discussed, substantiate the presence of children's extramission beliefs.

Although it appears that extramission beliefs do exist in at least a subset of children, the focus of studies revealing extramission beliefs typically has been educational, with the intent to summarize and improve children's knowledge about light and vision. The developmental nature or significance of extramission beliefs rarely was explored. A notable exception is a series of studies by Cottrell and Winer that directly address the developmental nature of extramission beliefs. These studies indicate a decline in extramission beliefs and an increase in intromission beliefs with age, as Piaget predicted. Using paper-and-pencil measures, Cottrell and Winer (1994) found that approximately 55% of sixth graders and 10% of college students agreed that when people see, "...rays or energy or something else goes out of their eyes" (p.
A similar percentage of sixth graders believed that something enters the eyes when people see, while 65% of college students agreed with the intromission theory.

A developmental trend of declining extramission beliefs was confirmed in studies with younger children and with different question formats (Cottrell & Winer, 1994). In one study, children in first, third, and fifth grades and college students were asked three separate questions verbally: 1) Do rays, energy, or something else go into people's eyes when they see?, 2) Do rays, energy, or something else go out of people's eyes when they see?, and 3) Do rays, energy, or something else first go into people's eyes and then go out of their eyes when they see? The three verbal questions were followed by three additional questions about how we see, each of which forced the subject to choose among one of the three alternatives represented in the three questions just described: 1) into the eyes, 2) out of the eyes, and 3) into and then out of the eyes. In the second set of items, the first and third questions were presented verbally and were identical, while the second question added line-drawn pictures to the verbally presented question. The pictures in the second question showed arrows going into the eyes of a person, arrows exiting the eyes of a person, and arrows going both in and out of the eyes of a person. When responses to the first four questions were combined (the three questions that presented the alternatives separately and the first forced choice question), analyses revealed a significant effect for grade, with college students providing significantly more intromission answers than elementary school students. When forced to choose among the three items, many elementary school students believed that something goes both into and out of the eyes when they see, while the majority
of college students believed that something only goes into the eyes when they see. For all age groups, the number of subjects giving pure extramission responses increased on the pictorial item. Additionally, the presentation of the pictorial item depressed correct responses on succeeding verbal, forced choice questions.

To determine if the effect of showing pictures during questioning was generalizable, other pictorial presentations also were employed. Computer-generated pictures were used in conjunction with the questions about visual input and output (Winer, Cottrell, Karefilaki, & Gregg, 1995). These computer representations depicted a person with his face directed toward a rectangularly shaped object, and dotted lines appeared to move between the rectangular object and the eyes of the face. In one study, first, third and fifth grade students and college students were asked five separate questions, each presented in concert with computer-generated pictures showing dotted lines which appeared to 1) enter the eyes, 2) exit the eyes, 3) first enter and then exit the eyes, 4) first exit and then enter the eyes, and 5) enter and exit the eyes at the same time. The order of presentation was varied, with some subjects receiving the items depicting output first and other subjects receiving the items depicting input first; these orderings did not produce significant differences in responses. When the scores for the five items were added together, analyses indicated that college students had significantly more correct responses than subjects in all other age groups, followed (in order) by first graders, fifth graders, and third graders. When compared to verbally presented items, students in all age groups tended to perform more poorly on items that included a computer-generated picture.
The items including the computed-generated images have also been used in a slightly modified form (Winer, Cottrell, Karefilaki, & Gregg, 1995). Third, fifth, and eighth grade and college students were asked seven questions, each of which forced the subject to choose among two, three, or four alternatives presented simultaneously: 1) into the eyes, 2) out of the eyes, 3) into and then out of the eyes, 4) out of and then into the eyes, and 5) into and out of the eyes at the same time. To ensure that the correct alternative was always present (in only), two choices, in only and out only, were held constant across all seven questions. The order of the questions was varied systematically by the number of choices on the screen at once (one order began with two choices and ended with four choices and the other began with four choices and ended with two choices) and the positioning of choices on the screen (one order presented the intromission picture on top of the computer screen while in the other order the extramission picture was on top). Once the seven computer questions were administered, all subjects received a final, verbal question which provided all five of the possible choices. The scores on the eight items were then summed to produce a total score for each subject, with each correct, in-only answer assigned a value of one and other answers assigned a value of zero. College students had significantly more correct responses than third, fifth, and eighth graders. On the simplest, two-alternative question in which subjects chose between the intromission-only and the extramission-only choices, third graders preferred extramission over intromission while college students preferred intromission over extramission. Surprisingly, college students did not maintain their preference for the intromission choice when they were presented with more than two alternatives; rather, the majority of college
students gave incorrect answers on 4 of the 7 computer items. As noted earlier, one purpose of these studies was to determine whether extramission responses were given more often when questions were asked in conjunction with pictorial representations than when purely verbal questions were asked. While this finding was supported, the combination of computer-generated graphics and the multiple choice question format produced the most powerful evidence of extramission beliefs. In fact, when verbal multiple choice questions were directly compared to multiple choice questions presented with computer graphics, all age groups showed a preference for the intromission response on verbal items, while the developmental trend from extramission to intromission was found only on the computer items. Although questions asked in conjunction with pictorial representations appear to have a negative effect on students' answers to questions about how they see, computer-generated graphics have an even greater effect than line-drawn pictures.

The response variations that occur with different question formats may have implications for the form and function of knowledge for both children and adults. Changes in extramission response frequency across question formats suggest that the understanding of visual perception is sensitive to situational factors. Some researchers have suggested that the intuitive knowledge demonstrated by children in many areas of science is fragmented and unsystematic, and that inconsistency in answers to superficially different questions such as those discussed here (e.g., picture versus verbal questions) are indicative of a more fragmented knowledge system (di Sessa, 1988). Others, however, believe that children's intuitive knowledge is coherent, systematic, and theory-like (Brewer & Samarapungavan, 1991; Carey, 1985,
1986; McCloskey, 1983). It is still unclear whether intuitive knowledge, such as extramission beliefs about visual perception, is better conceptualized as internally consistent or fragmented (Vosniadou & Brewer, 1992), but the variations found in beliefs about visual perception suggest fragmentation.

The way that extramission beliefs are structured (i.e., whether they are coherent or fragmented) may have educational ramifications. Pilot testing showed that a portion of college students continued to offer extramission explanations of vision after exposure to a visual perception section in an introductory psychology class. Moreover, college students who read a selection about visual perception from an introductory psychology book immediately before answering questions still gave extramission responses. These results demonstrate the resistance of these beliefs to traditional instruction, a finding which is expected to occur for children as well as college students. The resistance to instruction found for students who hold extramission beliefs may be due to the fragmented nature of their conceptualizations of vision. If the instruction presented did not enable the students who held extramission beliefs to draw the conclusion that extramission and intromission beliefs are conflicting, it would account for the persistence of extramission answers and for some of the variations that occur in response to different question formats.

In summary, although studies support the presence of extramission beliefs about vision in both children and adults, the developmental and educational significance of these beliefs has been minimized. Research suggests that extramission responses decrease with age, however a surprising number of college students continue to produce extramission responses even
after instruction. The format of the questions influences the production of extramission responses, with pictorially based items eliciting more extramission responses than verbal items. These inconsistencies may have implications for the nature of knowledge and conceptual change.

**Misconceptions in Science.**

In recent years, cognitive developmental psychologists and educators have become interested in children's conceptual frameworks and the effect of these frameworks on subsequent learning. Students enter the classroom with beliefs formed from personal experiences and information encountered outside of school, but, while these ideas may be logical, they are not necessarily correct (Rakow, 1992). For example, many adults believe that it is hotter in the summer than in the winter because the entire earth is closer to the sun in the summertime than in the wintertime (Rakow, 1992). While this may be a logical conclusion in view of everyday experiences with heat-producing sources (the closer one moves toward a fire, for example, the hotter the fire feels to the skin), it is, nevertheless, incorrect. Misconceptions abound in a variety of scientific domains, such as in the understanding of diffusion (Westbrook & Marek, 1991), electrostatics (McMillan & Swadener, 1991), homeostasis (Westbrook & Marek, 1992), electrochemistry (Garnett & Tregust, 1992), the characteristics of atoms and molecules (Griffiths & Preston, 1992), the nature of gases (Benson, Wittrock, & Baur, 1993), chemical equilibrium (Gussarsky & Gorodetsky, 1990), photosynthesis, and the digestion of food (Lawson, 1988), to name a few. The seemingly unending list of misconceptions in the scientific arena underlines the importance of understanding and addressing misconceptions in the classroom.
In order to do this, teachers first must be aware of common science misconceptions, of how resistant to change such misconceptions can be, and of the possibility that misconceptions can alter or distort the information that children are taught in the classroom (e.g., Chinn & Brewer, 1993; Posner, Strike, Hewson, & Gertzog, 1982; Rakow, 1992). The effect of preconceptions (i.e., beliefs that exist prior to being taught correct information) on learning may be particularly evident in the area of science because of the frequency with which differences between natural schemata and information taught in science classes occur. There are different views, however, of how preconceptions of scientific phenomena can be addressed most effectively in the classroom (see Gil-Perez & Carrascosa, 1990, for a brief review and for exceptions to these views). Many believe, however, that how the information is presented will determine whether children understand the phenomenon after exposure to the correct information (e.g., Chinn & Brewer, 1993; Posner, Strike, Hewson, & Gertzog, 1982).

A major difficulty in effectively eliminating misconceptions arises because misconceptions are resistant to instruction. Assuming that an incompatible knowledge structure is in place before instruction, there are a number of means by which knowledge structures can adapt to the incoming messages. Brewer and Chinn (1993) maintain that students respond to information that is discrepant from what they believe by: (1) ignoring the discrepant information, (2) rejecting the information, (3) excluding the information from their theory, (4) holding the information until they can decide where it belongs and how it fits, (5) reinterpreting the information, (6) making peripheral changes to the current theory, and (7) changing the theory to
accommodate the new information. According to Vosniadou and Brewer (1992), students' understanding of science, the strength of their misconceptions, their background knowledge, and their beliefs about the world will determine how the child responds to contradictory information. When children somehow retain parts of both the correct and the incorrect theory, Gardner (1991) states that situational and contextual factors determine which theory will be invoked.

There is some evidence that all of the outcomes discussed by Brewer and Chinn (1993) occur after exposure to information, although which teaching techniques produce which outcome is less well understood. In assessing changes in children's beliefs about the shape of the earth, Vosniadou and Brewer (1992) noted that some children combined correct and incorrect information. Children in first, third, and fifth grades were interviewed individually and were asked a number of questions about the shape of the earth, and the responses were placed into categories based on the model of the earth represented: a sphere, a sphere with a flat top on which we live, a hollow sphere like a pumpkin in which there is a flat surface upon which we live, a dual earth model in which both flat and spherical earths coexist, a disk earth which is similar to a plate or a frisbee, and a rectangular earth which is shaped like a piece of paper. Additionally, responses were rated for consistency to determine if the responses of each child represented a single, coherent model or multiple models. Evaluating the consistency of responses allowed the researchers to determine if children with an incorrect understanding of the

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1The questionnaire used in this study consisted of 48 items that addressed critical concepts in astronomy. Only 15 of these items were related to the shape of the earth.
shape of the earth had a model (albeit incorrect) of the earth or if they answered randomly due to a lack of a representation of the earth's shape.

Although most children in the study had consistent mental models of the earth, 26 of 60 children answered consistently using an incorrect model of the earth. In addition, all but one of the incorrect models described above contained elements of both a round earth (not always a sphere) and a flat earth. Thus, some of the children who were aware of the culturally-accepted belief that the earth is round distorted the information about a spherical earth so as to retain the intuitive belief that the earth is flat. In other words, the children did not abandon previously held notions about a flat earth and replace them with the correct concept of a round earth; instead, they assimilated the learned information about the earth's shape while maintaining some semblance of their previously held theory. Unlike the findings with extramission beliefs (described above), children usually answered questions using a consistent model of the earth's shape and responded to differently formatted questions accordingly. Thus, the majority of the children had coherent (or at least consistent) conceptualizations of the earth. The authors concluded that children gradually develop theories more consistent with culturally accepted models. It should be noted that Vosnaidou and Brewer (1992) did not attempt to change children's conceptualizations through instruction, therefore the ideas that children had about the shape of the earth were formed through information encountered in unknown and uncontrolled settings.

Alternatively, the outcome of another study suggests that children sometimes retain two intact conceptions of scientific phenomena. Children
built model cars, made predictions about which features of the cars would affect their speed, and then tested the cars to collect evidence supporting or disconfirming the predictions (Schauble, 1990). When faced with evidence that disconfirmed their predictions, children either made judgments that supported their original, incorrect theories or that were a more accurate reflection of what they had witnessed. Some children alternated between the two models, indicating that both the correct and incorrect models were available to them. Both the Vosniadou and Brewer (1992) study and the Schauble (1990) study indicate that merely exposing children to contradictory evidence is not sufficient for replacement of prior conceptions.

Furthermore, research shows that traditional educational techniques are not very effective in eradicating misconceptions in science (Clement, 1982; Halloun & Hestenes, 1985; Brown & Clement, 1987). Although work on misconceptions and science education typically focuses on children and adolescents, misconceptions about science are not limited to these age groups. Even college students who have successfully completed one or more related courses retain misconceptions about such things as principles of mechanics (e.g., Clement, 1982) and light (Galili, Bendall, & Goldberg, 1993). Because of the difficulty in overcoming misconceptions, a variety of strategies have been developed to eliminate common misconceptions. One method is that of concept mapping, in which knowledge structures and their changes over time are mapped hierarchically. Presenting the knowledge structures in this way assumes that "learning occurs through derivative or correlative subsumption of new concept meanings under existing concept/propositional ideas" (Novak, 1990, p. 93; see also Novak, 1979; 1980; 1981). While concept mapping may
be useful in portraying changes in concepts over time, it also has been used to help teachers understand children's metacognitive abilities and how to stimulate these abilities so that children can learn the correct information (Novak, 1990). Although concept mapping may be an effective way of aiding the instructor in teaching individual children, it is time consuming and may not be as effective in helping teachers disseminate information to groups of students. Specific strategies are needed, therefore, that address the information gleaned from techniques such as concept mapping (Zoller, 1990).

Other techniques, such as the use of concrete examples (Brown, 1992), analogies (Brown, 1992), discussion groups (Lundeberg, 1990; Thijs, 1992), active exploration (e.g., through experimentation) of the phenomena under examination (Stepans, Dyche, & Beiswenger, 1988), and expanded textbook/lecture information (Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993; Smith, Blakeslee, & Anderson, 1993), are more conducive to teaching groups of students and have been somewhat successful in overcoming misconceptions. These techniques typically involve a "constructivist" strategy in which students are active participants in the learning process rather than passive observers who absorb information.

A study by Brown (1992) exemplifies how these techniques may be incorporated into the classroom. High school students who were enrolled in a chemistry course but who had not taken a physics course were exposed to one of two written explanations of Newton's third law of action and reaction (Brown, 1992). The first excerpt was from a popular physics text, and the passage presented verbal examples of the law along with diagrams that pictorially represented the examples. The second excerpt was called a
"bridging explanation" because it presented a sequence of examples that, through their ordering and increasing difficulty, exposed the source of the force being exerted; students were given first an example in which the principle being demonstrated was easily understood. Then they were given a bridging example that they would understand with slightly more difficulty, and finally they were presented with the target example that was still more difficult but similar to examples used in the textbook excerpt.

The students were asked three pre-reading questions and five post-reading questions (three of which were identical to the pre-reading questions). Fourteen of the 21 students in the study gave incorrect answers on the pre-reading questions. Half of these students received the textbook explanation and half received the bridging explanation. The bridging explanation proved to be much more effective than the textbook excerpt. While fewer than half the students reading the textbook explanation correctly answered the post-reading questions, almost all the students in the bridging explanation correctly answered the post-reading questions. Accordingly, a technique which exposes students to progressively more difficult examples appears to be preferable to one that presents similarly difficult examples in a somewhat random order.

While the method used by Brown (1992) may be ideal when presenting multifaceted information representing many layers of understanding, it may not be amenable to more simplistic misunderstandings, such as those concerning the shape of the earth.

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All seven of the students in the bridging explanation condition answered two of the post-reading questions correctly while one student missed a portion of three of the post-reading questions.
Perhaps a more straightforward approach to overcoming misconceptions involves confronting students with the incorrect beliefs and then informing the students of the correct information. Including a direct contradiction of misconceptions in instruction creates cognitive conflict between correct information and misconceptions (Posner, Strike, Hewson, & Gertzog, 1982) and may be effective in inducing children to replace preexisting, incorrect schemata. Although studies that have challenged misconceptions during instruction have indicated the usefulness of this strategy, most of these studies did not include a comparison group in which there was no contradiction of erroneous beliefs (Smith, Blakeslee, & Anderson, 1993; Hashweh, 1988). Furthermore, the contradiction of misconceptions is sometimes confounded with other instructional techniques (Lundeberg, 1990; Smith, Blakeslee, & Anderson, 1993).

Although producing conceptual change by contradicting misconceptions represents the current educational zeitgeist, it should be noted that some educators do not believe in the necessity of directly contradicting misconceptions during instruction. The suggestion is that, assuming children are attentive, coherent, clearly presented information is adequate in order to overcome children's misconceptions (Muthukrishna, Carnine, Grossen, & Miller, 1993). In one study that supported this claim, children were presented with information via videodisk about two science phenomena. Following instruction, ninety-two percent of the children had overcome the misconceptions they held before instruction. Although the study produced a massive effect, there were possible confounding variables, including the
amount of one-on-one interaction with the teacher during and after videodisk instruction and the lack of a comparison group.

It is possible that all of the techniques described here help students overcome their misconceptions about scientific phenomena. As suggested above, some children may replace misconceptions when faced with contradictory information while other children retain the incorrect information. These individual differences may depend on whether students recognize the difference between misconceptions and correct information. One modern theory of cognitive development suggests that the differences in knowledge between children and adults are much like differences between novices and experts (Chi, 1978, Chi & Rees, 1983). Children integrate newly acquired information with preexisting information, causing a more intricate and complicated pattern of associations to form. Accordingly, as a child acquires more information in a particular domain, more associations are available to the child when new information is encountered. Children who continue to produce responses indicative of misconceptions may do so because the information learned is assigned incorrectly to categories (Chi, 1992; Rosser & Narter, 1995) and, therefore, would not replace the preexisting belief system. It may be necessary to refer to the inaccuracy of misconceptions during instruction for children who do not associate the two bodies of information otherwise. As Gardner (1991) suggests, misconceptions remain because earlier, more intuitive ways of knowing are not obliterated by knowledge gained through instruction, instead:

...children's earliest conceptions and misconceptions endure throughout the school era. And once the youth has left a scholastic setting, these
earlier views of the world may well emerge (or reemerge) in full-blown form. Rather than being eradicated or transformed, they simply travel underground; like repressed memories of childhood, they reassert themselves in settings where they seem to be appropriate (p. 29).

He claims that when children and adults encounter questions that cause them to use the information in a way somewhat different from which it was learned, the lack of correct understanding that exists becomes apparent. Individuals often present these alternative or blended frameworks confidently and with certainty (Gil-Perez & Carrascosa, 1990), suggesting that the individuals are unaware of their own lack of knowledge. A concrete, direct reference to misconceptions during instruction might increase awareness of existing beliefs.

In summary, students' misconceptions about scientific phenomena are widespread and resistant to instruction. Both researchers and educators have suggested that directly confronting these misconceptions during instruction may help students overcome them, but uncertainty about the need and the effectiveness of this approach remains. A direct comparison of instruction that incorporates the direct contradiction of misconceptions with instruction that is more traditional (i.e., does not address misconceptions) is needed, and the long-term effects of these techniques should be assessed.

Light and Vision in Science Education.

One area in which misconceptions are well documented is in the understanding of the principles of light (e.g., Guesne, 1985; Rice & Feher, 1987; Feher & Rice, 1988) and the role of light in vision (e.g., Galili, Bendall, & Goldberg, 1993; Repp, Callanan, Meier, & Miller, 1992). Children have difficulty understanding, for example, how shadows are formed (Goldberg,
Bendall, & Galili, 1991), image formation (Gallili, Bendall, & Goldberg, 1993), and the role of the reflection of light on the visual process (Guesne, 1985; Repp et al., 1992). The focus of previous research suggests that psychologists and educators believe that the primary deterrent to understanding visual perception is a lack of comprehension about the principles of light. Ignored is the possibility that a misunderstanding of the visual process itself may contribute to certain misconceptions.

The assumption that misconceptions about vision are the product of an incomplete understanding of light has led educators to develop strategies, often in the form of demonstrations, to help students understand the properties of light. In one study, children at a science museum participated in a series of demonstrations in which they predicted the results of different manipulations made to light (e.g., "What will the shadow look like if you..."; Feher & Rice, 1988). After making predictions, the children were able to witness the true effect of the manipulations. The authors concluded that children's active exploration of their predictions allowed them to overcome misunderstandings about scientific phenomena (in this case, about light). Although demonstrations such as these may allow children to challenge a priori predictions, as stated previously, the demonstrations may not be enough to counter the underlying beliefs that cause children to form these predictions and thus may not help them eliminate their misconceptions.

The impact of erroneous preconceptions about light on subsequent instruction was investigated in another study. The nature of fifth grade students' beliefs about vision and light were assessed before and after classroom instruction on these topics (Eaton, Anderson, & Smith, 1984).
Additionally, the teachers were observed and detailed information about the instruction itself and about the classroom environment was collected. Prior to the introduction of the unit on light and vision, children were given a 43-item test to determine their level of understanding about light and vision and to determine if they held misconceptions in these areas. The same test also was given after the light and vision unit. Prior to instruction, six of the students held the belief that light helps people see by shining on objects and brightening them, and none of the students was aware of the role of reflected light in vision. The children who held the misconception about the role of light in vision prior to instruction had more difficulty learning the correct information than children who did not have misconceptions. Although the students in the study received instruction about light and vision for several weeks, their responses indicated that they did not grasp the concept of the reflection of light. The authors concluded that in order for children to develop more coherent conceptual frameworks of light and vision, their misconceptions about light should be directly confronted.

These conclusions were tested in a follow-up study during the next school year with a new group of fifth grade students (Anderson & Smith, 1986). Two fifth grade teachers received documentation about the principles of light and the role of light in vision. The teachers also received transparencies designed to address directly common student misconceptions about light and color vision. The children answered questions to determine their knowledge of light and vision before and after instruction. Students who received instruction including the direct presentation of common misconceptions had higher post-instruction scores than students who did not receive this instruction.
While at first glance the findings appear to support strongly the identification of misconceptions during instruction, a few problems with the study exist. As the authors admit, the teachers themselves reported better understanding of light and color vision after reading the materials provided by the researchers. For this reason, the effect of the increase in teacher comprehension on student learning cannot be separated from the effect of the direct presentation of common misconceptions on student learning. As noted above, children who have drawn more prior associations may benefit from the presentation of accurate, coherent instruction alone. Were the students' correct responses due to a more accurate presentation of the accepted theory by the teachers or to the introduction of misconceptions about light? Also, there was little control over the teachers' presentational styles. The fifth graders in this study received instruction on light and vision 2-3 times a week for 4-6 week period, leaving ample time for different presentational styles to emerge. Finally, students' comprehension was assessed directly after the last lesson on the topic. The study did not determine whether the instructional method used had lasting effects.

The Anderson and Smith (1986) study supports the premise of addressing misconceptions during instruction even though it contained some methodological problems. Misconceptions about light have been described and addressed in science instruction, but the misconception about the visual process, namely the belief in extramissions, has not been addressed in this fashion. Instruction that explains how light functions in the visual process while addressing the incorrect nature of the extramission theory of vision should be most effective in reducing extramission beliefs at all ages. In order
for the hypothesis to be tested, however, both instruction presenting information about light and vision alone must be compared to instruction directly contradicting extramission beliefs.

Although the information outlined so far has focused primarily on the educational aspects of overcoming misconceptions in science, research in cognitive development has much to offer the educational endeavor. As Gardner (1991) suggests, development, especially after children enter school, cannot be completely separated from the cultural context in which it occurs. The development of importance here is the development of beliefs about vision and the cultural context explored is the educational institution.

As found in previous studies, extramission beliefs about vision decrease with age (Cottrell & Winer, 1994). The developmental trend associated with extramission beliefs probably occurs because of an increase in logical, rational thinking which allows scientific information to be more accurately represented within belief systems. This does not explain, however, those adults and older children who diverged from this model. The model of the novice-to-expert shift is helpful here. It is likely that students who do not hold a correct conceptualization of vision in all situations (or for all questions) have not progressed to the level at which they can completely abandon their misconceptions. Thus these students have a knowledge base that is more fragmented than students who did not produce extramission responses.

While the existence of extramission beliefs may seem a strange misconception to attempt to eliminate, it provides an ideal example of a simple, extremely resistant, common misconception. In areas such as physics, misconceptions are complex, and, therefore, the correct instruction about such
concepts is elaborate. Extramission beliefs, by contrast, allow for an uncomplicated examination of the manipulations made to instruction. The manipulations made to instruction will, in turn, have implications for conceptual structures, their composition, and their reconstruction.

In summary, children's misconceptions about light are well documented. Instructional techniques that directly address misconceptions may be more effective than traditional instruction which presents only correct information in dispelling misconceptions about light and vision. The little research that has been done on the effects of misconceptions of light and vision on instruction supports this conclusion; however tighter controls must be implemented to determine the effects of this instructional technique and the duration of its effects. It is expected that instruction using misconceptions will be more effective than traditional instruction. Contradicting extramission beliefs during instruction may seem trivial; however the failure of traditional instruction and books that supplement instruction to eliminate these beliefs justifies a direct challenge to these beliefs in the classroom. It is surprising how persistent these erroneous beliefs are, and including a simple contradiction of these beliefs may enable students to replace misconceptions with more accepted scientific ideas.
Hypotheses.

The following hypotheses were tested.

1. Instruction directly contradicting extramission beliefs about vision will be significantly more effective in replacing the extramission misconception than traditional instruction. Both traditional instruction and instruction countering extramission beliefs will be significantly more effective in replacing the extramission misconception than instruction that does not address principles of vision and light.

2. Instruction directly confronting extramission beliefs about vision will be more enduring over a three month lapse between teaching and testing than traditional instruction. Traditional instruction is expected to cause some short term effects, however students receiving this type of instruction will revert to their preconceptions as time since instruction increases (as they approach three months since instruction).

3. Children receiving instruction directly confronting extramission beliefs will be more resistant to question format differences than students receiving traditional instruction, suggesting that this technique facilitates the development of a coherent framework more than traditional instruction.

4. These results will be true for children of all ages as well as for college students.

5. School-aged children who are judged by their teachers to be science oriented and who have higher grades in their science classes will have more success than students who are not science prone regardless of the teaching method to which the children are exposed. College-aged students who have taken several science courses and who have a high
grade point average in science classes will have higher performance than other students.

6. Gender differences with respect to the effectiveness of instructional methods are not expected.
CHAPTER II

METHOD

Testing Time One

Subjects. Subjects were 75 fifth graders (31 males, 44 females, 10-11 years, \( M_{age}=10.49 \)), 62 eighth graders (34 males, 28 females, 13-15 years, \( M_{age}=13.58 \)), and 85 college students (45 males, 40 females, 17-43 years, \( M_{age}=19.40 \)). The fifth and eighth grade students were from three middle-class, urban parochial schools. The college students participated in the first testing session for course credit in an introductory psychology course at a large, midwestern university. The majority of college students were freshmen. Students in each age group were randomly assigned to one of three instructional conditions described below.

Questions and procedures.

Instruction. Students did not receive a preinstruction test to determine the level of knowledge because it may have sensitized the students to the nature of the study, therefore biasing subsequent answers. Students were taken into a conference-type room and were told that they would be watching a videotape on which they would be questioned. Approximately 25 students from each grade were placed in one of the three instructional conditions. Between six and ten students at a time participated in an
instruction session, thus ensuring that each of the three schools was represented in the three instructional conditions.

Students in each grade were placed in one of three conditions: (a) traditional instruction condition, (b) traditional instruction plus the discussion of the extramission theory (i.e., counter-teaching), and (c) instruction unrelated to vision (control). Although an attempt was made to place approximately the same number of males and females from each grade into each condition, this was not always possible because of the constraints associated with taking the fifth and eighth graders out of their classrooms and because college students randomly signed up for the experiments.

Instruction was presented in a videotaped format. It was felt that videotaping the instruction would reduce unintended presentational differences among the conditions. While interaction in the classroom typically is viewed as beneficial to instruction, it was necessary to reduce interaction here to maintain uniformity among conditions. Students in all three age groups received the same instruction, which was designed to be understood by the fifth grade subjects. A sixth grade science teacher was consulted to ensure that the level of presentation would be understandable to fifth grade students. Although another strategy would have been to tailor the level of presentation to each of the three age groups, this would have made interpretation of age differences difficult.

The three instruction conditions consisted of two experimental groups and one control group. Instruction for each of the conditions was as follows:

1) **Experimental Group One** received traditional instruction about light and vision. Students were given a verbal explanation of intromission in
visual processing. Demonstrations and models were used throughout to introduce principles of light and the structures of the eye (See Script One, Appendix A). To reduce the amount of extraneous information, the only structures of the eye presented were the pupil, the retina, and the optic nerve. This group will be referred to as the traditional instruction condition.

2) **Experimental Group Two** received virtually the same instruction about vision and light as students in the traditional instruction condition, however, the extramission theory of vision was directly contradicted in this second experimental group. Instruction emphasized that nothing leaves the eyes when we see, and that light only enters the eyes to allow us to see. (See Script Two, Appendix A). This group will be referred to as the counter-teaching condition.

   To ensure that the differences between the traditional instruction and counter-teaching conditions were minimized, a video tape of the counter-teaching was filmed first. The traditional instruction was then created by deleting from the counter-teaching videotape any of the information that denied output from the eyes.

3) **The Control Group** watched videotaped instruction on a topic unrelated to vision and the senses. Instead, students in this group were given conservation training instruction (e.g., the weight of an object remains stable despite superficial changes in the object such as shape). The videotaped instruction presented to students in the Control Condition approximated the methods and techniques used in the
experimental groups as closely as possible (see Script Three, Appendix A).

Instruction in all conditions was presented by the author and lasted for five to ten minutes.

Post-testing. Subjects were tested immediately after receiving instruction by trained undergraduate and graduate students. Students were instructed that the researchers were interested in how people see and about the students' thoughts about how a person sees something. They were warned that some of the questions would seem the same and that the questions may seem unrelated to the videotape shown.

After receiving these instructions, students were shown computer generated pictures of two to four faces with dotted lines entering and/or leaving the eyes. Subjects were told, "Here the pictures show something (coming into the eye, going out of the eye, something first coming in and then going out of the eye, something first going out and then coming into the eye, and/or something coming in and out of the eye at the same time)." Then subjects were asked, "Which one shows how or why we can see?" For example, each question presented the subjects with at least two choices, in only and out only. Subjects would see on the screen a face directed toward an object, and dotted lines would appear to move toward the eye-area of the face for the in-only choice or away from the face toward the object for the out-only choice. Similar faces and objects were seen for the other possible three choices (in and then out, out and then in, in and out simultaneously) with the exception of the direction in which the dotted lines appeared to move. Subjects were forced to choose the picture on the screen that best represented what happens when a person sees
something. Subjects were asked a series of seven such questions in conjunction with computer-generated pictures about what happens when a person looks at an object, and the experimenter referred to the pictures on the computer screen as the possible choices were mentioned (See Table 2).

There were four different orders of questions that the subjects could receive (see Table 1 and Appendix B). Regardless of the order, however, subjects were presented with "in" only and "out" only as possible answers for all seven questions. This procedure ensured that subjects were presented with a correct response for all questions and that more than one response was held constant across questions. In two of the four orders, the pictures were ordered on the computer screen so that the in-choices appeared at the top of the computer screen. For the remaining two orders, the pictures were ordered with the out-choices appearing at the top of the computer screen.

<table>
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<th>Order</th>
<th>In/Out First?</th>
<th>Simple/Complex First?</th>
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<td>1</td>
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<tr>
<td>4</td>
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The other variable related to order was the complexity of the alternatives presented in the first question. In two orders, subjects were asked
the simple, two-choice ("in" only or "out" only) question first and proceeded to more complex 3- and 4-choice alternatives. In the second order, a complex 4-choice item was presented first and the simple, two choice question last.

After the seven computer-generated questions were asked, students answered one final, verbally presented question. On this question subjects were asked, "Now we are not going to show you anything on the computer. But tell me, what do you think happens when we see? Does anything come into the eye, go out of the eye, first come in and then go out, first go out and then come in, or come in and go out at the same time?"
Table 2. Sequence of Seven Computer Items and the Final Verbal Item Used for the Main Test Questions, in the Order Proceeding from the Most Complex Computer Question to the Least Complex.

1. Here the pictures show something coming into the eye, going out of the eye, something going in and out at the same time, and something first going out of the eye and then coming back in. Which one shows how or why we can see?

2. Here the pictures show something coming into the eye, going out of the eye, something going in and out at the same time, and something first coming into the eye and then going back out. Which one shows how or why we can see?

3. Here the pictures show something coming into the eye, going out of the eye, and something going in and out at the same time. Which one shows how or why we can see?

4. Here the pictures show something coming into the eye, going out of the eye, something first coming into the eye and then going back out, and something first going out of the eye and then coming back in. Which one shows how or why we can see?

5. Here the pictures show something coming into the eye, going out of the eye, and something first going out of the eye and then coming back in. Which one shows how or why we can see?

6. Here the pictures show something coming into the eye, going out of the eye, and something first coming into the eye and then going back out. Which one shows how or why we can see?

7. Here the pictures show something coming into the eye and going out of the eye. Which one shows how or why we can see?

8. Now we are not going to show you anything on the computer. But tell me what do you think happens when we see? Does anything:

   A. Come into the eye
   B. Go out of the eye
   C. First come in and then go out
   D. First go out and then come in
   E. Go in and go out at the same time.
Students finished the session with a number of questions designed to determine if they had paid attention to the videotape. For example, students were asked, "Can you see if information is not carried to your brain?", "Can you see if there is no light at all?", and "Information is carried to your brain by a special pathway called a(n): a) pupil, b) retina, c) nerve, d) iris." These questions were intentionally simple so that no carry-over effects would occur.

Testing Time Two.

Subjects were retested three to five months after instruction to determine how enduring the effects of instruction were.

Subjects. Subjects were 71 fifth graders (30 males, 41 females), 59 eighth graders (32 males, 27 females), and 48 college students (21 males, 27 females). The fifth and eighth grade students were tested between three months and three months and three weeks after the first session, and the college students were tested between three months three weeks and five months after the first session. The college students were tested after more time had elapsed due to the difficult nature of rescheduling/retesting the college students.

As had been anticipated, it was difficult to schedule sessions to retest the college students. As an incentive to participate, college subjects were informed that all students who participated in the second session would be eligible for two prizes, $75 and $100, that would be given away in a raffle. A minimum of five attempts were made to contact the college-aged subjects. Twelve students who were tested at time one could not be reached and messages could not be left. Additionally, three subjects refused to participate.
in the second session, and three students had dropped out of college since the first session. The remaining college students were contacted and scheduled to be retested, however, many of these subjects failed to appear at their scheduled testing times.

Students who failed to come to scheduled testing times were recalled and rescheduled. At this time, students were informed of the importance of their participation. When this procedure also failed to motivate the majority of the subjects to arrive for scheduled appointments, the author's advisor began making appointments. It was thought that the authority associated with a professor's status would motivate students to attend their testing sessions. While this procedure proved successful for a number of participants, nineteen subjects still were not tested due to their failure to show up for testing sessions.

Questions. The first eight questions that subjects received during the second phase of testing were identical in wording and order to those in the first session. The simple follow-up questions were also the same as those presented in phase one.

Some more difficult and thought-provoking questions were asked to determine the nature of the students' understanding of vision and to help determine if extramission beliefs were truly eliminated. The first question was based on the answer the subjects had given to the last, verbal question that presented all possible choices to the question of what happens when a person sees something; subjects were asked to explain why the answer they chose on the verbal-only question was better than the other four choices. A second open ended question asked subjects to: "Pretend that you are speaking to a child who is younger than you. Explain to this child how we see. You want to make
sure that the child understands how the eyes work." Subjects were asked this question because research has shown that subjects tend to explain scientific phenomena in more detail when they are speaking to someone who is thought to be a novice than when they are speaking to an expert (i.e., someone who already knows the answers; Fay, 1995).

E valuation of science and academic abilities. For fifth and eighth grade students, teachers were asked to provide evaluations of students' science and overall academic abilities. The teachers were asked to rate each student's science ability on a five point scale, with a score of one representing "High Science Ability," a score of three representing "Moderate Science Ability," and a score of five representing "Low Science Ability." Similarly, teachers rated each student's academic ability on a five point scale, with a score of one representing "High Academic Ability," a score of three representing "Moderate Academic Ability," and a score of five representing "Low Academic Ability."

College students were asked how many science courses they had taken in college and the grades received in those science courses. Courses in the Behavioral Sciences were omitted from the listing of science courses. The grades were assigned a numeric value between zero and four (0=E, 1=D, 1.3=D+, 1.7=C-, 2.0=C, etc.) and an average "science grade" was calculated. Additionally, college students provided their cumulative grade point average (again from zero to four points) as a measure of their overall academic ability.
CHAPTER III

RESULTS

Responses on the eight main test questions (see Appendix B) were assigned a value of 1 if the subject gave the pure intromission response (i.e., something goes into our eyes [only] when we see) and a value of 0 if the subject gave any other response (i.e., a response which contained some reference to something going out of the eye). Subjects could receive a total of 7 on the items that were accompanied by computer-generated images and an 8 when the final, verbal item was included.

Initial analyses were conducted to determine the effect of the teaching condition on performance and to assess whether performance at time one differed from performance at time two. Therefore, a 3 (Condition: Counter-teaching, Traditional teaching, Control) x 2 (Sex) x 3 (Grade) x 2 (In-Alternative Position: in alternative above out alternative versus out alternative above in alternative) x 2 (Testing Time) repeated measures analysis of variance (ANOVA) was conducted.

As can be seen in Table 3, there was a significant Condition x Time effect. The Condition effect was as predicted. In looking at the means of Question Totals by Condition during the initial testing session presented in Figure 1, the subjects in the Counter-Teaching Condition had the highest scores (Mcounter=6.97), the subjects in the Traditional Teaching Condition had
the next highest scores ($M_{traditional}=4.73$), and the subjects in the Control Condition had the lowest scores ($M_{control}=3.01$). During time one, the scores of subjects in the Counter-Teaching Condition were significantly different from the scores of subjects in the Traditional Teaching and Control Conditions ($p<.0001$ in both cases). Although it was predicted, it was surprising, in light of previous research, that the subjects in the traditional teaching group also performed significantly better than the subjects in the control group ($p<.0001$). During the second testing session, subjects in the Counter-Teaching Condition ($M_{counter}=5.27$) and the Traditional Teaching Condition ($M_{traditional}=5.27$) again performed statistically significantly better than subjects in the Control Group ($M_{control}=3.21$; $p<.0001$ for both comparisons). There was not a significant difference, however, between the Counter-Teaching Condition and the Traditional Teaching Condition at time two. These results suggest that, although counter-teaching initially was more successful than the other teaching strategies in overcoming extramission beliefs, counter-teaching and traditional teaching were equally successful after a period of at least three months had passed.
Table 3. Repeated Measures Analysis of Variance Summary of Total Number of Intromission Responses by Condition, Grade, Sex, and In-Order.

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Between Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition</td>
<td>459.00</td>
<td>2</td>
<td>229.50</td>
<td>23.44**</td>
</tr>
<tr>
<td>Grade</td>
<td>67.24</td>
<td>2</td>
<td>33.62</td>
<td>3.43*</td>
</tr>
<tr>
<td>Sex</td>
<td>29.06</td>
<td>1</td>
<td>29.06</td>
<td>2.97</td>
</tr>
<tr>
<td>In-order</td>
<td>3.56</td>
<td>1</td>
<td>3.56</td>
<td>.36</td>
</tr>
<tr>
<td>Condition*Grade</td>
<td>42.94</td>
<td>4</td>
<td>10.73</td>
<td>1.10</td>
</tr>
<tr>
<td>Condition*Sex</td>
<td>16.32</td>
<td>2</td>
<td>8.16</td>
<td>.83</td>
</tr>
<tr>
<td>Condition*In-order</td>
<td>13.06</td>
<td>2</td>
<td>6.53</td>
<td>.67</td>
</tr>
<tr>
<td>Grade*Sex</td>
<td>42.06</td>
<td>2</td>
<td>21.03</td>
<td>2.15</td>
</tr>
<tr>
<td>Grade*In-order</td>
<td>6.50</td>
<td>2</td>
<td>3.25</td>
<td>.33</td>
</tr>
<tr>
<td>Sex*In-order</td>
<td>12.47</td>
<td>1</td>
<td>12.47</td>
<td>1.27</td>
</tr>
<tr>
<td>Condition<em>Grade</em>Sex</td>
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<td>4</td>
<td>5.13</td>
<td>.52</td>
</tr>
<tr>
<td>Condition<em>Grade</em>In-order</td>
<td>13.43</td>
<td>4</td>
<td>3.36</td>
<td>.34</td>
</tr>
<tr>
<td>Condition<em>Sex</em>In-order</td>
<td>11.64</td>
<td>2</td>
<td>5.82</td>
<td>.59</td>
</tr>
<tr>
<td>Grade<em>Sex</em>In-order</td>
<td>13.41</td>
<td>2</td>
<td>6.70</td>
<td>.68</td>
</tr>
<tr>
<td>Grade<em>Condition</em>Sex*In-order</td>
<td>12.65</td>
<td>4</td>
<td>3.14</td>
<td>.32</td>
</tr>
<tr>
<td><strong>Within Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>7.89</td>
<td>1</td>
<td>7.89</td>
<td>2.19</td>
</tr>
<tr>
<td>Time*Condition</td>
<td>75.30</td>
<td>2</td>
<td>39.15</td>
<td>10.87**</td>
</tr>
<tr>
<td>Time*Grade</td>
<td>2.61</td>
<td>2</td>
<td>1.31</td>
<td>.36</td>
</tr>
<tr>
<td>Time*Sex</td>
<td>4.00</td>
<td>1</td>
<td>4.00</td>
<td>1.11</td>
</tr>
<tr>
<td>Time*In-order</td>
<td>.14</td>
<td>1</td>
<td>.14</td>
<td>.04</td>
</tr>
<tr>
<td>Time<em>Condition</em>Grade</td>
<td>30.45</td>
<td>4</td>
<td>7.61</td>
<td>2.11</td>
</tr>
<tr>
<td>Time<em>Condition</em>Sex</td>
<td>3.11</td>
<td>2</td>
<td>1.55</td>
<td>.43</td>
</tr>
<tr>
<td>Time<em>Condition</em>In-order</td>
<td>6.23</td>
<td>2</td>
<td>3.11</td>
<td>.86</td>
</tr>
<tr>
<td>Time<em>Grade</em>Sex</td>
<td>8.59</td>
<td>2</td>
<td>4.30</td>
<td>1.19</td>
</tr>
<tr>
<td>Time<em>Grade</em>In-order</td>
<td>1.88</td>
<td>2</td>
<td>.94</td>
<td>.26</td>
</tr>
<tr>
<td>Time<em>Sex</em>In-order</td>
<td>1.67</td>
<td>1</td>
<td>1.67</td>
<td>.46</td>
</tr>
<tr>
<td>Time<em>Condition</em>Grade*Sex</td>
<td>3.32</td>
<td>4</td>
<td>.83</td>
<td>.23</td>
</tr>
<tr>
<td>Time<em>Condition</em>Grade*In-order</td>
<td>34.90</td>
<td>4</td>
<td>8.72</td>
<td>2.42</td>
</tr>
<tr>
<td>Time<em>Condition</em>Sex*In-order</td>
<td>2.67</td>
<td>2</td>
<td>1.34</td>
<td>.37</td>
</tr>
<tr>
<td>Time<em>Grade</em>Sex*In-order</td>
<td>3.59</td>
<td>2</td>
<td>1.80</td>
<td>.50</td>
</tr>
<tr>
<td>Time<em>Grade</em>Condition<em>Sex</em>In-order</td>
<td>17.89</td>
<td>4</td>
<td>4.47</td>
<td>1.24</td>
</tr>
<tr>
<td><strong>Error</strong></td>
<td>507.95</td>
<td>141</td>
<td>3.60</td>
<td></td>
</tr>
</tbody>
</table>

Note. *p<=.05, **p<=.0001
There was also a significant Grade effect in the repeated measures analysis. The Grade effect was in the predicted direction, with the college students scoring highest ($M_{\text{college}}=5.43$), eighth graders having the second highest scores ($M_{\text{8th}}=4.42$), and fifth graders having the lowest number of correct answers ($M_{\text{5th}}=4.39$). Whereas college students performed significantly better than the fifth and eighth graders ($p<.02$; $p<.03$, respectively), there was not a significant difference between the scores of the fifth and eighth graders (see Figure 2).
A second analysis was conducted to determine if the order of question complexity (i.e., whether the two choice, in/out question came first or last) had an effect. Thus, the data were subjected to a 3 (Condition: Counter-teaching, Traditional teaching, Control) x 2 (Sex) x 3 (Grade) x 2 (Question Order: simple to complex or complex to simple) x 2 (Testing Time) repeated measures ANOVA, with repeated measures again on testing time. Because of the small number of college subjects who participated in the second session, there was not an adequate number of college subjects in each of the question complexity orders during the second testing session. Thus, this analysis was restricted to fifth and eighth grade subjects. Question order (the only new variable in this analysis) was not significant and thus the results of this analysis will not be presented in more detail.
It also is interesting to examine the frequency with which students in the different teaching conditions obtained perfect scores on the eight main questions. Chi square analyses were performed on the number of subjects who performed perfectly versus imperfectly in each condition. Separate chi squares were performed at testing time one and testing time two. Students who gave intromission-only answers on all eight items were scored as performing perfectly, while students who missed even one item were scored as performing imperfectly. The chi square analyses were significant at time one and time two, indicating that the number of subjects performing perfectly on the eight items was dependent on the type of instruction they had received. As can be seen in Table 4, the highest number of subjects having perfect scores during time one was in the Counter-Teaching Condition (74%) followed by subjects in the Traditional Teaching Condition (29%) and the Control Condition (11%). Further comparisons indicated that all three groups were significantly different from one another, with the subjects in the Counter-Teaching Condition scoring significantly better than subjects in the Traditional Teaching Condition and the Control Condition. However, the number of the subjects scoring perfectly in the Counter-Teaching Condition dropped dramatically (to 53%) whereas slightly more subjects in the other two groups performed perfectly at time two (Traditional Teaching=40%; Control=18%). During time two (see Table 5), the difference between the Counter-Teaching and Traditional Teaching Conditions was no longer significant ($\chi^2=1.75, p>.05$; see Figure 3). These data again support the effectiveness of counter-teaching and traditional teaching to overcome extramission beliefs, and, although counter-teaching is
more effective in the short-term, it appears to be only marginally more effective than traditional teaching over time.
Table 4. Frequency of Subjects Showing Perfect versus Imperfect Performance as a Function of Conditions during Time One.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Imperfect</th>
<th>Perfect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counter-teaching</td>
<td>20</td>
<td>56</td>
</tr>
<tr>
<td>Traditional teaching</td>
<td>53</td>
<td>22</td>
</tr>
<tr>
<td>Control</td>
<td>62</td>
<td>8</td>
</tr>
</tbody>
</table>

χ²(2, N=221) = 63.80, p < .0001

Table 5. Frequency of Subjects Showing Perfect versus Imperfect Performance as a Function of Conditions during Time Two.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Imperfect</th>
<th>Perfect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counter-teaching</td>
<td>28</td>
<td>31</td>
</tr>
<tr>
<td>Traditional teaching</td>
<td>38</td>
<td>26</td>
</tr>
<tr>
<td>Control</td>
<td>45</td>
<td>10</td>
</tr>
</tbody>
</table>

χ²(2, N=178) = 14.70, p < .001
A second set of chi square analyses was performed to determine whether students in different conditions performed significantly differently on the single question providing students with the in and out choices only. The two choice question is a critical one because it forces participants to declare extramission as the correct theory of vision and to deny intromission (if they are extramissionists). Choosing the out-only choice over the in-only choice suggests a much stronger commitment to extramission beliefs than when some combination of in and out is chosen, as can occur in the other seven questions. The chi square analyses were performed separately for time one and time two. The results of these analyses can be seen in Table 6 (Time One) and Table 7 (Time Two). While the frequency of correct responses to the in/out question was significantly different among the three conditions at time one (all
comparisons were statistically significant), the analysis was not significant at time two (none of the comparisons were significant). Whereas more subjects in the Counter-Teaching Condition gave the correct intromission response than subjects in the other two conditions, after three months this difference virtually disappeared (see Figure 4). These results suggest that intuitive beliefs such as extramission beliefs are resistant to instruction, even when instruction explicitly denies the intuitive belief.

Table 6. Frequency of Subjects Giving Intromission versus Extramission Responses on a Two Choice Item as a Function of Condition (Time One).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Correct</th>
<th>Incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counter-teaching</td>
<td>71</td>
<td>5</td>
</tr>
<tr>
<td>Traditional teaching</td>
<td>59</td>
<td>16</td>
</tr>
<tr>
<td>Control</td>
<td>44</td>
<td>26</td>
</tr>
</tbody>
</table>

$\chi^2(2, N=221) = 20.23, p < .001$
Table 7. Frequency of Subjects Giving Intromission versus Extramission Responses on a Two Choice Item as a Function of Condition (Time Two).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Correct</th>
<th>Incorrect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counter-teaching</td>
<td>42</td>
<td>17</td>
</tr>
<tr>
<td>Traditional teaching</td>
<td>46</td>
<td>18</td>
</tr>
<tr>
<td>Control</td>
<td>33</td>
<td>22</td>
</tr>
</tbody>
</table>

$\chi^2(2, N=178) = 2.33, p > .31.$

Figure 4. Graph of Percentage of Subjects having Correct Performance on the Two Choice Question at Time One and Two as a Function of Condition.
Additionally, the effect of the ordering of the 2 choice item (i.e., whether it came first or last) was analyzed with series of chi square analysis to determine if the positioning of this item in the series of questions had an effect on performance. Other studies (Hedman, 1995) have found that subjects have a higher success rate when the two choice question comes first rather than last in the sequence. These analyses were performed separately for time one and time two. Neither of these analyses was significant, indicating that whether the two choice question came first or last in the sequence of questions did not have an effect on the number of correct and incorrect responses to the single item.

To ensure that the differences between the Counter-Teaching Condition and the Traditional Teaching condition were due to the videotaped presentations and not to the amount of attention paid to the videotapes and to determine if a base level of knowledge was gained from the videotapes, a 3 (Condition: Counter-teaching, Traditional teaching, Control) x 2 (Sex) x 3 (Grade) x 2 (Testing Time) repeated measures ANOVA was performed with participants' scores on the sum of the five informational questions as the dependent variable and the repeated measure on testing time. The question order and in-order variables were left out of this analysis since they were not relevant to the questions involved. As can be seen in Table 8, there was a significant main effect for Condition and Condition x Time. Analysis of the means showed that, during testing time one, subjects in the Counter-Teaching (M=4.74) and Traditional Teaching (M=4.73) Conditions performed significantly better on the information questions than subjects in the Control Condition (M=3.81; p=.0001 for both comparisons). These results are expected,
considering the Counter-Teaching and Traditional Teaching videotape provided the answers to the information questions while the Control videotape did not. Although the means at time two on the information questions decreased in the Counter-Teaching ($M=4.47$) and Traditional Teaching ($M=4.57$) conditions, both experimental groups continued to perform significantly better than the subjects in the Control Condition ($M=4.13$). Additionally, there was no significant difference between the mean scores of the experimental groups.

Surprisingly, there was a significant decrement in the performance of the subjects in the Counter-Teaching Condition from time one to time two but not for the subjects in the Traditional Teaching Condition. Therefore, these results suggest that it is unlikely that the higher performance of the subjects in the Counter-Teaching Condition during Time One was due only to attentional differences and that a basic understanding of the visual process was gained from the videotaped presentation. The results also suggest, however, that the Counter-Teaching videotape was no better than the Traditional Teaching videotape at instructing students about the basic elements of the eyes and how they work.

There was also a significant Grade*Sex interaction. When the means were examined, it could be seen that college males performed significantly better than females in all three age groups and from fifth grade males (see Figure 5). This was unexpected, particularly because the college males did not perform significantly better than the other subjects on the eight main questions. There is no real explanation for the higher performance of male college students, and to provide an explanation here would be speculative. What is interesting, however, is that there was not a stronger relationship
between performance on the information questions and performance on the eight main questions.

Table 8. Repeated Measures Analysis of Variance Summary of Total Number of Correct Responses on Information Questions by Condition, Grade, and Sex.

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Between Subjects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition</td>
<td>29.08</td>
<td>2</td>
<td>14.54</td>
<td>24.67***</td>
</tr>
<tr>
<td>Grade</td>
<td>2.92</td>
<td>2</td>
<td>1.46</td>
<td>2.48</td>
</tr>
<tr>
<td>Sex</td>
<td>3.40</td>
<td>1</td>
<td>3.40</td>
<td>5.78*</td>
</tr>
<tr>
<td>Condition*Grade</td>
<td>2.74</td>
<td>4</td>
<td>.68</td>
<td>1.16</td>
</tr>
<tr>
<td>Condition*Sex</td>
<td>.65</td>
<td>2</td>
<td>.32</td>
<td>.55</td>
</tr>
<tr>
<td>Grade*Sex</td>
<td>4.40</td>
<td>2</td>
<td>2.20</td>
<td>3.74*</td>
</tr>
<tr>
<td>Condition<em>Grade</em>Sex</td>
<td>3.71</td>
<td>4</td>
<td>.93</td>
<td>1.57</td>
</tr>
<tr>
<td>Sub (Grade<em>Condition</em>Sex)</td>
<td>119.04</td>
<td>202</td>
<td>.59</td>
<td>1.98***</td>
</tr>
<tr>
<td><strong>Within Subjects</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>.13</td>
<td>1</td>
<td>.13</td>
<td>.44</td>
</tr>
<tr>
<td>Time*Condition</td>
<td>4.81</td>
<td>2</td>
<td>2.41</td>
<td>8.10**</td>
</tr>
<tr>
<td>Time*Grade</td>
<td>.22</td>
<td>2</td>
<td>.11</td>
<td>.36</td>
</tr>
<tr>
<td>Time*Sex</td>
<td>.42</td>
<td>1</td>
<td>.42</td>
<td>1.41</td>
</tr>
<tr>
<td>Time<em>Condition</em>Grade</td>
<td>1.15</td>
<td>4</td>
<td>.29</td>
<td>.97</td>
</tr>
<tr>
<td>Time<em>Condition</em>Sex</td>
<td>.46</td>
<td>2</td>
<td>.23</td>
<td>.78</td>
</tr>
<tr>
<td>Time<em>Grade</em>Sex</td>
<td>.19</td>
<td>2</td>
<td>.10</td>
<td>.32</td>
</tr>
<tr>
<td>Time<em>Condition</em>Grade*Sex</td>
<td>1.62</td>
<td>4</td>
<td>.40</td>
<td>1.36</td>
</tr>
</tbody>
</table>

*Note. *p<.05, **p<.001, ***p<.0001*
Figure 5. Graph of Subjects' Means on Five Information Questions as a Function of Grade and Sex.

Because the information questions were a fairly superficial test of how much the subjects knew about how vision works, an analysis of subjects' answers on the open-ended questions was conducted to explore further possible differences in the depth of subjects' understanding of the visual system among subjects in the three conditions. There were two open-ended questions, one in which subjects were asked, following the final, verbal question, "On the last question, you said that something goes [into, out of, into and then out of, out of and then into, into and out of at the same time] our eyes when we see. Why do you think this answer is better than the other four choices?" The second open-ended question asked subjects to "Pretend that you are speaking to a child who is younger than you. Explain to this child how we see. You want to make sure
that the child understands how the eyes work." It was predicted that the subjects in the Counter-Teaching Condition would give more detailed and accurate answers than the subjects in either of the other two conditions, because it was thought that the schemas would be better organized for these subjects and, therefore, more accurate.

Answers to the two open-ended questions were coded into one of six categories, with scores of one to six given to represent each of the categories. In category six, subjects' responses did not include the direction in which information travels to or from the eyes. For example, when asked to explain how we see to a younger child, one subject reported that she would "take a book and ask them if they see it, and then explain to them the reason they see it is because of the light." Although this answer mentions light, it does not mention the direction in which light travels. A response was placed into category five if the response was wrong because it indicated that something went out of the eyes or into and out of the eyes. One subject stated that he chose that something goes out of and then into the eye because "...when you look out and as you're looking it sorta comes back in." A category of four was assigned if the subject was correct in stating that something goes into the eyes but gave an incorrect explanation of how it goes in or what goes in. For example, one subject answered that something goes into the eyes when you see, but went on to say that "when you see, something comes into your eye and then is kept there so you can see it." Responses received a score of three if the response indicated that something went into the eyes but did not explain the process further. A score of two was assigned if the subject said that something goes into the eyes and also mentioned some aspects (but not all) of how the eyes or
light works. A response in this category would include some additional detail, such as the parts of the eyes or how light reflects off objects, but would still be incomplete. One subject said that "when you see something, light reflects off it, and light goes into your eyes." Finally, a score of one was assigned if the subject had a fairly thorough understanding of the visual process. Subjects had to mention at least two of the following: the parts of the eyes, the role of light, and the brain. Although it is clear that this subject still has some gaps in his knowledge and may not be clear about the role of light in vision, his response indicates that he has a fairly good understanding of how the eyes work: "If anything goes out of the eye then there would be no need for the back of our eyes. The objects produce an image that goes into the eye and is transferred to the back of the eye, and the image is sent by a nerve to your brain. I heard somewhere about the images being flipped upside-down."

Eight questionnaires from each grade were chosen randomly so that interrater reliability could be obtained. The author scored all of the questionnaires, and a colleague rated the open-ended questions on the 32 randomly selected questionnaires. The correlation between the two raters was .93 for the first open-ended question and .82 for the second open-ended question. These correlations indicate that there was good interrater reliability on the open-ended questions.

Chi square analyses were conducted to determine whether there was a relationship between condition and response on the two subjective questions. These analyses were conducted on each open-ended question separately. To reduce the number of categories on the open-ended questions, categories one and two were collapsed to combine all elaborated correct answers, category
three was left in tact (correct, unelaborated answers), and categories four through six were collapsed to combine all incorrect and nonresponsive answers. The results of this analysis were not significant, indicating that whether subjects gave correct or incorrect answers or whether they elaborated upon their correct answers were not related to which videotape the subjects had seen. This was unexpected, considering that previous analyses showed a strong relationship between condition and number of correct answers. The reason for the insignificance of these results may have been because the analysis was based on only two questions, and these two questions may not have elicited the desired depth. When the correlation among the three groups and the responses to the in-depth questions were examined, the correlations were quite low (all below the absolute value of .1). The lack of a correlation among these variables indicates that there was no systematic relationship among conditions and answers to the in-depth questions, even within subgroups of the chi-square analysis.

A second exploratory analysis was conducted to examine the relationship between the number of subjects receiving perfect scores on the eight main questions in the questionnaire and responses on the open-ended questions. Four analyses were conducted here, one for each of the two questions by perfect/imperfect at time one and time 2. All four of these analyses were significant, suggesting that subjects' responses on the open-ended questions were related to whether they had received perfect scores on the eight main questions. As can be seen in Tables 9 though 12, subjects who scored perfectly on the eight questions were more likely to give expanded correct or correct responses to the open-ended questions than subjects who did
not answer all eight questions perfectly; there was not a significant difference in this analysis between subjects who gave expanded correct and correct answers ($\chi^2=1.90, p>.05$). This indicates that subjects who answer all eight questions correctly have a clearer and more detailed understanding of the visual process. Only in the analysis of Open-Ended Question Two at Time One was there a non-significant difference between subjects who answered the question correctly and those who answered it incorrectly.
Table 9. Frequency and Percentage of Subjects' Answers to Open Ended Question 1 by Perfect versus Imperfect Performance on Eight Main Questions during Time One.

<table>
<thead>
<tr>
<th></th>
<th>Perfect</th>
<th>Imperfect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expanded Correct</td>
<td>18 (62)</td>
<td>11 (38)</td>
</tr>
<tr>
<td>Correct</td>
<td>23 (46)</td>
<td>27 (54)</td>
</tr>
<tr>
<td>Incorrect/Direction not mentioned</td>
<td>22 (24)</td>
<td>71 (76)</td>
</tr>
</tbody>
</table>

$\chi^2(2, N=172) = 16.72, \ p > .0001.$

Note: Numbers in parentheses indicate the percentage of respondents in that condition giving a correct or incorrect response.

Table 10. Frequency and Percentage of Subjects' Answers to Open Ended Question 1 by Perfect versus Imperfect Performance on Eight Main Questions during Time Two.

<table>
<thead>
<tr>
<th></th>
<th>Perfect</th>
<th>Imperfect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expanded Correct</td>
<td>19 (68)</td>
<td>9 (32)</td>
</tr>
<tr>
<td>Correct</td>
<td>35 (71)</td>
<td>14 (29)</td>
</tr>
<tr>
<td>Incorrect/Direction not mentioned</td>
<td>13 (14)</td>
<td>80 (86)</td>
</tr>
</tbody>
</table>

$\chi^2(2, N=170) = 55.72, \ p > .0001.$

Note: Numbers in parentheses indicate the percentage of respondents in that condition giving a correct or incorrect response.
Table 11. Frequency and Percentage of Subjects' Answers to Open Ended Question 2 by Perfect versus Imperfect Performance on Eight Main Questions during Time One.

<table>
<thead>
<tr>
<th></th>
<th>Perfect</th>
<th>Imperfect</th>
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</thead>
<tbody>
<tr>
<td>Expanded Correct</td>
<td>33 (53)</td>
<td>29 (47)</td>
</tr>
<tr>
<td>Correct</td>
<td>9 (38)</td>
<td>15 (63)</td>
</tr>
<tr>
<td>Incorrect/Direction not mentioned</td>
<td>18 (21)</td>
<td>66 (79)</td>
</tr>
</tbody>
</table>

\( \chi^2(2, N=170) = 15.85, p > .0001. \)

Note: Numbers in parentheses indicate the percentage of respondents in that condition giving a correct or incorrect response.

Table 12. Frequency and Percentage of Subjects' Answers to Open Ended Question 2 by Perfect versus Imperfect Performance on Eight Main Questions during Time Two.

<table>
<thead>
<tr>
<th></th>
<th>Perfect</th>
<th>Imperfect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expanded Correct</td>
<td>40 (67)</td>
<td>20 (33)</td>
</tr>
<tr>
<td>Correct</td>
<td>12 (50)</td>
<td>12 (50)</td>
</tr>
<tr>
<td>Incorrect/Direction not mentioned</td>
<td>12 (14)</td>
<td>72 (86)</td>
</tr>
</tbody>
</table>

\( \chi^2(2, N=178) = 42.40, p > .0001. \)

Note: Numbers in parentheses indicate the percentage of respondents in that condition giving a correct or incorrect response.
Because male college students had performed significantly better on the five information questions than the female subjects at all age groups and fifth grade male subjects, four chi square analyses were run to determine if sex or grade was related to responses on the open-ended questions. It was expected that males would tend to have a higher number of elaborated correct responses than females and that college students would have more elaborated correct responses than fifth and eighth graders. The results were mixed. While there was not a significant association between grade and why subjects chose a particular response on the last verbal question ($\chi^2(4, N=172) =7.29, p>.10$), there was a significant association between grade and responses on the question in which subjects explained vision to a younger child ($\chi^2(4, N=172) =7.29, p>.10$). As expected, there was a higher percentage of college-aged subjects who gave elaborated responses (60%) than fifth (21%) or eighth (34%) graders. Fifth and eighth graders tended to give more correct-unelaborated or incorrect responses than college subjects. Thus, college students show a clearer and more detailed understanding of the visual process, but only when they are asked to explain vision to a younger child.

A similar pattern occurred when the chi squares were performed as a function of sex. Again as predicted, a higher percentage of male subjects (26%) gave elaborated responses than female subjects (9%) on the question that asked why subjects had chosen a particular answer on the last verbal item ($\chi^2(2, N=172) =10.26, p>.006$). Males and females had similar response patterns on the open-ended item that asked subjects to explain vision to a younger child ($\chi^2(2, N=170) =3.71, p>.156$). Males may have a slightly more
detailed understanding of vision, but they only exhibited this difference on the question that asked to explain why they chose a particular answer.

Finally, a series of regression analyses was performed to determine the effect of science and academic ability on performance on the 8 main questions. One analysis was performed on the data of the fifth and eighth grade subjects and another on the data of the college subjects because different measures of academic and science abilities were used at these ages. For the college subjects, Overall Grade Point Average and Grade Point Average in Science Courses were regressed on the total number of intromission responses on the eight main questions. The results of this analysis were not significant (F=1.45, p<.30). A second regression was performed in which only Grade Point Average was regressed on the total number of intromission responses. This analysis was performed because only 22 of the college students participating in time two had taken science courses during college. The result of the second regression analysis, however, was also not significant (F=.08, p<.80). For the fifth and eighth graders, teachers' ratings of academic ability and science ability were regressed on the total number of intromission responses. This analysis was not significant (F=.39, p<.80). Although the results of these analyses should be seen only as exploratory, they suggest that academic and science abilities do not determine students' answers on questions about intromission.
CHAPTER IV
DISCUSSION

Although not the main purpose of the study, the results support previous findings which show that fifth and eighth graders as well as college students have intuitive, extramission beliefs about vision. The extramission beliefs expressed by subjects are characterized as intuitive because it is unlikely that they have ever learned that something goes out of the eyes when they see. As in the past, college students gave significantly fewer extramission responses than fifth and eighth graders, but the number of college students who gave extramission responses, even after instruction about vision, continues to be surprising.

Unlike previous studies (Cottrell & Winer, 1994; Hedman, 1995), the results of this study show that teaching can be effective in overcoming extramission beliefs about vision. It was predicted that subjects in the Counter-Teaching Condition, which expressly rejected extramission beliefs, would give more intromission responses on the eight main questions than subjects in the Traditional Instruction and Control Conditions. As predicted, subjects in the Counter-Teaching condition performed significantly better than subjects in the two other groups when the subjects were tested immediately after instruction. Also as predicted, the subjects in the Traditional Teaching Condition performed better at testing time one than subjects in the Control Condition. Although it was predicted, it was still somewhat surprising that the Traditional Teaching Condition did produce significant results. Because the
information provided in the Traditional Teaching videotape was analogous (although simplified) to the information presented previously to college students in introductory psychology readings, it was thought that there may be no difference between the Traditional Teaching Condition and the Control Condition. This was not the case, however, and in fact, the effects of Counter-Teaching were not more robust over time than the effects of the Traditional Teaching, although subjects in both experimental groups continued to perform significantly better than subjects in the control group. Again, the similarity of effects over time of the Traditional Teaching Condition and the Counter-Teaching Condition was surprising, given the expectation that the Counter-Teaching Condition was so amazingly straightforward.

The analysis of the number of subjects demonstrating perfect performance also supports the effectiveness of the teaching strategies used here. More subjects in the Counter-Teaching Condition and the Traditional Teaching Conditions performed perfectly on the eight main questions than subjects in the Control Condition. These results persisted during testing time two, although, again, the difference between the Traditional Teaching and Counter-Teaching conditions decreased to some extent. These results are important because they are indicative of the certainty subjects have in their responses. Not only do subjects in the Counter-Teaching and Traditional Teaching Conditions give more intromission responses than subjects in the Counter-Teaching Condition, but more of the subjects in the two experimental groups were sure enough of their answers to give consistent answers over eight similarly worded questions. The consistency of their answers may be
indicative of the coherence of the schemas about vision that these subjects have formed.

Also indicative of subjects' certainty in their responses is the way that they answered the two-choice question, which only allowed them to indicate that something goes into the eyes or that something goes out of the eyes. Of interest here, however, are the subjects who answer that something goes out of the eyes only. Choosing the out-only answer attests to the subjects' certainty in their extramission beliefs because it forces them to deny their belief in the existence of intromissions to the eyes. Whereas the placement of the two-choice question (whether it came first or last in the sequence) had an impact in other studies (Hedman, 1995), placement did not matter in this study. The instruction used here may be responsible for the lack of significance of the ordering of the two-choice question, but why instruction would have an effect is uncertain. It is also possible that the results from the Hedman (1995) study, although strong, were spurious.

Alternatively, subjects' answers to the two-choice questions were related to the instruction that they received, at least during testing time one. Subjects in the Counter-Teaching and Traditional Teaching conditions again performed significantly better on the two-choice question than subjects in the Control condition. Thus, there were more subjects in the Control Condition who were willing to reject the "in" answer. Moreover, subjects who have received no instruction may truly have pure extramission beliefs (even though this may still be hard to believe), suggesting that the findings of this study and previous studies are not just due to methodological difficulties.
Other findings strengthen the conclusion that the experimental conditions were effective in overcoming extramission beliefs. There is a possibility that subjects in the experimental groups could have found the videotapes they watched more interesting than subjects in the Control Group. The results did not support either of these possibilities, however. Subjects in the Counter-Teaching and Control Conditions performed better than subjects in the Traditional Teaching Condition on items that were designed to test subjects' attention to the videotape and superficial knowledge about the visual process (e.g., the black dot in the middle of your eye is called the ________), but there was not a significant difference between the subjects in the Counter-Teaching and Traditional Teaching conditions on these items. Consequently, it is unlikely that the effects of instruction were due either to attentional differences or to systematic knowledge differences.

Another possibility was that academic ability and science ability could have been related to subjects' performance on the questions asked. In fact, it was predicted that these two variables would be related to subjects' performance. The results indicate, however, that science and academic abilities, as measured here, had no effect on subjects' answers to questions about vision. These results should be seen as exploratory, because there were problems associated with the way in which these variables were measured at different ages. Likewise, information about science and academic abilities were not collected until the second testing session, limiting the number of college subjects for whom the information was available. It is still possible that the subjects who would have given intromission answers prior to instruction would have had either higher academic or science abilities than subjects who would
not have given intromission answers. Because subjects in this study were not asked questions prior to instruction, this possibility cannot be tested here.

Whereas there is evidence that subjects in the experimental groups had stronger intromission beliefs and were more likely to contradict extramission beliefs than subjects in the control group, responses to the open-ended questions show that the three groups are fairly equal in their overall, extended understanding of the visual system. When subjects were asked to explain to a younger child how we see, the subjects in the experimental conditions were no more likely to explain the intromission process correctly and in detail than those in the control group. Similarly, subjects in the experimental groups did not provide more information about why they chose "in" on the last verbal question than did the subjects in the control group. Even though the results of these analyses should be seen as exploratory, they lead one to conclude that, while the experimental instruction was more effective in overcoming extramission beliefs, it was no more effective in increasing students' deeper understanding of how vision works. These results are puzzling, especially because subjects in the Traditional Teaching Condition heard information about the visual system but did not hear information about the falsity of extramission beliefs.

Responses to the open-ended questions were associated with sex, grade, and number of subjects who scored perfectly on the eight main questions, however. These results were all in the expected directions (with the possible exception of the sex difference), with more males, more college-aged subjects, and subjects with perfect scores giving elaborated-correct answers on the open-ended questions than females, fifth and eighth graders, and subjects who
did not have perfect scores. The only result that is surprising is the association between sex and answers on the open-ended questions. The results indicate that males have a more detailed understanding of the visual system than females. However males did not give more detailed answers when asked to explain vision to a younger child. Perhaps males are more prepared to explain why they have chosen a particular answer than females, but why males would have this advantage is unclear.

A final and surprising finding was that college-aged males performed better than females on the information questions with age. As stated previously, these questions were somewhat superficial and the answers to them were stated in the two experimental videotapes, but by college, males performed significantly better than all other subjects except for eighth grade males.

The results of this study are somewhat encouraging, because they suggest that instruction is not altogether inconsequential in overcoming misconceptions (at least simple misconceptions, such as the one presented here), as previous research using more traditional techniques would lead one to believe (Clement, 1982; Halloun & Hestenes, 1985; Brown & Clement, 1987). Even in similar studies, college students continued to perform poorly even after reading a section on visual perception from an introductory psychology book (Cottrell & Winer, 1994); this study, however, supports the use of simplified, straightforward instruction to aid students in overcoming misconceptions. It appears that the type instruction used in the Traditional Teaching Condition was just as effective, in the long run, as that of the Counter-Teaching
Condition, suggesting that there is really no benefit to directly contradicting misconceptions during instruction.

The simplicity of the information presented in the videotapes cannot be the sole explanation for the findings here, however. In a study performed as a follow-up to this one, we presented one group of college students with a reading about visual perception from an introductory psychology textbook, a second group with a reading copied from the scripts from the traditional teaching videotape used in this study, a third group with a reading copied from the counter-teaching videotape used in this study, and a fourth group with an unrelated reading. Although the results of the current study would lead one to predict that subjects who read the traditional teaching and counter-teaching readings would give more intromission responses than other subjects, only the subjects with the counter-teaching reading gave more correct responses. The difference between the study using the readings and the study using the videotaped presentation may have occurred for a number of reasons. One possibility is that subjects who saw the videotapes were more engaged with this type of presentation (e.g., demonstrations, visual aides) than subjects who had to read the same information. Another, related possibility is that subjects in the current study found the information more interesting than subjects who only read the information. A third possibility is that subjects who watched the videotapes were more motivated to pay attention than subjects who read the information because, in the current study, an experimenter stayed in the room with the subjects while the videotape was played. In the study with the readings, the subjects were left alone in the waiting area while they read the passages. The presence of the experimenter in the current study may have
motivated or encouraged subjects to pay attention to the information presented. These possibilities should be explored further; however, the importance of presentational style is evident regardless of which explanation is correct.

It must be added that, although the teaching strategies did have an effect on performance, the performance of subjects in both experimental groups was far from perfect at either testing time one or two, even for college-aged subjects. In examining the percentage of subjects giving intromission answers on all eight questions, only 74% of subjects in the counter-teaching condition, 29% of subjects in the traditional teaching condition, and 11% of the subjects in the control condition had perfect scores immediately after instruction occurred. Considering the number of times the Counter-Teaching videotape directly contradicted the validity of extramission beliefs, it is unexplainable why subjects would not show perfect performance immediately after instruction. After three to five months elapsed, the percentage of subjects in the Counter-Teaching Condition who continued to score perfectly dropped to 53% and the percentage of subjects in the Traditional and Control Conditions who scored perfectly rose to 40% and 18%, respectively. Again, these results support the use of instruction in overcoming extramission beliefs, but they also remind the reader that even these teaching techniques do not completely (and perhaps, to some, only slightly) eliminate intuitive beliefs such as the ones studied here. Additionally, the present study does little to illuminate which of Brewer and Chinn's (1993) "models" of responding to information that is different from what one believes are occurring. Had the relationship between the open-ended questions and conditions been significant
and in the expected direction, it would have been possible to at least speculate about how the different teaching styles affected the ways that children responded to the information that they encountered during instruction. Finally, the nature of children's concepts (i.e., whether they were coherent a la Brewer & Samarapungavan, 1991, or fragmented a la di Sessa, 1988) also remains unclear. It was thought that subjects in the Counter-Teaching Condition would have the most consistent responses to the open-ended questions, to the eight main questions, and to the informational questions, thus indicating that Counter-Teaching influenced the cohesiveness of the knowledge structures, but conclusions are difficult because of the lack of consistency on the open-ended questions.

Why was the counter-teaching videotape more effective in the short-run but not in the long-run? It is startling that although the counter-teaching videotape directly addressed the questions asked on the subsequent test and no reasoning was required to move from the information to the questions, the subjects in the counter-teaching condition reverted to performance that was equal to that of subjects who did not receive information directly related to the questions asked. A partial explanation may be that there was a regression to the mean in all conditions. During testing time one, subjects in the counter-teaching condition were almost at ceiling levels. It was inevitable, therefore, that some decrement in performance would occur at time two, regardless of the effectiveness of the instruction. Regression to the mean does not account, however, for the magnitude of the drop in performance of subjects in the Counter-Teaching Condition or for the disappearance of the difference in performance of Counter-Teaching and Traditional Teaching subjects.
In conclusion, the effects of the simplified, unambiguous instruction, as used here, was effective in overcoming a common misconception about vision. This finding is significant in light of the ineffectiveness of previous instruction attempts. The instruction was not as effective, however, in increasing students' overall knowledge about the visual system.
APPENDIX A

SCRIPTS
Group 1: Counter-Teaching (Contradiction of Extramission Beliefs)\(^4\)

(Close up shot of the presenter) Hi! I’m Ms. Gregg. Today we are going to talk about how the eye works. Now I want you to think about this. When you see, does anything go into your eyes? (Close up of the question written on a poster board) The answer is yes (PAUSE). It is light that goes into your eyes and that’s how you see. **But even though light goes into your eyes when you see, nothing goes out of your eyes.** Today I am going to show you how the light that enters your eyes helps you see. **Then you will understand why you see and why nothing has to leave the eyes to help you see.**

Before I talk about the eye, let’s talk about light and where it comes from. Light can come from the sun (picture of sun). When you look at the sun, light rays come out of the sun, just as the light rays are leaving the sun in this picture. Light can come from other things, too. Light comes from fire (picture), lightbulbs (picture), the moon (picture), and from the stars (pictures). Light rays come from all of these different things. Light rays from all of these types of light enter your eyes to help you see.

When there is no light around you, such as when you are in a very dark room, it’s much harder to see. If there was absolutely NO light coming into your eyes it would be impossible to see anything. Watch what happens when the lights go off (cover up the camera). It’s completely dark now and you cannot see me because there is no light. But when the light comes back on (uncover the camera), you can see me again.

So now we know that there must be light in order for us to see. But how does light work to make us see? First light must come from something, like the

\(^4\)Parts of the Counter-Teaching script which are in bold type indicate information that did not appear in the Traditional Teaching script.
sun. When light rays come from the sun, the light rays might shine directly into our eyes. That's how we see light coming from the light bulb, a fire, or this flashlight that I am shining into your eyes right now (shine flashlight toward the camera).

But we see other things that don't shine light rays directly into our eyes. For example, we can see this mirror even though there are no light rays shining from it. We can see the mirror because light from the sun or a flashlight or the lights over head shine on the mirror and bounce off. The word "reflects" (show the word reflects) means bounces off. So when the light reflects off the mirror, it means that light bounces off it.

Let's look at light being reflected. We can see light reflecting off the mirror. Here is light reflecting off a mirror (shine a flashlight into a mirror so that the light shines back toward the camera). You can see the light actually reflecting or bouncing off the mirror.

But look at this book. It doesn't look like there is any light reflecting or bouncing off the book. But there is. The light that is in this room is bouncing off of the book, the chalkboard, and everything that you can see around you. You can see all of the objects around you because light is reflecting off all of those things and going into your eyes.

So now we know how light works. But how does light help us see? Close your eyes (demonstrate–put hand over eyes). When you close your eyes you cannot see. The light is still in the room and it is still reflecting or bouncing off the objects in the room. But you can't see because the light isn't entering your eyes. If light does not enter your eyes, you cannot see.
Let's see what we have learned. First we learned that we need light in order to see. (Sign). Then we learned that light must get into the eye in order for you to see (Sign).

But how does light get into the eye? I'm going to show you how light gets into the eye by using this model. The light that reflects off objects actually gets into your eye through a hole in your eye, called the pupil. The pupil is the black circle right in the middle of the colored part of the eye. (Show on model). Many of you thought that the pupil was a black dot, but it's really a hole that lets the light go right inside of your eye. It doesn't seem like a hole because over the pupil there is a clear, tough cover. The cover is something like saran wrap (show some saran wrap). Look on the model. Here is the covering over the pupil (show the cornea) and here is the pupil (show the pupil).

So now we know there is a pupil, a hole in eye that lets the light enter. What happens to the light when it goes through the pupil? The light forms a picture on the back, inside part of the eye. Then, the picture formed by the light is carried to your brain by a special pathway called a nerve. Here is the nerve on the model. This nerve carries the message to your brain. If the message carried by the light doesn't get to the brain you cannot see.

Some people think that something must go out of the eyes when we see. Other people think that our eyes work kind of like Superman's eyes (show a picture of Superman's x-ray eyes). Superman has rays that go out of his eyes, and the rays help him see better. Cyclops, the character from X-Men, also has rays that go out of his eyes. But Superman and Cyclops are just pretend or make believe. Nothing has
to leave our eyes in order for us to see. When we look at the things around us, light enters our eyes, but nothing at all goes out of our eyes.

Let's review what we have learned. (Show each point written on a poster, and flip through the posters as you mention each point). First we learned that in order to see there must be light. (sign) The second thing we learned is that light rays must come into our eyes through the hole called the pupil. (sign) The third thing is that the message from light makes a picture on the back of the eye. (sign) The last thing is that the message on the back of the eye gets sent along a nerve to the brain. (sign)

Remember, nothing leaves your eyes in order for you to see. The only thing that enters your eyes is light rays, and nothing ever goes out of your eyes when you see. Although Superman may send rays out of his eyes to help him see, real people don't send anything out of their eyes to help them see.
Group Two: Traditional Instruction (Intromission presented only)

(Close up shot of the presenter) Hi! My name is Ms. Gregg. Today we are going to talk about how the eye works. Now I want you to think about this. When you see, does anything go into your eyes? (Close up of the question written on a poster board) The answer is yes (PAUSE). It is light that goes into your eyes and that's how you see. Today I am going to show you how the light that enters your eyes helps you see.

Before I talk about the eye, let's talk about light and where it comes from. Light can come from the sun (picture of sun). When you look at the sun, light rays come out of the sun, just as the light rays are leaving the sun in this picture. Light can come from other things, too. Light comes from fire (picture), lightbulbs (picture), the moon (picture), and from the stars (pictures). Light rays come from all of these different things. Light rays from all of these types of light enter your eyes to help you see.

When there is no light around you, such as when you are in a very dark room, it's much harder to see. If there was absolutely NO light coming into your eyes it would be impossible to see anything. Watch what happens when the lights go off (cover up the camera). It's completely dark now and you cannot see me because there is no light. But when the light comes back on (uncover the camera), you can see me again.

So now we know that there must be light in order for us to see. But how does light work to make us see? First light must come from something, like the sun. When light rays come from the sun, the light rays might shine directly into our eyes. That's how we see light coming from the light bulb, a fire, or this
flashlight that I am shining into your eyes right now (shine flashlight toward the camera).

But we see other things that don't shine light rays directly into our eyes. For example, we can see this mirror even though there are no light rays shining from it. We can see the mirror because light from the sun or a flashlight or the lights over head shine on the mirror and bounce off. The word "reflects" (show the word reflects) means bounces off. So when the light reflects off the mirror, it means that light bounces off it.

Let's look at light being reflected. We can see light reflecting off the mirror. Here is light reflecting off of a mirror (shine a flashlight into a mirror so that the light shines back toward the camera). You can see the light actually reflecting or bouncing off the mirror.

But look at this book. It doesn't look like there is any light reflecting or bouncing off the book. But there is. The light that is in this room is bouncing off of the book, the chalkboard, and everything that you can see around you. You can see all of the objects around you because light is reflecting off all of them and going into your eyes.

So now we know how light works. But how does light help us see? Close your eyes (demonstrate--put hand over eyes). When you close your eyes you cannot see. The light is still in the room and it is still reflecting or bouncing off the objects in the room. But you can't see because the light isn't entering your eyes. If light does not enter your eyes, you cannot see.

Let's see what we have learned. First we learned that we need light in order to see. (Sign). Then we learned that light must get into the eye in order for you to see (Sign).
But how does light get into the eye? I'm going to show you how light gets into the eye by using this model. The light that reflects off of objects actually gets into your eye through a hole in your eye, called the pupil. The pupil is the black circle right in the middle of the colored part of the eye. (Show on model). Some of you may have thought that the pupil was a black dot, but it's really a hole that lets the light go right inside of your eye. It doesn't seem like a hole because over the pupil there is a clear, tough cover. The cover is something like saran wrap (show some saran wrap). Look on the model. Here is the covering over the pupil (show the cornea) and here is the pupil (show the pupil).

So now we know there is a pupil, a hole in eye that lets the light enter. What happens to the light when it goes through the pupil? The light forms a picture on the back, inside part of the eye (show on model). Then, the picture formed by the light is carried to your brain by a special pathway called a nerve. Here is the nerve on the model. This nerve carries the message to your brain. If the message carried by the light doesn't get to the brain you cannot see.

Let's review what we have learned. (Show each point written on a poster, and flip through the posters as you mention each point). First we learned that in order to see there must be light. (sign) The second thing we learned is that light rays must come into our eyes through the hole called the pupil. (sign) The third thing is that the message from light makes a picture on the back of the eye. (sign) The last thing is that the message on the back of the eye gets sent along a nerve to the brain.
A man named Jean Piaget was a famous developmental psychologist who was interested in how we know what we know. For example, how do you know that one plus one is two? You don't have to answer that out loud, but think about it for a minute. How do you know that one plus one is two? This is the kind of thing that Piaget was interested in.

Piaget's job when he was a young man was to write tests, similar to some of the tests that you may take in school. He became fascinated by the wrong answers that children gave to the test questions. Now most of you probably think this is slightly strange--we try very hard to get the right answers to questions, and we think that the right answers are more important than the wrong answers. But Piaget thought that understanding children's WRONG answers would tell him something about the way children think. For example, if you don't know that one plus one equals two, then that would tell your teacher something about the way you think about math problems.

Piaget also noticed that children at different ages make different types of mistakes. Think about the things you learn in school at each grade. Students in first grade probably don't know how to read yet, but children in third grade are pretty good at reading. This is one difference between older and younger children, and Piaget thought that this type of age difference was very interesting. He spent a lot of time finding out differences in thinking between older and younger children, and your teachers probably use some of this information when teaching you new things.
One thing that Piaget was particularly interested in was something called **conservation**. Conservation means that when an object changes in some way, certain things about that object still stay the same. For example, if you were eating a piece of pizza and cut that piece of pizza into four pieces, like this, would you have the same amount of pizza after you cut the piece of pizza as you did before you cut it? (Let the students answer the question). The answer is yes. You still have the same amount of pizza even though you cut that pizza into smaller parts. This is because if you put the smaller parts of the pizza back together, it would form the same piece of pizza that you started out with. You haven't added anything or taken anything away, and you have the same amount of pizza before and after you cut the pizza into four pieces.

In the last example of conservation, we changed the pizza from a whole, bigger piece to four, smaller pieces. Changing the size of the pieces didn't matter as long as we didn't add any pizza to it or take any pizza away. Let's look at another example. Look at these two balls of play dough. Is there the same amount of play dough in each ball? Let's weigh them and make sure that there is the same amount of play dough in each ball. Ok. Now, what would happen if I took one ball of play dough and broke it into two pieces. Would the first ball of play dough still weigh the same as the ball of play dough that we broke into two pieces? Let's weigh it and make sure. They do weigh the same, even though one ball of play dough was cut into two pieces. Why is this? It is because even though we made the ball of play dough look different, we didn't add anything to it or take anything away from it, and so the ball of play dough weighs the same before and after we break it into two pieces.
Piaget has found that children understand these two examples at different ages. Younger children usually understand the first example before they understand the second example. These kinds differences have been used to teach children in schools.
APPENDIX B

EIGHT MAIN QUESTIONS: TIMES ONE AND TWO

ORDERS 1-4
8 Main Questions, Order 1

Testers: There are 8 trials. Use 4 for the number of repetitions.

Trial 1. **Enter on computer numbers 1;2**
Point to the images
Here the pictures show something coming into the eye and going out of the eye.

**Which one shows how or why we can see?** (Circle response)
A: Incoming
B: Outgoing

Trial 2. **Enter on computer numbers 1;2;3**
Point to the images
Here the pictures show something coming into the eye, going out of the eye, and something first coming into the eye and then going back out.

**Which one shows how or why we can see?** (Circle response)
A: Incoming
B: Outgoing
C: First in then out

Trial 3. **Enter on computer numbers 1;2;4**
Point to the images
Here the pictures show something coming into the eye, going out of the eye, and something first going out of the eye and then coming back in.

**Which one shows how or why we can see?** (Circle response)
A: Incoming
B: Outgoing
C: First out then in

Trial 4. **Enter on computer numbers 1;2;3;4**
Point to the images
Here the pictures show something coming into the eye, going out of the eye, something first coming into the eye and then going back out, and something first going out of the eye and then coming back in.

**Which one shows how or why we can see?** (Circle response)
A: Incoming
B: Outgoing
C: First in then out
D: First out then in
Trial 5. **Enter on computer numbers 1;2;5**
Point to the images

*Here the pictures show something coming into the eye, going out of the eye, and something going in and out at the same time.*

**Which one shows how or why we can see?** (Circle response)
A: Incoming
B: Outgoing
C: Simultaneous

Trial 6. **Enter on computer numbers 1;2;5;3**
Point to the images

*Here the pictures show something coming into the eye, going out of the eye, and something going in and out at the same time and something first coming into the eye and then going back out.*

**Which one shows how or why we can see?** (Circle response)
A: Incoming
B: Outgoing
C: Simultaneous
D: First In, then Out

Trial 7. **Enter on computer numbers 1;2;5;4**
Point to the images

*Here the pictures show something coming into the eye, going out of the eye, and something going in and out at the same time, and something first going out of the eye and then coming back in:*

**Which one shows how or why we can see?** (Circle response)
A: Incoming
B: Outgoing
C: Simultaneous
D: First Out, then In
Trial 8. Now we are not going to show you anything on the computer. But tell me what do you think happens when we see. Does anything:

A: Come into the eye
B: Go out of the eye
C. First come in and then go out
D. First go out and then come in
E. Come in and go out at the same time
8 Main Questions, Order 2

Testers: There are 8 trials. Use 6 for the number of repetitions on the computer.

Trial 1 Enter on computer numbers 2;1.
Point to the images
1. Here the pictures show something going out of the eye and coming into the eye.

Which one shows how or why we can see? (Circle response)
A: Incoming
B: Outgoing

Trial 2. Enter on computer numbers 2;1;3
Point to the images
Here the pictures show something going out of the eye, coming into the eye, and something first coming into the eye and then going back out.

Which one shows how or why we can see? (Circle response)
A: Incoming
B: Outgoing
C: First in then out

Trial 3. Enter on computer numbers 2;1;4
Point to the images
Here the pictures show something going out of the eye, coming into the eye, and something first going out of the eye and then coming back in.

Which one shows how or why we can see? (Circle response)
A: Incoming
B: Outgoing
C: First out then in
Trial 4. Enter on computer numbers 2;1;4;3
Point to the images
Here the pictures show something going out of the eye, coming into the eye, something first going out of the eye and then coming back in, and something first coming into the eye and then going back out.

Which one shows how or why we can see? (Circle response)
A: Incoming
B: Outgoing
C: First in then out
D: First out then in

Trial 5. Enter on computer numbers 2;1;5
Point to the images
Here the pictures show something going out of the eye, coming into the eye, and something going in and out at the same time.

Which one shows how or why we can see? (Circle response)
A: Incoming
B: Outgoing
C: Simultaneous

Trial 6. Enter on computer numbers 2;1;3;5
Point to the images
Here the pictures show something going out of the eye, coming into the eye, something first coming into the eye and then going back out, and something going in and out at the same time.

Which one shows how or why we can see? (Circle response)
A: Incoming
B: Outgoing
C: First in then out
D: Simultaneous
Trial 7. Enter on computer numbers 2;1;4;5
Point to the images

Here the pictures show something going out of the eye, coming into the eye, something first going out of the eye and then coming back in, and something going in and out at the same time.

Which one shows how or why we can see? (Circle response)
A: Incoming
B: Outgoing
C: First out then in
D: Simultaneous

Trial 8. Now we are not going to show you anything on the computer. But tell me what do you think happens when we see. Does anything:
A: Come into the eye
B: Go out of the eye
C: First come in and then go out
D: First go out and then come in
E: Come in and go out at the same time
8 Main Questions, Order 3

Testers: There are 8 trials. Use 6 for the number of repetitions.

Trial 1. Enter on computer numbers 1;2;5;4
Point to the images
Here the pictures show something coming into the eye, going out of the eye, something going in and out at the same time, and something first going out of the eye and then coming back in:

Which one shows how or why we can see? (Circle response)
A: Incoming
B: Outgoing
C: Simultaneous
D: First Out, then In

Trial 2. Enter on computer numbers 1;2;5;3
Point to the images
Here the pictures show something coming into the eye, going out of the eye, something going in and out at the same time, and something first coming into the eye and then going back out.

Which one shows how or why we can see? (Circle response)
A: Incoming
B: Outgoing
C: Simultaneous
D: First In, then Out

Trial 3. Enter on computer numbers 1;2;5
Point to the images
Here the pictures show something coming into the eye, going out of the eye, and something going in and out at the same time.
Which one shows how or why we can see? (Circle response)
A: Incoming
B: Outgoing
C: Simultaneous
Trial 4. **Enter on computer numbers 1;2;3;4**  
Point to the images

Here the pictures show something coming into the eye, going out of the eye, something first coming into the eye and then going back out, and something first going out of the eye and then coming back in.

Which one shows how or why we can see?  (Circle response)

A: Incoming  
B: Outgoing  
C: First in then out  
D: First out then in

Trial 5. **Enter on computer numbers 1;2;4**  
Point to the images

Here the pictures show something coming into the eye, going out of the eye, and something first going out of the eye and then coming back in.

Which one shows how or why we can see?  (Circle response)

A: Incoming  
B: Outgoing  
C: First out then in

Trial 6. **Enter on computer numbers 1;2;3**  
Point to the images

Here the pictures show something coming into the eye, going out of the eye, and something first coming into the eye and then going back out.

Which one shows how or why we can see?  (Circle response)

A: Incoming  
B: Outgoing  
C: First in then out
Trial 7. **Enter on computer numbers 1;2**

Point to the images

*Here the pictures shows something coming into the eye and going out of the eye*

Which one shows how or why we can see? (Circle response)

A: Incoming  
B: Outgoing

Trial 8. Now we are not going to show you anything on the computer. But tell me what do you think happens when we see. Does anything:

A: Come into the eye  
B: Go out of the eye  
C. First come in and then go out  
D. First go out and then come in  
E. Come in and go out at the same time
8 Main Questions, Order 4

Testers: There are 8 trials. Use 6 for the number of repetitions on the computer.

Trial 1. Enter on computer numbers 2;1;4;5
Point to the images
Here the pictures show something going out of the eye, coming into the eye, something first going out of the eye and then coming back in, and something going in and out at the same time.

Which one shows how or why we can see? (Circle response)
A: Incoming
B: Outgoing
C: Out first, then in
D: Simultaneous

Trial 2. Enter on computer numbers 2;1;3;5
Point to the images
Here the pictures show something going out of the eye, coming into the eye, something first coming into the eye and then going back out, and something going in and out at the same time.

Which one shows how or why we can see? (Circle response)
A: Incoming
B: Outgoing
C: In first, then out
D: Simultaneous

Trial 3. Enter on computer numbers 2;1;5
Point to the images
Here the pictures show something going out of the eye, coming into the eye, and something going in and out at the same time.

Which one shows how or why we can see? (Circle response)
A: Incoming
B: Outgoing
C: Simultaneous
Trial 4. Enter on computer numbers 2;1;4;3
Point to the images
Here the pictures show something going out of the eye, coming into the eye, something first going out of the eye and then coming back in, and something first coming into the eye then going back out.

Which one shows how or why we can see? (Circle response)

A: Incoming
B: Outgoing
C: First in then out
D: First out then in

Trial 5. Enter on computer numbers 2;1;4
Point to the images
Here the pictures show something going out of the eye, coming into the eye, and something first going out of the eye and then coming back in.

Which one shows how or why we can see? (Circle response)

A: Incoming
B: Outgoing
C: First out then in

Trial 6. Enter on computer numbers 2;1;3
Point to the images
Here the pictures show something going out of the eye, coming into the eye, and something first coming into the eye and then going back out.

Which one shows how or why we can see? (Circle response)

A: Incoming
B: Outgoing
C: First in then out
Trial 7. **Enter on computer numbers 2;1.**

Point to the images
Here the pictures show something going out of the eye and coming into the eye.

Which one shows how or why we can see? (Circle response)

A: Incoming  
B: Outgoing

Trial 8. **Now we are not going to show you anything on the computer. But tell me what do you think happens when we see.** Does anything:

A: Come into the eye  
B: Go out of the eye  
C. First come in and then go out  
D. First go out and then come in  
E. Come in and go out at the same time
APPENDIX C

INFORMATION QUESTIONS, TIMES ONE AND TWO
Information Questions, Time 1 and 2

1. The black dot in the middle of your eye is called the:
   A. pupil
   B. retina
   C. nerve
   D. iris

2. Can you see if there is no light at all?  YES  NO

3. Information is carried to your brain by a special pathway called a(n):
   A. pupil
   B. retina
   C. nerve
   D. iris

4. Can you see if information isn't carried to your brain?  YES  NO

5. Does light help us see?  YES  NO
APPENDIX D
OPEN-ENDED QUESTIONS, TIME 2
Open-Ended Questions

1. On the last question, you said that something goes (Circle One):

   INTO
   OUT OF
   INTO AND THEN OUT OF
   OUT OF AND THEN INTO
   IN AND OUT OF AT THE SAME TIME

   our eyes when we see. Why do you think this answer is better than the other four choices?

2. Pretend that you are speaking to a child who is younger than you. Explain to this child how we see. You want to make sure that the child understands how the eyes work.
REFERENCES


