EFFECTS OF CONSIDERATIONS OF NECESSITY AND SCIENTIFIC REASONING UPON BELIEFS ABOUT VISUAL PERCEPTION

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ABSTRACT

In this experiment an attempt was made to correct the erroneous belief, called the extramission theory, that something leaves the eye as part of visual perception, and replace this belief with the correct intromission theory, that something comes into the eye. One hundred thirty-two students from an introductory psychology course (54 males and 78 females) were tested on their beliefs about vision using a computer-graphic format. Prior to testing, four groups of participants received training on the concept of necessity in terms of one event being necessary for the occurrence of another event. Two other groups of participants did not receive this training but instead wrote explanations of vision that forced them to consider the scientific facts of the process. A final group of participants experienced neither of these manipulations but only answered a series of irrelevant questions prior to vision testing. Results indicated that all of the groups gave similar numbers of correct, intromissionist responses to the vision trials, and that males gave more correct answers on average than did females. A positive

relationship between the description of the role of light entering the eye in vision and the number of correct responses emerged for the students who were required to write explanations of vision. Analyses suggest that the difficulty many students experience on the computer-graphic vision trials is due to a lack of understanding of either the concept of light entering the eye or perhaps of light in general.

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CHAPTER 1

INTRODUCTION

That light must reflect off objects in the external world and enter our eyes for us to sense and perceive anything may seem self-evident to many people today. In fact, this piece of knowledge, referred to hereafter as the intromission theory of vision, became a scientific certainty relatively recently, having only been in place since scientists such as Kepler and Newton formulated the modern views of vision and light in the seventeenth century (Karrqvist & Anderson, 1986; Lindberg & Steneck, 1976). Biological discoveries, such as the facts that nothing leaving the eye aids in vision and that the receptors for light line the retina and allow vision to occur, were also needed to cement the intromission theory into place (Meyering, 1989).

An opposing idea about vision, namely the hypothesis that vision is possible because something such as waves or rays leaves the eye and strikes the objects to be seen, is

Empedocles, Plato and Euclid over two thousand years ago, and these ideas remained alive in Western thought well into the Middle Ages.

Although modern science has refuted the extramission theory, it has reemerged in the psychological study of children's and adolescents' knowledge of vision. Piaget (1929/1974), following an observation by G. Stanley Hall, is perhaps the first to note that many young children believe the eyes emit light and aid in vision; more recent research by Guesne (1984, 1985), Anderson and Smith (1986), and Repp, Callanan, Meier, and Miller (1992) also demonstrate that many children hold various misconceptions about vision, and for some of these children one of the misconceptions is that the eyes emit something to make vision possible. However, these researchers did not directly question the participants about intromission and extramission, and in one case (Guesne, 1984; 1985), the investigator actually denied that extramission beliefs were present in children's minds.

A more surprising and perplexing finding has emerged in a series of studies by Winer and colleagues (Cottrell & Winer, 1994; Winer, Cottrell, Karefilaki & Gregg, in press; Winer, Cottrell, Karefilaki & Chronister, 1996), who provide evidence that many college students who would be expected to possess a basic understanding of vision (intromissionist beliefs) nevertheless profess ideas about sight that are in fact extramissionist. Such beliefs have been found in a variety of testing conditions. A question readily follows from these data: Is it possible to change these beliefs, and if so, how? The present study is an attempt at providing an answer.

Purpose and Goals

The purpose of this thesis is to determine whether the extramissionist beliefs many students hold about vision can be changed, as this is one aspect of students' understanding of vision which has not yet been fully explored. I will attempt to change inaccurate beliefs by requiring participants to think about what is absolutely necessary for people to see, that is, intromission. Two "necessity training" conditions will provide students practice in thinking about events which seem to occur simultaneously and which may or may not have a directional component; i.e. one event must necessarily occur before the other event can occur. An additional condition is aimed at inducing students to activate scientific schemas on vision and might also improve performance.

CHAPTER 2

REVIEW OF THE LITERATURE

This review will first briefly cover the historical developments leading from various extramission theories of vision to the current intromission theory. I will then consider the literature which bears on childrens' and adolescents' beliefs about vision and how they might change from early childhood to adulthood.

Historical Overview of Visual Theories

The process of vision was a much-debated topic for various ancient thinkers. One proposal, put forth in various forms by philosophers such as Galen and Empedocles, was that something must leave the eye and come into contact with objects in the external world for a person to see them (Karrqvist & Anderson, 1983; Meyering, 1989). The Galenic school of thought held that a substance called "pneuma," a mixture of fire and air, "flows from the seat of consciousness... through the nervus opticus (or optical nerve) to the eye" (Meyering, 1989, p. 26). Once leaving the eye, the pneuma mixes with the air and illuminates it in much the same manner as sunlight, making vision possible.

Empedocles believed in extramission but also thought intromission of a sort was necessary. Specifically, he proposed that objects emit an "'external fire'" (Karrqvist & Anderson, 1983; p. 380) which contains information about shape and color, and that this external fire combines with an emission from the eye to cause vision.

An early intromission theory, albeit one which does not correspond to the current scientific view, was put forth by Leucippus, a contemporary of Empedocles. He hypothesized that every object issues forth an image called an "eidola" which transmitted shape and color information to the soul via the eyes (Karrqvist & Anderson, 1983).

Another proposal about vision was put forth by Euclid, who was a firm extramissionist and applied his developments in geometry to the study of vision. He is also important for introducing the concept of the ray of light. Rays of light leaving the eye in straight, diverging lines are responsible for vision, according to Euclid, and the angles they form when they contact objects can explain such perceptual phenomena as perceived size and shape (Meyering, 1989). Euclid also applied his geometry to rays of light from natural sources, i.e. the sun, but did not include sun rays in his theory of vision (Karrqvist & Anderson, 1983).

The first firmly scientific intromission theory of vision was proposed by the Arab thinker Alhazen around the year 1000, who relied upon physiological knowledge about the eye. Briefly, he proposed that rays of a material sort enter the eye and convey visual information with them. These rays must be composed of light and are reflected back from objects which are struck by the rays from some light source such as the sun. Alhazen also proposed that specific points inside the eyeball must correspond to specific points in space in the exterior, thus allowing the transmission of information about shape and location (Meyering, 1989).

Alhazen's work faded into obscurity in the Middle Ages, however, as the works of Aristotle and other Classical Greek writers were resurrected and upheld by thinkers such as Roger Bacon, who wished to reconcile Classical views with those of the Scholastics, church-influenced thinkers of the Middle Ages. It took Johannes Kepler, who developed ideas about light and optics that were free of Classical influence, to devise the first theory of vision which corresponds with the modern scientific view, which he proposed in 1604. The philosopher Rene Descartes refined Kepler's views in the early seventeenth century, devising a theory of perception which is generally the current one--i.e. perception is an interpretative process, separate from the pure sensory mechanism, mediated by the brain. Thus we see that the modern view of visual perception is less than four centuries old (Meyering, 1989).

The above analysis demonstrates that in the history of science, views about vision have gradually shifted from those emphasizing extramission to those requiring intromission while denying that any form of extramission is necessary. I will now review the psychological literature on beliefs about vision. The review will demonstrate that extramission beliefs occur in development and that a developmental shift from extramission to intromission beliefs occurs as children grow older, mirroring developments in the history of science.

Research on Beliefs About Perception

Piaget, following up on an observation by G. Stanley Hall, was perhaps the first developmentalist to document extramission beliefs in children. He described three cases in which children asserted that the eyes are a source of light and help us see; he also noted that one of his fellow researchers wondered as a child why the gazes of two people looking at each other did not collide and why one never felt the look of another (1929/1972). Implicit in these beliefs is the idea that light rays, waves, or something else which leaves the eye and strikes objects is responsible for seeing.

In recent years, work on students' misconceptions about science concepts has illuminated further the extramissionist beliefs that some children hold about vision. An investigation into how Swedish students aged 12-15 understand light and its properties revealed that they often did not understand that light exists in space and is reflected off objects into the eye, making sight possible (Karrqvist & Anderson, 1983). Karrqvist and Anderson found many students who believed the eye to be an active agent in sight, either sending rays toward an object or first receiving and then sending out light. Furthermore, these beliefs did not change markedly after instruction in optics. Karrqvist and Anderson (1983) speculate that common linguistic expressions, such as "casting glances" and "throwing looks," combined with a lack of understanding of light's properties might explain extramissionist tendencies.

Similarly, Eaton, Anderson, and Smith (1984) described several case studies in which fifth-grade students did not change their erroneous beliefs about vision even after their classes had gone through a unit on light (although these researchers reported no extramissionist beliefs in their sample). These researchers proposed that the failure of the instructional unit to eradicate the students' misconceptions could be due to a (faulty) assumption on the part of textbook writers and teachers, namely that "everyone" knows that light reflects off objects to the eyes. The resistance of children's intuitive beliefs about vision to instruction is part of the dilemma of reformulating one's intuitive notions of natural phenomena when the scientific view contradicts one's own view (Chinn & Brewer, 1993).

Working in a structuralist vein, Guesne (1984, 1985) found using clinical interview procedures that most children she studied (aged 13-14 years) held incorrect beliefs about light, not understanding that every object in our perceptual worlds (as opposed to obviously reflective surfaces like mirrors) reflects light to our eyes, causing us to see it. She further noted that a few of her subjects explicitly professed extramissionist beliefs about perception. However, she reported only a few children had such ideas (although the lack of mention of sample sizes and of descriptive statistics muddies the meaning of the term "few"), and she claimed these childrens' beliefs were "qualitatively" different from those of the ancients (p. 26, 1985) and therefore not extramissionist in an historical sense. Most of her respondents, she reported, explained vision without reference to transmission of any sort occurring between the eye and the to-be-viewed object (1985).

Some empirical work does exist to document the erroneous conceptions of vision that many students hold. Anderson and Smith (1986) investigated the nature of the beliefs that fifth-grade students professed about light and also attempted to design an instructional unit on light which could help students overcome any incorrect theories about light and vision. They found that most students did not understand the nature of light, not understanding that it is in constant motion and can reflect off any object. They replicated the finding that very few children clearly understand how light makes vision possible and also found some evidence of extramissionist beliefs. Many participants in their sample seemed to hold no consistent view about the nature of light. The specialized instruction they developed improved students' understandings of light significantly, but Anderson and Smith (1986) note that this was an extensive unit explaining many things that science textbooks seem to take for granted, such as the role of reflected light in vision.

Unpublished work by Repp, Callanan, Meier, and Miller (1992) documents the beliefs about vision held by kindergartners, second- and fourth-grade students, and adults. Results indicated a trend in explanations about how we see: Kindergartners attributed no role to reflected light, second-graders had a slight and non-significant tendency to explain vision in terms of light reflecting into the eye and back out to the object, while fourth-graders most often explained vision by simply stating that light illuminates objects and makes vision possible; reflected light was absent from this type of explanation. Adults generally gave the correct scientific explanation. Following some of the kindergartners longitudinally for a year gave additional support for this trend, as Repp et al. (1992) were able to identify a shift from the kindergarten explanation to the light-reflected-in-and-back-out explanation typical of the second-graders. These researchers hypothesize that understanding of vision progresses from a period of complete lack of understanding about the role of light and the eyes in seeing through a period of "naive optics" (p. 25), which may be the result of combining a naive psychology with school instruction.

A common theme in the above-mentioned research is that many children and adolescents lack some very basic ideas about light: that it is an entity which propagates through space and that it reflects off objects to the eyes, making vision possible. Furthermore, these notions seem to be taken for granted in typical educational units which cover light and vision, meaning that these units are not as effective as they could be. However, none of the research cited above explicitly focused on a concept basic to understanding vision, intromission.

A series of experimental studies directed at this question by Winer, Cottrell and colleagues (Cottrell & Winer, 1994; Fournier, 1994; Winer, Cottrell, Karefilaki, & Gregg, in press; Winer & Cottrell, in press; Winer, Cottrell, Karefilaki & Chronister, 1996) supports the hypothesis that many children and some adults hold extramission beliefs about vision, a finding which has endured under various modes of questioning. In particular, some evidence for a J-shaped developmental curve in intromissionist conceptions of vision has been obtained, with very young children professing a belief in intromission which tapers off until fifth grade; however, college students are mostly intromissionists. Beliefs in extramission follow the opposite pattern, rising until grade five. College students are generally less likely to display extramission beliefs, but such notions do not disappear (as I will discuss below). In a study which focused on the beliefs preschoolers hold about perceptual processes, Fournier (1994) found that these young children professed beliefs about vision, audition and olfaction that were both intromissionist and extramissionist, with the results possibly being due to an egocentric, "ballistics" theory of perception that interprets all information about the world as entering the body from without. In other words, their intromission beliefs were relatively unsophisticated, not giving a role to light, and coexisted with extramissionist beliefs.

Cottrell and Winer (1994) found that approximately half of their sixth-grade participants gave extramission responses to verbal questions about how vision occurs, while only 9 percent of college students did so. However, even a large minority of college students (24 percent) admitted a belief in extramission on a pictorial question, specifically that something first leaves the eye and then comes back in. Additionally, 12 percent of the college students denied that intromission of any sort aids in seeing! These results give support to the J-shaped age trend in the frequency of intromissionist beliefs. Participants of all ages agreed to a large extent that looks can mix, a la Piaget (1929/1972), with a surprisingly large proportion of college students (40 percent) assenting to this idea.

Winer et al. (1996) found that the type of stimulus (luminous versus nonluminous) used in questioning did not alter beliefs in college students but did increase the number of intromission responses in third- and fifth-graders. Interestingly, inducing a positive affect in college students actually lowered the number of correct responses! Possibly, the authors suggest, the induction of a positive emotional state interfered with rational thinking and caused a regression to more intuitive responding.

Further experiments (Winer et al., in press) germane to this study found that purely verbal questions elicited more correct (intromission) responses than did a series of seven computer-graphic questions, although the effect was small. One experiment in which students received both a verbal question about vision and a graphic question revealed a reversal due to mode of presentation, with participants almost always changing their answers from the first trial to the second regardless of whether they were correct or not. Whatever beliefs participants did possess about vision appeared not to be very strong.

In general, then, a clear developmental trend appears to be present, with most children evincing some type of extramissionist idea about vision and many college-aged adults holding to the intromissionist view. However, the college-aged participants have been by no means unanimous in their endorsements of intromission, as just documented.

One important finding, which has remained under various testing conditions, is that the mode of representation used in the question about vision affects performance: Pictorial renditions of what might occur during vision tend to increase extramissionist responses in students, while verbal questions lead to more intromissionist answers (Cottrell & Winer, 1994; Winer et al., in press). In particular, the forced-choice computer graphic questions used by Winer et al. (in press), which depict various processes that could occur during vision, seem quite difficult even for college students. Further research utilizing this mode of presentation has shown that roughly two-thirds of college students endorse at least one choice which includes extramission on these questions.

On the other hand, when asked to write an explanation of how someone sees something, one study revealed that NO student explicitly mentioned anything leaving the eye (Winer & Cottrell, in press, Experiment 1). However, when asked to draw a representation of how we see using arrows to refer to input and output of something to and from the eye, students of various ages, including college students, have shown a tendency to draw an arrow or arrows leaving the eye and going to the object. Winer and Cottrell (in press, Experiment 1) found in one study that only 5 of 101 college students drew only inward-directed arrows! Explicitly asking students to draw arrows indicating input and/or output from the eye decreased this tendency, although approximately half of college students tested still drew renditions of vision which included extramission (Winer & Cottrell, in press, Experiment 3). The authors suggest that explicitly referring to input and output brings to mind an otherwise dormant distinction between the outwardness of visual orientation and the inward-directed flow of light to the eyes that is part of the actual visual process.

Altogether, these data indicate that different forms of representation can affect the visual ideas that some students endorse. Pictorial renditions of vision could possibly induce thinking about the orientational aspects of vision, evidenced in common phrases like "Look at this." Thus students who draw outward-directed arrows or who endorse extramission responses on the computer items might merely be thinking in terms of orientation, in an intuitive fashion, causing them to give extramissionist or intro- and extramissionist responses. Being required to write about vision might release them from the influence of these tendencies and allow them to instead rely upon their store of scientific knowledge of the subject (Winer & Cottrell, in press). Of course, this theory, if accurate, would still not explain what separates these persons from those who are pure intromissionists, regardless of the modality of representation used.

The work of Winer and colleagues is especially relevant to the present study. For one thing, the finding that many college students, most of whom have learned about vision in the course of an introductory psychology class, nevertheless manifest notions of vision that clearly include extramission is astounding. Indeed, as several informal discussions of this research with colleagues and acquaintances has indicated, this result flies in the face of all common sense to many people.

This result is also problematic for a theoretical metaphor currently popular in developmental psychology, namely that developments in the history of science are recapitulated in the course of child development, at least in Western children (Carey, 1991). Such an idea has its roots in the concept of the paradigm shift devised by Thomas Kuhn in <u>The Structure of Scientific Revolutions</u> (1970). Briefly, in Kuhn's version of scientific progress, a set of core theoretical assumptions about reality called a paradigm dominates a scientific field for a time, then as more and more evidence accumulates which the paradigm cannot accommodate, the paradigm weakens. Finally, a relatively sudden, radical change in assumptions occurs (this is the paradigm shift), so that the findings which were anomalous to the old paradigm are now central to the new one. The historical move from ideas about extramission, which were prominent for nearly two thousand years, to the modern intromission theory, is a sterling case of a paradigm shift.

In the study of cognitive development, several psychologists have adopted the Kuhnian view to explain changes in many cognitive phenomena, including scientific beliefs. Susan Carey is probably the staunchest supporter of this approach. Carey (1991) describes changes in intuitive theories about scientific phenomena as paralleling changes in the history of science. She refers to changes in intuitive scientific theories as "strong conceptual changes." Although she also describes "weak conceptual changes" which are not as radical as paradigm shifts, changes in scientific beliefs are asserted to be strong ones. Children begin with a few innate, primitive beliefs about the world which undergo restructuring in development in the same way that paradigms change in science; such restructuring is a function both of knowledge acquisition and biologically-constrained development. For example, research in children's understanding of basic astronomy has shown that beliefs about the earth in space progress from the ancient "flat-earth" view in early childhood, through various misconceptions which are probably due to erroneous attempts at combining phenomenological impressions with school-acquired knowledge, to the current scientifically-accepted view about the earth as a planet (Vosniadou & Brewer, 1992). This result and others have contributed to the "ontogeny recapitulates history of science" proposal.

The findings summarized on vision, however, do not fully support this idea. While many college-aged adults do demonstrate intromissionist ideas about vision, many others do not believe, or at least do not understand, the scientific concept of intromission. It is arguable that the beliefs these students hold about vision, at least with regard to directionality, have changed very little with development, inasmuch as they evince extramissionist beliefs essentially the same as those held by young children in the Cottrell and Winer (1994) studies.

The present study is concerned with the extent to which college students believe in the necessity of extramission for vision. That is, I assume that in the past research, students might have affirmed beliefs about extramission during vision but might also have believed that this phenomenon is not necessary for vision. In other words, they may view extramission as incidental to and not necessary for vision to occur. Indeed light might escape from the eye if it should happen to reflect off the retina (witness the red-eye phenomenon in flash photography). If students view extramission as unnecessary for vision, then asking them about necessity should increase the number of intromission responses.

Conditions in which participants are asked to respond in terms of what is necessary for vision might decrease extramission for other reasons as well. Thus, students might not really possess a correct understanding of vision, but when asked to reason in terms of what is necessary, they might infer the correct answer. Another possibility is to assume that extramissionists give incorrect responses because they are responding on the basis of intuition or fleeting impressions. Asking them to respond in terms of necessity may force them to consider what must happen during vision and conceivably lead to more correct responses.

However, in two pilot studies I have made some initial examinations of conditions of necessity, and I have found, contrary to the assumptions of this study, that many college students do at least appear to affirm a belief in the necessity of extramission for vision to occur. The first study relied upon the computer-question format utilized by Winer et al. (in press), in which different renditions of vision are depicted for 7 trials and students must choose among them, but also included a necessity factor. Some participants were asked questions which explicitly mentioned this consideration; for example, one question read "In order for us to see, is it absolutely necessary for something to come into the eye or to go out of the eye?" Other students received identical questions without any mention of necessity, such as "When we see, does something come into the eye or go out of the eye?" This experiment also included a warning factor (some students were warned in advance that we would be asking them whether something goes into, comes out of or both goes into and out of the eye when we see). These two factors produced no effect upon students' stated beliefs about vision, as measured by the number of correct, intromission-only responses.

A second study again utilized the computer-graphic format and the necessity factor but instead included a factor of cognitive conflict. That is, some participants were asked to justify their responses to each of the 7 trials, a procedure designed to induce a sort of disequilibrium by confronting the student with any contradictions among his or her responses. This procedure could potentially alter beliefs about vision (see Pascual-Leone, 1991, and Kuhn, 1993-a & b, for discussions of the possible roles of cognitive conflict and rational argument in increasing understanding of science). This second study also included a variant of an appearance-reality distinction question (Flavell, Green & Flavell, 1986). Some participants were asked, after their responses to each computer trial, if the rendition of vision they chose really occurs or only seems to occur. These manipulations also had no effect upon participants' theories of vision, as measured by number of intromission-only responses. However, it is possible that they really did not have an understanding of necessity in general or of necessity in the realm of scientific phenomena.

This possibility, that participants are lacking an explanation of what "necessity" actually means in the context of the study, is a problem because participants may have different notions of the concept of necessity than what I intend. They could therefore rely upon their own interpretations of this term when responding, and there is no reason to believe that these ad hoc definitions (if they are in fact formed) involve the role of light in seeing; that is, participants may not even be thinking in terms of "in" and "out." For example, for visual perception to occur, signals must necessarily travel from the optic nerves to the brain, but light is not central to this example of necessity. A more basic example is that for a person to see an object she must be looking at it. This type of necessity contains an outward orientation which again does not give a role to light (Recall that Winer and Cottrell [in press] found evidence for a distinction between orientational and scientifically-based interpretations of vision by some college students.). The point is that participants do not know in advance what "necessity" refers to and must somehow rely upon their own meanings, which are a possible source of error in the design as they are beyond experimental control. The present study provided a definition of necessity pertaining to scientific phenomena, along with simple pretrials designed to cause participants to think about necessity in a way consistent with the definition, to remove this potential error and hopefully lead to more intromissionist responding.

Research Questions

The present study, building upon the findings of Cottrell and Winer (1994), Winer et al. (in press) and Winer et al. (1996), further explored conditions under which college-aged adults retain extramission beliefs while required to think about the concept of necessity. I will now present a brief outline of the study's research questions:

(1) Holding to the overarching idea of requiring students to consider vision in terms of what is necessary for it to occur, it will explore possible effects of strengthening this factor beyond the extent to which it was utilized in the two pilot studies. Will presenting students with an explicit definition of the term "necessary" in the context of the study, along with an example and a series of pretest items designed to induce thinking about phenomena in terms of this definition, improve performance on the computer vision trials as compared to a control group which is not exposed at all to the concept of necessity?

(2) Furthermore, will the specific type of pretest items used make a difference on the vision trials? In particular, will pretest items requiring participants to think about sensory processes other than vision and processes involving the body lead to more correct responding on the vision trials than pretest items about nonbiological processes?

(3) A more exploratory question deals with the nature of the scientific knowledge that participants possess. The influence of this existing scientific understanding of vision is important because it can be argued, should the necessity conditions improve performance, that they do so not because they induce thinking about the causal necessity in phenomena such as vision (i.e. light reflected from objects must enter the eye) but because they activate scientific schemas the participants possess for vision. Thus, another question of this study is as follows: can activating the scientific knowledge that students possess about vision improve performance on the vision trials independently of any exposure to the concept of necessity in terms of vision? This result, if it occurred, would suggest that the necessity training was effective only because it allowed students to recall their scientific knowledge of vision; crediting such improvement to necessity considerations would not be warranted in that case.

CHAPTER 3

METHODOLOGY

Participants

Participants were 132 college students at Ohio State University, all of whom were enrolled in an introductory psychology class at the time of the experiment and participated in the study as part of a class requirement. Participants consisted of 54 males and 78 females (Mean age = 19.4 years, Range = 17-33 years). It is worth noting that, prior to testing, all of them had been exposed to the unit on vision in their introductory psychology classes and had taken a midterm exam which included questions on the topic. This prior exposure to the study of vision could of course be considered a contaminating factor, meaning that perhaps we are not studying "pure," intuitive theories of vision. However, such contamination is unlikely to have marked effects on many students' beliefs. Previous unpublished research (Winer & Cottrell, 1994) has shown that students who have already experienced the unit on vision in the introductory class at Ohio State perform only slightly better on the computer vision trials (to be described below) than students without such education. Over one-half of the students with the pertinent education still endorsed at least one extramission response, and the mean difference in pre- versus post-education number of correct responses was not great (3.1 out of 5 versus 4 out of 5).

Measures

For the main dependent variable, participants received scores based on eight vision trials, seven presented in the computer-graphic format following that used in Winer et al. (in press), with the eighth question being purely verbal. The computer graphics showed faces in profile looking at blocks, and dotted lines representing light were shown going into, out of, or both into and out of each face's eyes and coming into contact with one block. From two to four faces, aligned vertically on the left side of the screen, were shown for each trial. Each face regarded a block situated on the right side of the screen. The blocks were also aligned vertically, each one directly across from one of the faces. Thus, each face-block combination depicted one possible version of how vision occurs, with the specific version being determined by the direction(s) of flow of the dotted lines that represented light. Over the seven trials, five possible renditions of vision were depicted (something going into the eyes, something going out of the eyes, something going in and out of the eyes simultaneously, something first coming into the eyes and then going back out, and something first going out of the eyes and then coming in). Each trial showed from two to four of these renditions. No more than four could be shown because of space limitations on the computer screen. Each trial included as answer choices the correct process (intromission only) and the process of extramission only; every trial thus required a choice between at least these two processes. These vision trials were arranged in a single order of decreasing complexity, running from four-choice trials at the start, to three-choice questions in the middle, to a single two-choice question (intromission vs. extramission) on the seventh trial. However, the eighth, purely verbal trial, read aloud to each participant by the experimenter, required the participant to choose one answer from descriptions of all five of the possible visual processes described above.

All of the participants in this study responded to these trials, with the number of correct responses serving as the dependent variable. However, students in the necessity conditions were given training on the concept of necessity before they responded to the vision trials, and the questions accompanying the vision trials in these conditions were worded slightly differently from those asked of students in the non-necessity conditions. In contrast, the students in the scientific schema-activation conditions received a writing task prior to the vision trials which did not involve necessity and which was designed to evoke a scientific frame of mind for vision; their vision trials were also worded so as to omit any mention of necessity. Finally, the control-condition participants only answered a set of questions unconnected to the notions of necessity and scientific knowledge of vision, and they received the same vision trials as did the schema-activation participants. I will now more precisely describe the various conditions.

Necessity Conditions

To eliminate any possible confusion about the vague idea of necessity, participants in the two necessity conditions received explicit instruction on the idea of necessity before responding to the computer questions. To clarify how they were to conceptualize this notion, they first heard a definition of the word "necessary" framed in terms of events that occur, or seem to occur, simultaneously:

> Sometimes certain things that happen at the same time seem to be related closely to each other. This may make it seem to us that each one is necessary for the other to occur. What do I mean by "necessary?" "Necessary" means that one thing has to happen before some other thing can happen. For example, for a radio to work, radio waves have to move through the air. Radio waves moving through the air are ABSOLUTELY NECESSARY for a radio to work.
>
> However, just because two things happen close together or at the same time doesn't always mean that one is necessary for the other. It could be the case that two things might happen at the same time even though they have nothing to do with each other. In this case neither thing is necessary for the other to occur.
>
> For example, is it absolutely necessary for

> you to have a book in order to read? No, it isn't, because you could read other things, such as a magazine, newspaper, or even a sign along the side of the road.

As noted, there were two groups of participants who received this definition prior to the vision test. These participants then answered eight trials meant to augment their understanding of necessity in terms of the definition. These additional pretest items were in essence a series of yes/no questions about commonly-occurring processes which either covary or only seem to covary. The tasks of the participants were to answer each trial and explain their answers. There were two types of pretest questions, each corresponding to one of the necessity groups. Within each type, half of the questions had correct "yes" answers and half, correct "no" answers:

(1) Relevant items: These eight questions were "relevant" in that they referred to sensory or biological processes. For example, one relevant pretest item asked, "When you breathe is it absolutely necessary for something to come into your lungs?" Notice this example makes reference to a biological process and involves input to the person.

(2) Irrelevant items: These eight pretest items were termed "irrelevant" because they did not involve biological or sensory processes. One irrelevant pretrial read "If I hold up a baseball in front of you right now and let go, is it absolutely necessary that it fall?"

Additionally, each group of items was further divided into two types. One type of question merely asked for a yes-no response, and the examples listed above were questions of this type. A second type of pretest item was actually divided into two parts. The first part of each item asked whether one thing would happen given that something else has happened; for example, "If you have not cut yourself, can you feel pain?" The second part of the item then asked whether the first state of affairs mentioned in the question was necessary for the second; e.g. "Could you say that it is NECESSARY for you to cut yourself in order for you to feel pain?" Each participant in the two necessity conditions thus answered eight pretest questions, four of the simple items and four of the two-part items, of either the Relevant or Irrelevant type. After a participant answered each item, the experimenter restated the correct answer and read a brief explanation of why that answer was correct, correcting the participant if necessary.

To prevent the possibility of inducing in participants a "set" to answer yes or no, each set of pretrials (Relevant and Irrelevant) was divided into two orders with the correct "yes" and "no" responses arranged so that no more than two of the same correct response occurred consecutively. Within each order, the four simple yes-no items always preceded the four two-part items because it was felt that this presentation of the questions would lead participants to think about necessity in a way that closely matched how they were to apply the definition on the vision questions. The complete list of pretrials is presented in Appendix A.

The instructions for the vision test, and then the vision questions themselves, came after the necessity training. The instructions, read aloud by the experimenter, informed the participants that they were to tell the experimenter "what must happen in order for us to see." Participants were further told that we wanted to know whether "it is absolutely necessary for anything to go into the eye, out of the eye, or both into and out of the eye in order to see." Finally, the instructions also warned the participants that they would see depictions of vision which showed rays, waves or energy moving into and out of the eyes.

For each of the vision trials, from two to four of the previously-described renditions of vision were shown on the computer screen, and the experimenter read aloud a question. The question required the participant to choose among the various processes being shown, with question alternatives following the order of the processes on-screen from top to bottom. For example, one trial depicted lines flowing from the block into the eyes for the top rendition, lines flowing from the eyes to the object for the middle rendition, and lines flowing simultaneously back-and-forth between the block and the eyes for the bottom rendition. The accompanying question read, "In order for us to see, is it absolutely necessary for something to come into the eye, go out of the eye, or go into and out of the eye at the same time?" The complete set of computer trials used for these participants appears in Appendix B.

Scientific Schema-Activation Conditions

Two other groups of participants, hereafter deemed the Schema-Activation groups, did not receive the necessity definition, examples, or pretest items. Instead, before the vision test, they were given a set of seven words related to vision, plus the word "book," and asked to write an explanation of how a person sees an object like a book. The instructions here asked participants to include all eight terms in their explanations. The seven vision terms were eye, brain, retina, pupil, optic nerve, lens, and light. "Light" was included because much of the confusion over how people see appears to be related to misunderstandings about the role of light.

As stated, the design included the Schema-Activation participants to control for the possibility that the concept of necessity might not be the actual source of improvement on the vision trials, assuming performance improved at all. However, this condition also permits a more thorough understanding of how well students understand basic facts of vision after receiving instruction on it (Recall that all participants had learned about vision prior to testing.).

Of course, drawing inferences about students' knowledge of vision based on a subsample of all possible terms that could have been used is a risky proposition; using a different set of terms could produce different results. However, the terms included were very basic and were surely not new to the participants, since they had been exposed to them all in introductory psychology and probably in secondary school classes before then. Scoring criteria for these concepts, which I will discuss in the Results section, appear in Appendix C.

The oral instructions for the two groups were as follows:

> I want you to write an explanation of what occurs when you see something, such as a book. I will give you a list of words related to vision. Write an explanation of what occurs when we see, <u>using all of these words in your explanation</u>. Please make sure to use ALL of these terms. Also, rely on your understanding of the scientific explanation of vision as much as possible. In other words, base your answer upon what you have learned about vision in school, read in a textbook or encyclopedia, or learned from some other authoritative source. Do you have any questions?

Once these instructions were read and any questions answered, participants received the word list, which included a brief restatement of the instructions. Each participant responded on the sheet of paper containing the word list. The experimenter allotted five minutes for completion of the explanation, but most participants finished before then, and none required more time to finish.

The difference between the two Schema-Activation groups appeared after each participant had completed his or her explanation. At this time, students in one group, called the Clarification group (the other group is called the No Clarification group), were asked this question by the experimenter:

> I want you to clarify something for me. What does your explanation mean? Does something like rays, waves, or something else only come into the eye, only go out of the eye, or both come into and go out of the eye?

The experimenter then circled the answer the student gave, either <u>in</u>, <u>out</u>, <u>first in then out</u>, <u>first out then in</u>, <u>simultaneous</u> (if the student replied that something goes in and out at the same time), or <u>other</u> for any other response. The rationale behind this clarification was that, given that the participant had verbally committed to a certain directionality involved in vision, his or her answers on the computer questions would surely reflect that verbal commitment. Additionally, previous testing has shown that virtually no respondent writes that something leaves the eye during vision (Winer & Cottrell, in press). Having written that something enters the eye, the participant should be inclined to answer in a similar manner on this question and on the computer trials to appear consistent.

The instructions for the computer vision trials, and then the trial themselves, followed the explanations. In this case, the instructions were identical to those for the

Necessity groups except that all references to necessity were omitted. The experimenter informed each participant that we wanted to know "how people see" and "whether anything goes into the eye, out of the eye, or both into and out of the eye when we see." As before, these instructions warned participants that they would see renditions of rays, waves or energy moving into and out of the eyes. The computer trials presented to these participants were identical to those presented to the Necessity participants, but the questions accompanying them were worded to make no mention of necessity. Thus, for example, the trial (previously described under the Necessity condition section) which forced a choice among an intromission-only depiction, an extramission-only depiction, and a simultaneous intromission-extramission depiction was attended by this question: "When we see does something come into the eye, go out of the eye, or go into and out of the eye at the same time?" The complete list of these computer trials appears in Appendix D.

Control Group

A fifth group of participants served as a control group and did not experience the necessity training or write explanations of how vision occurs. Instead they received eight two-choice questions on facts not involving any notion of necessity or vision, on which the experimenter corrected them if there were any incorrect responses. For example, one question asked "Does a heliotropism mean a plant grows toward the earth or sun?" Another asked, "Is the population of the United States closer to 300 million or 200 million?" These questions were also presented in a way to prevent inducing a "set" to pick either the first or second choice; they were ordered so that no more than two in a row had as correct answers the first or second choice. Students in this group received the computer-question instructions and then the computer trials after answering these pretest items. The instructions preceding the computer trials and the questions accompanying the trials were identical to those responded to by the Schema-Activation participants.

Followup Questions

After responding to the seven computer trials and one verbal trial, each student also answered a few verbal followup questions, which were included in the study to further bring to light the students' understandings of the visual process. Some of the questions asked about extramission and some about intromission, and which questions a participant answered depended on how she had responded on the computer trials and verbal trial. For example, if a student gave at least one answer involving extramission, she was asked the followup extramission questions. The same condition applied to intromission responses, meaning that a student could be asked about both processes. The main question first asked whether the specific process, intromission or extramission, was necessary, and if so, why. All participants also responded to another question on an unrelated topic.

Design and Procedure

This experiment can be described as a single factor experiment with five levels, each involving a condition that might differentially influence responses to the computer vision tests: (a) the control group; (b) the Schema-Activation No Clarification group; (c) the Schema-Activation Clarification group; (d) the Necessity-Relevant group; and (e) the Necessity-Irrelevant group. Participants' gender was also included as a variable in analyses because pilot research has shown gender to be an important factor in subjects' responses in some studies.

The main dependent variable for this study was the number of correct responses to the seven computer trials and one verbal trial: Every correct response received a 1, while all incorrect responses received zeroes; a participant's total score was thus the number of correct responses. For the Schema-Activation groups, additional variables were each student's scores for the individual vision-related items and a total vision term score which was the sum of all of these.

Students were tested individually. First the experimenter gave the appropriate pre-test task (either the control questions, the necessity training, or the schema-activation writing task). Immediately afterward the student received the computer instructions and the computer vision questions. Finally, the experimenter asked the student the appropriate follow-up questions. All responses (except for the writing task in the Schema-Activation conditions) were recorded by the experimenter on answer sheets.

CHAPTER 4

RESULTS

As the research questions indicated, the major thrusts of this study were to ascertain whether the necessity training and/or the Schema-Activation conditions could improve performance on the computer vision trials, that is, increase the number of intromission-only responses. Briefly put, the data analyses will emphatically show that these conditions did not improve students' performance at all as compared to the control group and that, while many students were firm believers in intromission, over one-half of all students agreed to extramission on at least one trial. Additionally, female students were somewhat more likely to give responses involving extramission than were male students, a finding which accords with pilot data I have collected.

Analyses of responses to the follow-up questions indicated some surprising results, showing that how students responded on these questions was not clearly related to how they responded to the computer questions. In general, these data suggest that many of these college students, even if they respond in an extramissionist fashion, are less willing to affirm the necessity of extramission verbally than they are the idea of intromission.

Regarding the written explanations of the Schema-Activation participants, the data indicate firstly that students have widely varying understandings of the visual process as defined in this study. Secondly, the summed score derived from students' usage of the seven concepts enumerated earlier proved to be moderately predictive of their performance on the computer vision questions, indicating that the computer questions and the explanations required of students in these conditions might be tapping into some of the same aspects of their knowledge of vision. Subsequent analyses showed that only one of the concepts scored, light entering the eye, appeared to be largely responsible for this association. This correlation was not especially large, but it suggests that students who do not grasp the role of light in seeing are likely to give extramission responses on the computer trials.

In all the analyses to be reported, an alpha level of .05 was used for the statistical tests.

Analyses of Effects of the Experimental Conditions on Correct Intromission Responses

The major thrust of this study was to see whether necessity training would lead to an increase in intromission responses to the computer vision trials and the verbal vision trial (Research question 1). Additionally, I sought to determine whether the type of pretrial used in the necessity training conditions differentially affected the number of intromission responses given (Research question 2). To these ends I conducted two 2 (Gender) X 7 (Experimental condition: Control, Schema-Activation No-Clarification, Schema-Activation Clarification, Necessity-Relevant Order A, Necessity-Irrelevant Order A, Necessity-Relevant Order B, Necessity-Irrelevant Order B) between-groups analyses of variance. One ANOVA was performed on the number of correct responses to the seven computer trials, and a second ANOVA was conducted on the number of correct responses to the seven computer trials plus the verbal trial. Correct, intromissionist answers were scored as 1s, while all other responses received 0s. For these analyses, the dependent variable (number of intromissionist responses) could thus range from 0-7 and 0-8, respectively.

The results of the two ANOVAs were essentially identical, a finding which was repeated in all the subsequent analyses to be reported here. This is not suprising in light of the fact that the point-biserial correlation of participants' scores on the seven computer trials with their scores on the final verbal trial was quite high, $r_{pb}(130) = .798$, $p < .0001$. Furthermore, dichotomizing subjects according to whether they were correct on all seven computer trials and cross-tabulating them according to whether they were correct on the verbal trial revealed a strong association between pure intromission answers on the seven computer trials and pure intromission on the verbal trial, phi = .728, $p < .0001$. Of 53 students who were perfect on the seven computer trials, 52 of them selected intromission only on the final verbal trial. Of the 79 students who chose at least one response that included extramission, 60 of them selected an answer that involved extramission on the verbal trial. In other words, participants in general answered this question in the same manner in which they answered the seven computer questions: firm intromissionists were likely to give intromission-only responses, while students of other convictions responded incorrectly. Consequently, I will only report the results of the analyses involving all eight vision trials.

The analysis of variance on these scores yielded a significant effect of gender, $F(1, 118) = 11.09$, $p < .01$, with males ($M = 5.83$, $SD = 2.81$) giving more intromission answers than females ($M = 4.10$, $SD = 2.73$). The effects of experimental condition and the gender-by-condition interaction were not significant, $Fs(6, 118) = .80$ and .84, respectively, $ps > .50$. Refining these analyses by collapsing over the two orders of necessity pretrials, so that the design was then a 2 X 5 (Gender X Condition) one, did not change the pattern of results one iota. The main effect of gender remained significant, $F(1, 122) = 10.53$, $p < .005$. The effect of experimental condition and the gender-by-condition interaction effect did not achieve significance in this analysis, both $Fs(4, 122) < 1.25$ and $ps > .25$ (Means across the five main experimental conditions and participant gender are reported in Table 1.). Obviously, then, the necessity training and the intended activation of scientific knowledge of vision did not affect the number of intromission responses that subjects gave in this study.

The necessity conditions did not lead to more intromission responses despite the fact that the necessity pretest items themselves seemed easy for most participants. Of the 56 students in the necessity conditions, thirty-seven of these participants (20 females and 17 males) correctly answered all eight of the pretest items which specifically mentioned necessity, and no student answered fewer than 5 correctly. As the restriction of range on this measure would suggest, the correlation between it and the number of correct vision trials was slight and nonsignificant, $r(54) = .208$, $p = .12$. When I examined the number of correct responses to all 12 pretest items (the eight necessity questions plus the four questions which asked whether one thing would occur given that another had occurred), the same restriction of range appeared (see Table 2). As Table 2 shows, no participant had less than 7 correct answers to these pretest items, and 30 students (15 males and 15 females) were correct on all 12 items. The correlation between this score and score on the vision trials approached significance, $\underline{r}(54) = .253$, $\underline{p} = .06$. Further correlational analyses showed no associations among the number of correct pretest items, participants' gender and specific necessity condition. Thus, although some evidence for a modest relationship between success in necessity training and success on the vision trials appeared, most participants could grasp the concept of necessity as I defined it, but they did not appear to apply it to their responses on the vision trials.

To ascertain exactly where the distributions of vision-trial scores for males and females differed (aside from means), some follow-up analyses were conducted which compared these distributions (These distributions are presented in Table 3). When the students were dichotomized according to whether they were pure intromissionists (all intromission versus at least one response involving extramission), males were pure intromissionists 56% of the time (30/54) while 28% (22/78) of females fell into this category. The difference in proportions of pure intromissionist students was significant, chi-square(1, $\underline{N} = 132) = 9.98$, $\underline{p} < .005$. Also, 65% of males (35/54) were correct on the final verbal trial versus 46% of females (36/78), a difference that was statistically significant,

Condition	Male		Female	
	M	n	M	n
Control	5.70	10	3.53	15
Schema-Activation/ No Clarification	6.00	11	4.67	15
Schema-Activation/ Clarification	5.89	9	5.19	16
Necessity/Relevant	5.36	11	3.08	13
Necessity/Irrelevant	6.38	13	4.68	19

Note. Necessity conditions are collapsed across order.

Table 1: Mean Number of Intromission Responses as a Function of Gender and Experimental Condition.

	Number of Correct Responses					
Condition	7	8	9	10	11	12
Necessity/Relevant						
Male	1	0	0	0	3	7
Female	0	0	1	3	3	6
Necessity/Irrelevant						
Male	0	0	0	1	4	8
Female	0	0	3	3	4	9

Table 2: Number of Correct Responses to the 12 Necessity Training Trials by Necessity Condition (Collapsed Across Order) and Gender.

chi-square(1, N = 132) = 4.47, p < .05. Thus we see that female students were more likely to endorse at least one extramission response, and for all eight trials, a surprising 61% of students (80 of 132) endorsed at least one response involving extramission.

It was not possible to compare the distributions of males and females categorized by how many of each gender obtained a given score (i.e. how many males and females gave 0 intromission-only responses, how many males and females gave 1 such response, etc.) because inspection of these distributions showed that roughly half the cells in the table had expected frequencies less than five, making the chi-square goodness-of-fit test an inappropriate statistic to use. However, inspection of Table 3 makes it readily apparent where the difference lies; a higher proportion of females than males fell in the lower half of scores (from 0-4 correct answers). The median number of correct responses over all eight trials was 4, and the proportion of males' scores above the median was significantly greater than the proportion of females' scores above the median, chi-square(1, N = 132) = 11.02, p < .001. 67% (36/54) of males' scores fell above the median, while 37% (29/78) of females' scores were in this category. Another way of saying this finding is that only 65 participants were correct more than they were wrong on the vision trials.

	Number of Correct (Intromission-only) Responses								
Gender	0	1	2	3	4	5	6	7	8
Male	2	4	5	3	4	0	3	3	30
Female	4	6	17	11	11	2	3	2	22

Table 3: Distributions of Number of Correct Responses to Vision Trials Classified by Participant Gender.

Analyses of Follow-up Questions and Comparisons of Responses to Them with Responses to Vision Trials

The above analyses illustrated the failure of the conditions of necessity and of schema-activation to increase the number of intromission responses on the eight vision trials. In light of these results, I next turned to analyses of the responses participants gave to the verbal questions which followed the computer trials and verbal trial. Recall that these questions asked whether the process(es) that participants had endorsed on the vision trials were really necessary for vision to occur, and that which questions a participant was asked depended on the answers that she had just made to the vision questions. Thus a student who gave all intromission-only responses would only be asked the intromission question, while a student who endorsed at least one response involving both intromission and extramission in some form would be asked about both. These questions were designed to probe the nature of participants' beliefs about vision.

The first analysis focused on answers to the question asking about the necessity of intromission in seeing, which was asked of the 129 participants who gave at least one response involving intromission. For these analyses a "yes" answer was coded as a 1 and a "no" answer as a 0. Displaying near perfect agreement, 123 of these students, or 95%, affirmed the necessity of intromission in seeing (see

Table 4). As Table 4 shows, the proportions of participants affirming intromission across all experimental conditions were at or near unity, so that a statistical test comparing these proportions would not be meaningful. The proportions of males and females answering "yes" to this question are of course quite high (96% and 95%, respectively; see Table 4), so that a statistical comparison of these data would also be extraneous. Additionally, the point-biserial correlation between answers to this question and score on the eight trials was slight and non-significant, $\underline{r}_{pb}(127) = .10$, $\underline{p} = .26$. In a nutshell, almost all students affirmed the necessity of something coming into the eyes during vision regardless of the number of intromission answers they endorsed on the computer trials. Thus even students who might have given only one or two responses involving intromission to the computer questions were nevertheless very likely to agree verbally that something must enter the eyes for us to see.

Responses to the question asking about the necessity of extramission during vision were more evenly distributed. As with the previous question, a "yes" was coded as a 1 and a "no" as a 0. for use in analyses. Seventy-eight students, 59% of participants, answered this question (see Table 5). Due to errors in administration, two students who affirmed extramission at some point in the vision trials did not receive this question. Across the various experimental

		Response	
Condition	n	Necessary	Not necessary
Control	25	24 (14;10)*	1 (1;0)
Schema-Activation/ No Clarification	25	23 (14;9)	2 (0;2)
Schema-Activation/ Clarification	24	23 (15;8)	1 (1;0)
Necessity-Relevant/ Order A	14	14 (7;7)	0
Necessity-Relevant/ Order B	10	10 (6;4)	0
Necessity-Irrelevant/ Order A	15	15 (8;7)	0
Necessity-Irrelevant/ Order B	16	14 (8;6)	2 (2;0)

Note. This question was given only to students who gave at least one response involving intromission on the vision trials, hence 129 participants answered this question.
* (females; males)

Table 4: Responses to the Necessity-of-Intromission Follow-up Question by Experimental Condition.

conditions, the percentages of students affirming the necessity of extramission ranged from 43 to 68 percent (see Table 5); however, a preponderance of expected frequencies below 5 made a chi-square analysis unfeasible. When students were classified according to how they answered this question and whether or not they were in an experimental condition involving necessity, the association between the two was virtually nonexistent, phi = .024, $p = .83$. Thus, experimental condition seems not to have influenced answers to this question. A chi-square analysis of answers to this question cross-tabulated by gender also did not show a difference in the proportions of males and females agreeing to this question, chi-square(1, $N = 78$) = 2.45, $p = .12$. Seven of 24 males (29%) and 26 of 54 females (48%) agreed to the necessity of extramission, meaning that 33 subjects (42% of those asked) answered this question affirmatively.

When I compared answers to this question to participants' scores on the vision trials, however, an interesting relationship emerged. The point-biserial correlation between answers to this question and vision trial score was significant, $r_{pb}(76) = -0.411$, $p < .0005$. This finding indicates that the tendency to give intromission-only responses to the vision trials is moderately negatively correlated with the tendency to agree to the necessity of extramission in a verbal format.

		Response	
Condition	n	Necessary	Not necessary
Control	19	6 (6;0)*	13 (7;6)
Schema-Activation/ No Clarification	14	6 (4;2)	8 (7;1)
Schema-Activation/ Clarification	13	7 (7;0)	6 (2;4)
Necessity-Relevant/ Order A	7	4 (3;1)	3 (1;2)
Necessity-Relevant/ Order B	7	3 (1;2)	4 (4;0)
Necessity-Irrelevant/ Order A	9	4 (4;0)	5 (3;2)
Necessity-Irrelevant/ Order B	9	3 (1;2)	6 (4;2)

Note. Only participants who gave at least one response involving extramission to the vision trials were asked this question. Two such participants did not receive this question because of procedural errors, hence n = 78.
* (females; males)

Table 5: Responses to the Necessity-of-Extramission Follow-up Question by Experimental Condition.

Overall, students were more reluctant to state that extramission is necessary in vision than they were to state that intromission is necessary.

The general impression to be gained from analyses of these follow-up questions is that many participants did not answer them in the same way that they responded to the vision trials. Despite the wide range in performance on those trials, the verbal agreement that intromission is necessary was almost unanimous. Possibly, extramissionist students did believe, at some level, that something must enter the eyes for us to see, but some aspect of the vision trials weakened this belief for some of them. Likewise, participants in general were less likely to agree verbally with the necessity of extramission, yet most students gave at least one response which included extramission on the vision trials. These data suggest that different modalities of questioning influenced these students' beliefs, as has occurred in other research (Winer & Cottrell, in press).

Analyses of Written Explanations of Vision in Schema-Activation Conditions

The last set of analyses, more exploratory in nature, focused upon the descriptions of the visual process that the two Schema-Activation groups of participants wrote. Inspection of these data could be especially enlightening because the vision trials and followup questions were concerned with establishing the beliefs of the participants regarding the directionality involved in vision. However, merely identifying students as intromissionist or extramissionist does not provide any possible explanation for why they profess the beliefs that they do; in particular, what sort of misconceptions do the extramissionists hold, and are the students who answer all the computer questions in strict intromissionist fashion responding on the basis of informed beliefs about vision, or do they also hold some poorly-developed conceptions of vision? Analyses of the written responses, it was hoped, would provide some at least preliminary answers to these questions. In presenting these analyses, I will first describe the method used to score the written explanations. I will then report the results deriving from the verbal question given to the Schema-Activation Clarification participants, and whether this question distinguished them from the Schema-Activation No Clarification participants. I will then present the data deriving from the written explanations themselves of both groups.

<u>Scoring of Schema-Activation Written Explanations</u>

To achieve the goal of measuring the Schema-Activation students' understanding of vision, as well as to allow comparison of the adequacy of their written explanations with their performances on the computer trials, I devised a coding system with which to score their explanations. In this coding procedure, I rated the accuracy with which every participant used the each of following terms and concepts: (a) brain; (b) retina; (c) optic nerve; (d) lens; (e) the passage of light into the eye; (f) the reflection of light off the object to the eye; and (g) pupil. The term "eye" was dropped from analyses because it is not clear what precisely would constitute a correct use of that term, since the various parts of the eye were somewhat redundant with it. The brain, retina, optic nerve, lens and pupil are all basic vocabulary words in the section devoted to vision in the introductory psychology class at Ohio State and are presumably relatively simple concepts to grasp in terms of their functions. The role of light in vision, however, is not really focused on in the textbook, possibly because the facts of intromission and reflection of light from objects to the eye are taken for granted. Also, the research on conceptions of light cited previously indicates that many younger children and some adolescents do not understand this entity.

In general, usage of each of the seven items above was assessed in the students' answers and rated along a three-point scale:

1. A 1 was given if the concept was not mentioned at all, or the only mention of the concept was clearly incorrect.

2. A 2 was given if the concept was used in a manner which indicated incomplete understanding (e.g. if only a

partial account of some item's function appeared in the answer), if the concept's use was ambiguous, or if the concept's correct function was given but was accompanied by incorrect information about the concept.

3. A 3 was given for a clearly correct and complete use of the concept which did not include any incorrect statements. The complete list of scoring criteria for each concept may be found in Appendix C. Each participant's scores for the seven items were summed to create a total vision-term score; thus, a student's score could range from 7 to 21.

Additionally, I scored every explanation for the presence of any extramission in responses, in terms of something leaving the eye as part of vision.

All of the written responses were photocopied, and the present author and a second trained rater (both of whom were blind to participants' sex and condition), scored every response. For the individual items, interrater Pearson correlations ranged from .841 to .679, showing fairly adequate reliability. For the total vision-term scores based on all seven items, the interrater Pearson correlation was .867. The two scores for each item were then added to create a single set of scores for use in analyses; thus the final total vision-term score could range from 14-42. Cronbach's alpha for the summed scores was .72.

Analyses of Individual Item Scores and Total Vision-Term Scores

Recall that the difference between the two Schema-Activation groups is that members of the Clarification group had to clarify verbally their explanations in terms of directionality, i.e. whether they wrote that anything entered the eye during vision, left the eye, or both. Of the 25 students in this condition, 18 stated that something enters the eye, 5 stated that something first enters the eye and then goes back out, and 2 stated that something simultaneously goes into and out of the eye. These students thus had a propensity to be pure intromissionists (or at least to claim to be such). The 7 students who verbally implicated some sort of extramission in vision displayed some inconsistency, however. In their written explanations, none of them described, according to my scoring criteria, that something leaves the eye during vision (As we shall see, none of the Schema-Activation subjects did.), yet they nevertheless said that their answers described some type of extramission. Inspection of these students' explanations did not illuminate these perplexing verbal responses because nothing that could be construed as extramission was mentioned in any of them. One possible explanation for this discrepancy is that the beliefs that these participants held interfered with or shaped their memories of what they had written, although the clarification question asked them to respond in terms of what their explanations meant, not what they had actually written. Tentative evidence for this proposal is the finding that the correlation between answers to the clarification question (dichotomized as intromission-only versus all others) and vision trial score was significant, $r_{pb}(23) = .402$, $p = .046$. Thus these students, who wrote descriptions of vision which did not involve extramission and then stated that their descriptions DID involve this process, might not have held any firm intromission beliefs in the first place. This lack of a strong belief in intromission could have manifested itself as a tendency to pick extramission responses on the vision trials. Another possibility, which could also produce this result, is that these students believed both in intromission and in extramission, so that their affirmations of extramission on the clarification question were not incompatible with their beliefs in intromission.

Analyses of the written explanations of vision first focused on whether any student wrote an explanation implicating extramission. This technique is a rough, preliminary indicator of the students' understandings of how we see. In agreement with expectations based on past research, not one of these students wrote that something leaves the eye at any point during vision. This is still a remarkable finding in light of the proportion of extramission responses chosen on the vision trials. Only one description, stating that the brain processes sensory input and then sends the processed information back to the lens to cause vision, mentioned an extramission-like idea. This misconception is interesting in its own right, but because only one student mentioned it, no sigificance should be attributed to it.

The total vision-term scores, which were created by summing the ratings of scores on the seven individual items, proved to be widely varying. The mean for this score was 29.10 (SD = 6.33), with a range extending from 18-40. A two-tailed t test comparing the mean scores for males and females was significant, with males (M = 31.45, SD = 7.21) obtaining higher scores on average than females (M = 27.58, SD = 5.39), $t(49) = 2.19$, $p = .03$. Note that the mean scores were far from perfect.

I also conducted a 2 (Gender) X 7 (Vision concept) ANOVA on participants' scores for the individual vision concepts, with repeated measures on the Vision-concept factor. This analysis revealed a significant main effect for gender, $F(1, 49) = 4.80$, $p < .05$; a significant main effect for vision concept, $F(6, 294) = 10.08$, $p < .0001$; and a non-significant gender-by-vision concept interaction, $F(6, 294) = .31$, $p = .93$. Inspection of the gender effect showed that males (M = 4.49) obtained higher average scores across the seven concepts than females (M = 3.94). Analysis of the means for the seven vision concepts revealed several differences among them. These means are presented in descending order in Table 6. Since this analysis was exploratory and obviously post-hoc, the possibility of capitalizing on chance looms large. However, even if the per-comparison alpha-level is conservatively adjusted by dividing the familywise alpha-level (.05) by the number of pairwise comparisons (21), giving a per-comparison significance level of .0024, several differences remain. All adjacent pairs of means are not significantly different from one another. The mean score on optic nerve proved to be significantly higher than all other means except for that of light entering. Light entering mean score, in turn, did not differ from the means for pupil and brain but was significantly higher than the means for lens, light reflecting, and retina. Finally, the mean for pupil equalled the mean for lens but was significantly higher than the mean score for retina. These differences are interesting because they imply that some vision concepts are easier to learn than others, but because of the post-hoc nature of the analysis and the lack of any theory to explain these differences, they will not be considered here.

Having obtained the total vision-term scores, I put them to use. One way of assessing the coherence of the Schema-Activation students' beliefs is to see whether these scores they obtain on the written responses are at all

Concept	*M*
Optic nerve	5.19
Light entering the eye	4.71
Pupil	4.31
Brain	4.16
Lens	3.90
Light reflecting off object	3.75
Retina	3.47

Note. *N* = 51.

Table 6: Means for the Seven Vision Concepts Scored in Schema-Activation Participants' Written Explanations of Vision.

predictive of their scores on the vision trials. If such is the case, then one putative explanation for the origins of their ideas about vision would be their understanding of the visual process, as I defined it: it could be the case that a high number of correct, intromission responses is associated with high degree of knowledge about the basic physiological facts of vision.

To test this idea I constructed a regression equation using students' total vision-term scores as the predictor variable. The dependent variable was the number of correct responses on the eight vision trials. The Pearson correlation between total vision-term score and vision trial score was .411 ($\underline{r}^2 = .169$), showing that total vision-term scores were moderately predictive of scores on these vision trials. The regression model was significant, $\underline{F}(1, 49) = 9.99$, $\underline{p} < .005$, with the adjusted $\underline{R}^2$ equalling .152. Thus the variance in total vision-term scores accounted for approximately 15% of the variance in the eight vision trial scores. Although this correlation is rather modest, it is surprising in light of the fact that none of the written explanations made reference to emanations of any sort from the eyes.

I attempted to improve this model by creating a set of dummy variables, one for subject gender (males coded as 1, females as 0), one for experimental condition (No Clarification coded as 1 and Clarification coded as 0), and one for the gender-by-condition interaction, and including these variables in the equation. This procedure did not improve the prediction at all. The simultaneous regression of vision trial score on all predictors yielded almost identical results: $R^2 = .200$, $F(4, 46) = 2.87$, $p < .05$ (the adjusted $R^2 = .130$ for this model, which is to be expected since non-significant predictors were added to the equation). As with the previous analysis, total vision-term score uniquely explained a significant amount of variance in the dependent variable, $t(46) = 3.08$, $p < .005$, $sr^2 = .165$. For the other predictors, all ts $<= 1.25$, ps $> .20$, demonstrating that none of them uniquely explained any variance in vision trial score. (I performed further regressions in which total vision-term score was added hierarchically to the model already containing all other predictors, and the pattern of results was the same. The model containing only the set of dummy variables was insignificant, and the addition of total vision-term score significantly incremented the proportion of explained variance and allowed the model to achieve significance.)

The results of these analyses give support to the hypothesis that students' understanding of the basic facts about vision, as demonstrated in their written explanations, moderately predicts the number of intromission responses they give on the vision trials themselves. The prediction is far from perfect, however, as the sizes of the correlation indicates. Clearly the scores assigned to students' written explanations of vision do not explain all or even most of the variance in their scores on the vision trials and hence do not explain why some students are more intromissionist than others. Many sources are possible for this unexplained variance, including other aspects of the written explanations which were not scored, cognitive abilities and/or styles of the students which affect performance on the computer trials, and possibly general personality characteristics which come into play during the experimental procedure.

Having examined how adequate an explanation the total vision-term scores were in predicting scores on the vision trials, I then turned to the correlations of the summed scores for each individual item with scores on the vision trials. Of the seven vision terms, only one was significantly associated with vision trial score, namely the concept light entering the eye, which yielded a positive correlation of $r(49) = .488$, $p < .0005$. The correlations between vision trial score and the remaining six terms ranged from .134 to .274, all ps > .05, although the correlation between this score and the term optic nerve approached significance, $r(49) = .274$, $p = .051$. The complete set of correlations is presented in Table 7.

Term	Correlation with Vision Trial Score
Brain	.236
Retina	.210
Optic nerve	.275
Lens	.230
Light entering the eye	.488*
Light reflecting off object	.135
Pupil	.229

Note. $N = 51$.
*$p < .0005$

Table 7: Correlations Between Each of the Seven Vision Terms and Vision Trial Score.

These correlations indicated that scores on light entering might be just as adequate a predictor as total vision-term score. Also, the correlation between light entering score and the summed score derived from the other six terms was high, $r(49) = .637$, $p < .0001$; this suggests that the other six items, or light entering, might be extraneous to the prediction of vision-trial score. Analysis of light entering scores revealed that the mean score was 4.65 ($SD = 1.28$) and the range was 2-6, encompassing all possible values for the score. A two-tailed t test performed upon the group means for males and females approached significance, $t(49) = 1.82$, $p = .07$, with males ($M = 5.05$, $SD = 1.32$) obtaining slightly higher scores than females ($M = 4.39$, $SD = 1.23$). To test the above-mentioned possibility, that only of the two scores was a necessary predictor, a regression equation was constructed for the dependent variable of vision-trial score using light entering score and the summed score of the other six terms as predictors.

For these regression analyses, the results may be summarized as follows: The regression equation containing only the six-term score did account for a significant proportion of variance in the vision-trial scores, $R^2 = .133$ (adjusted-$R^2 = .115$), $F(1, 49) = 7.49$, $p < .01$. When scores for light entering were added as a separate predictor, however, the picture changed. The addition of *light entering* yielded an $R^2 = .243$, $F(2, 48) = 7.69$, $p < .005$ (adjusted $R^2 = .211$), but six-term vision score was no longer a significant predictor. For this predictor the squared semipartial correlation was .005, and the test for the regression weight yielded $t(48) = .55$, $p = .58$. Only *light entering* score was a significant predictor, $t(48) = 2.64$, $p < .05$, $sr^2 = .110$. Repeating these analyses by switching the order of entry of the predictors into the equation produced essentially the same results. The model containing just *light entering* as a predictor was significant, $R^2 = .238$ (adjusted-$R^2 = .222$), $F(1, 49) = 15.30$, $p < .0005$. Adding the six-term vision score to this model did not produce any significant increment in the proportion of explained variance in vision-trial scores.

These results thus support the idea that total vision-term score is a moderate predictor of scores on the vision trials primarily because of the inclusion of the concept *light entering*. In Cohen and Cohen's (1983) terminology, the relationship between total vision-term score and vision trial score appears to be a spurious one: when *light entering* score and the six-term score are used to predict vision trial score, the only unique source of variance is *light entering* score, almost all of the rest of the explained variance being due to the combination of the two. When *light entering* is used by itself, it predicts vision trial score with similar accuracy, and the addition of the six-term score to this equation does not improve the prediction at all.

While this finding is interesting and potentially very meaningful, it should be remembered that the analyses performed were admittedly data-driven and require cross-validation. Until that time, no great weight should be given to these results. However, the finding would be of great interest if replicated because a major point of the research program of Winer and his colleagues is that many students do not differentiate between the outward, orientational aspect of vision ("looking at" something) and the actual role of light. This lack of differentiation is precisely what is being implied in the explanations of those students who did not describe, or did not describe well, light entering the eye during vision.

CHAPTER 5

DISCUSSION

The main purpose of this experiment was to determine whether the well-documented difficulties that many college students show on basic questions about vision could be corrected, so that students would respond in the scientifically correct intromissionist fashion. To this end, I gave some students a brief training session on necessity, while others were required to write an explanation of vision based on their scientific knowledge in hopes of improving their performance. In the discussion to follow, I will first summarize the results of this study and attempt to integrate them with previous research. I will then comment upon some possible implications of these results for the "ontogeny-recapitulates-scientific history" paradigm and for science education. Lastly, I will return to a troubling problem, that of how to reliably differentiate believers in intromission from those who endorse extramission or some combination of both, and consider some possible solutions.

The results of the analyses allow me to shed some light on the nature and coherence of the students' beliefs about vision. However, some aspects of students' beliefs are still vague. In examining the results of this study, I will consider them in terms of the original research questions.

The first two research questions dealt with the concept of necessity; I postulated that college students who failed in previous studies on the computer-graphic vision trials might be doing so because they are not explicitly thinking about what must occur for us to see. Perhaps, I hypothesized, they might believe that something leaves the eye during vision but is incidental to the process. Alternatively, perhaps students tend to respond intuitively to these trials because they are rendered in a compelling visual format, and students are really not considering what must happen in vision but only giving "off the cuff" answers. The results of the data analyses, however, give no support to either of these hypotheses. Necessity training did not lead to a significant alteration in the number of correct intromission responses, and the type of pretest trial used in this training also had no effect. The proportions of students giving all correct responses and giving at least one response which included extramission on these trials are consistent with those observed in pilot research. However, they are somewhat higher than those observed by Winer et al. (in press), who did not include a condition asking about necessity.

Responses to the two follow-up questions did not provide a reason for the failure to find an effect, since virtually all students who gave at least one answer involving intromission agreed that something needs to come into the eye for us to see. This consensus favoring intromission which appeared in the verbal format was clearly not reflected in vision trial scores. On the other hand, while almost half of those asked did agree that some form of extramission is necessary for vision, students were in general more reluctant to support this idea, and affirmative answers to this question were somewhat negatively associated with success on the vision trials. Apparently the verbal question about the necessity of extramission did separate, to a moderate degree, those who believed in the necessity of such an occurrence from those who really did not, but the intromission question did not differentiate among subjects. If virtually all subjects agreed that intromission must occur, why wasn't this belief reflected on the vision trials, especially in the Necessity conditions which required students to consider this concept?

Possible explanations for the failure of the necessity training abound, and none of them is definitive at this point. It is possible that the distinction I wanted students to make, involving the necessity of one physical event preceding another for that second event to occur, was just too subtle. After all, the finding that light must reflect off objects and enter the eyes for us to see is an empirical discovery and not a logical necessity. An alternative explanation for the failure of this training is that not all students in these conditions knew the relevant facts about vision. However, since they did not provide a pretest measure of their visual knowledge, unlike the Schema-Activation students, there is no way to know whether these participants knew the relevant facts.

Aside from missing or incorrect knowledge, there are other possible reasons for the failure of the necessity training. Perhaps the entire procedure, in which students had to answer a series of seemingly-strange pretest items and then respond to the vision questions, was confusing. Conceivably, the training may have hindered some students instead of correcting any extramissionist tendencies, so that they gave more responses involving extramission instead of fewer. The fact that the pretest trials were verbal and the actual test questions on vision were visual might have also hindered the training, since previous research has shown that modality of representation can affect response tendencies (Cottrell & Winer, 1994; Winer et al., in press).

Apart from the nature of the training procedure, the nature of the vision questions themselves deserves comment. Each participant in this experiment answered essentially the same question eight times, the only variations being those in the answer choices, and she received no feedback after any of her responses. Those students who were suggestible or unsure of themselves might have been led to respond in ways inconsistent with their beliefs simply because of the demand characteristics of the procedure. Indeed, several of the undergraduate experimenters who aided in the study commented that they felt that the repetition inherent in the procedure seemed to cause some of the participants to change their answers.

Aside from number of intromissionist responses, another result worth some comment is the finding that students were remarkably consistent in their responses to the one verbal trial and seven computer trials. In general, pure intromissionists on the computer trials remained so on the verbal trial, while students who had implicated extramission at some point in the computer procedure were very likely to do so again on the verbal question. As noted, some studies have found that the type of representation used in questioning affects responses (Cottrell & Winer, 1994; Winer et al., in press); however, unpublished research using within-subjects designs and different modalities of questioning have failed to elicit modality effects. In the case of this study, it is possible that the act of responding to seven repetitive computer trials induced in students a set to respond in whatever fashion they had chosen, so that the set determined answers to the verbal trial.

The other experimental manipulation in this study, the focus of the third research question, was the inclusion of the Schema-Activation conditions. I hypothesized that requiring students to write an explanation of vision, based on what was scientific fact to the best of their knowledge, could activate the knowledge they had learned about vision and thus lead to more intromission-only responses on the critical vision trials, independently of any consideration of necessity. This was not the case, however. These students were no more intromissionist on average than any of the other students in the study, demonstrating a failure of these conditions. Also, requiring some of the students to clarify their explanations verbally and thus commit to a directionality of some sort also did not lead to more intromission, on average, on the computer trials, although a pure intromission response on the clarification question was positively correlated with the number of such responses on the vision trials. An obvious possibility for the failure of the Schema-Activation conditions to increase intromission responses is that some students might not have learned the relevant information in the first place. A second possible explanation is the same as one proposed for the Necessity conditions-- the explanations were verbal, but the critical vision trials were graphic, and the modality switch might have been a stumbling block.

Analyses of these participants' explanations proved to be instructive in evaluating the first possibility mentioned above. Preliminary analyses showed that a student's total score on these explanations was a moderate predictor of success on the vision trials, suggesting that general knowledge of what occurs during vision might be a factor determining failure or success on the critical vision trials. However, as later analyses showed, this correlation was a spurious one, being in fact largely due to the participant's score on the concept light entering the eye. Results of the regression analyses showed that this score predicted the number of correct vision trial responses with approximately the same accuracy as did the six-term score and that when both variables were used as predictors, only the score on the single item uniquely explained variance in the vision-trial score. Thus, for these students, the factor in their written explanations which was most predictive (albeit to a limited extent) of vision trial score was how adequately they described this step in the process of vision.

The correlation between light entering score and vision-trial score is a moderate one, leaving much variance in the latter score unexplained, but this result nevertheless supports the contention of Winer and his colleagues: Many college-age adults, despite previous education on the topic, do not understand that light must enter the eyes for us to see. That none of these students wrote that anything must leave the eye is a fact all the more remarkable in light of this finding. This lack of extramission shown in the writing task does accord with previous research (Winer & Cottrell, in press). It is important to note that the light entering-vision trial correlation is one which occurs across two different modalities of questioning, one verbal (the writing task) and one pictorial. Thus there is evidence for the claim that some college students possess belief systems about vision which lack the notion of light entering the eye.

This tentative conclusion meshes with the literature on understanding of vision and light in general. Of course, this agreement must be qualified by noting that most of this research has focused on children and adolescents, not college students. Nevertheless, some parallels appear. Karrqvist and Anderson's (1983) study of Swedish students aged 12-15 revealed the presence of extramission beliefs in many of them, with the misconception remaining in place after instruction on the topic of vision. Requiring students to recall what they had learned also did not lead to more intromission responses in this study, suggesting that the instruction they received was inadequate. Likewise, Guesne's (1984, 1985) research with French adolescents documented the reality of extramission beliefs in at least a minority of these participants. Finally, the failure of conventional science teaching to correct misconceptions about light and vision held by elementary students has been noted by others (Anderson & Smith, 1986; Eaton, Anderson & Smith, 1984). Although none of these researchers investigated the beliefs of college students, the results of this and other studies give me reason to believe that vision- and light-related education at the college level is also not addressing extramissionist notions.

Other research on vision (which did not explicitly force a choice between different renditions of vision) has found that college-aged adults hold beliefs that are loosely aligned with the scientific explanation (Repp et al., 1992). On the other hand, these authors also found that, for their adult participants, performance on a drawing task was significantly higher when the experimenter prompted the students to consider light ("Show how the light helps Kermit see Gumby.") than when no prompting occurred (Repp et al., 1992, Experiment 1). This effect of modality of representation accords with the findings of Winer and

Cottrell (in press), who found that cuing students by mentioning input and output led to more intromission drawings than when such cues were not given. This result reported by Repp et al. may thus be another manifestation of the fact that graphic renditions of vision cause less sophisticated responses, often including notions of extramission along with intromission.

The results of this study also have implications for the parallel drawn by many developmentalists between ontogeny and advances in science. In particular, the results of this study do not clearly support the idea that developments in the history of knowledge about vision are recapitulated in the course of human development. Although college-aged adults were the only age group involved in this study, the finding that 67 participants (51%) missed at least half (4 or more) of the vision trials certainly does not sustain the idea that persons of this age have developed firm, intromissionist notions of vision. Also, the utter lack of any mention of extramission in the written explanations of the Schema-Activation subjects, when combined with the vision trial data, support the Winer-Cottrell contention that beliefs, at least for some students, vary as a function of form of representation. Specifically, a lack of a clear understanding that light enters the eyes, as expressed in writing, is seemingly associated with a tendency to endorse intromission and extramission when given graphic depictions of what might happen during vision. This dependence of scientific beliefs upon modality of representation has not been addressed in other research on scientific misconceptions, to this author's knowledge.

Another issue to which the present study pertains is the manner in which science concepts are taught. Many science classes, especially in secondary schools, like to rely upon visuographic presentations of scientific phenomena, and often rely upon analogies with more familiar events in explaining these events. My study and other research on understanding of vision imply that both techniques may have flaws for this topic.

More specifically, if graphic/pictorial representations of vision tend to activate intuitive beliefs which fuse orientation with scientific knowledge, then these techniques may not be desirable for teaching the subject. Of course, no direct evidence exists to support this idea, but the fact remains that the misconceptions that students in this and other studies have shown persist in the face of instruction on the topic.

Furthermore, drawing analogies between a scientific process and a more familiar idea (for example, comparing the reflection of light rays to a ball bouncing off a wall) may inhibit a thorough understanding of the actual process because of overreliance on the analogy. This proposal has appeared before, in a slightly different form, as a putative explanation for the difficulties many students experience in learning basic physics concepts such as heat, force, electricity and light (Chi, 1992). The core of this proposal is that many students possess naive intuitions about physics entities which attribute to these entities properties of physical matter, although these concepts are ontologically distinct from matter. This distinction means that these entities cannot possibly possess any attributes of matter (such as size or shape).

For example, commonly held misconceptions about force are that a force resides within an object and that forces can be transferred from one object to another, much as water can be poured from one glass to another. However, the physicist's view of a force is that it is what Chi (1992) calls a "constraint-based event:" it exists only as a function of the relationships among various physical entities and does not reside within any one of them. Chi (1992) asserts that the typical physics curriculum does not address these intuitive conceptions, and many students therefore fail to grasp the concepts. A successful program would have to confront the misconceptions and, if not replace them, at least add to them a separate set of ontologically distinct conceptions that correspond to the notion of constraint-based events. Drawing analogies between the concept to be learned and a familiar event involving physical objects is not likely to accomplish this goal (an hypothesis which was not disconfirmed by the failure of the Necessity training in this study).

In the case of vision, some students might not grasp the role of light because they do not really understand light as an entity; they may take the analogy of a bouncing ball literally and conflate it with what they are taught, creating notions of vision that involve extramission. For example, the "ball" representing light might be interpreted as being "thrown" from the eyes to the object, or as bouncing off an object, to the eyes, back to the external world. This idea is only speculation at this point, but one should not easily dismiss it given the present study's data.

One aspect of this study which is difficult to accommodate in a theory of understanding of vision is the sex difference observed. On the vision trials, males gave on average more pure intromission answers than females, and a higher proportion of females than males picked at least one answer which included an extramission component. In the two pilot studies I conducted, this difference also appeared and was in the same direction. This is a difficult finding to explain, and no theory readily lends itself to justifying why males should be more intromissionist than females. This difference also appeared on the written explanation scores in the Schema-Activation conditions, with males achieving higher total vision-term scores than females, and yet again on answers to the verbal vision trial. Previous research using the computer-animation paradigm has not revealed any sex differences (Winer et al., in press), although those studies did not require subjects to consider necessity or ask them to write about vision. Males have been found to be more intromissionist in some drawing studies, however (Winer & Cottrell, in press). An interpretion which could resolve the present study's somewhat peculiar findings with previous research will not be attempted here, as no sex differences have been consistent across studies.

The overriding question, one which has not been satisfactorily answered, is, what causes someone to endorse both intromission and extramission beliefs about vision? One tentative proposal was mentioned earlier, that perhaps some people's beliefs do not incorporate the notion of light entering the eye, so that when they are confronted with compelling pictorial renditions of the process (or asked to draw them), they confuse the looking-outward orientation with what they have learned in school. However, the evidence for this theory is not at all conclusive, since many students in this study and in previous studies do not show the expected pattern of response. For example, in this study, a number of students wrote rather incoherent explanations of vision yet were correct on the computer trials, as the results of the regression analyses indicated.

Thus, the factors which differentiate the intromissionists from those who show both beliefs at different times are still in doubt. Of course, scientific knowledge seems to be important here. However, other influences not related to vision are also likely to be determinants of the intromission-extramission distinction. For example, general IQ could be an influential variable. The different results produced by different ways of representing the problem suggest that some cognitive-style variables (for example field-dependence/independence) may help distinguish believers in intromission from respondents whose beliefs seem to fluctuate. Cognitive style could be influential if the Winer-Cottrell hypothesis is true, that asking about vision with graphic means causes a fusion of subjective orientation with scientific knowledge. All of these possible influences, along with any changes they undergo during the course of development, are worthy of investigation in further research on beliefs about vision.

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APPENDIX A

PRETRIALS FOR PARTICIPANTS IN

THE NECESSITY CONDITIONS

Relevant Necessity Pretrials

Pretrials with Correct "Yes" Responses

1. Is it absolutely necessary for a message to get sent to your brain in order for you to hear?
2. Is it absolutely necessary for something to come into your lungs in order for you to breathe?
3. If something is not touching your tongue, can you taste it [no]? Could you say that it is necessary for something to touch your tongue in order for you to taste it?
4. If your heart stopped pumping, would blood flow through your veins [no]? Could you say that it is necessary for your heart to pump in order for blood to flow through your veins?

Pretrials with Correct "No" Responses

1. Is it absolutely necessary for something to go out of your nose in order for you to smell?
2. Is it absolutely necessary for you to move your hand for you to touch something?

3. If you have not cut yourself, can you feel pain [yes]? Could you say that it is necessary for you to cut yourself in order for you to feel pain?
4. If something is not very big, can it be heavy [yes]? Could you say that it is necessary for something to be big in order for it to be heavy?

Irrelevant Necessity Pretrials

Pretrials with Correct "Yes" Responses

1. If I hold up a baseball in front of you right now and let go, is it absolutely necessary that it fall?
2. If I throw a large rock into a still, quiet pond of water, is it absolutely necessary that there be waves or ripples on the pond's surface?
3. If I deprive a plant completely of water and light, will that plant grow [no]? Could you say that it is necessary for a plant to have some light and water in order to grow?
4. If there were no electricity, from batteries or some other source, would TV's work [no]? Could you say that it is necessary to have electricity for TV's to work?

Pretrials with Correct "No" Responses

1. Is it absolutely necessary for you to laugh for you to be happy?
2. Is it absolutely necessary for it to rain for it to be cloudy?

3. If someone is not an adult, can that person be smart [yes]? Could you say that it is necessary to be an adult in order to be smart?
4. If you are not inside a moving car, can you still travel quickly [yes]? Could you say that it is necessary to be inside a moving car in order to travel quickly?

APPENDIX B

VISION TRIALS FOR PARTICIPANTS

IN THE NECESSITY CONDITIONS

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Testers: There are 8 trials. Use 7 for the number of repetitions.
Trial 1. **Enter on computer numbers 1;2;5;4**
Point to the images
In order for us to see, is it absolutely necessary for something to come into the eye, go out of the eye, go in and out of the eye at the same time, or first go out of the eye and then come back in?

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
In order for us to see, is it absolutely necessary for something to come into the eye, go out of the eye, go in and out of the eye at the same time, or first come into the eye and then go back out?

A: Incoming
B: Outgoing
C: Simultaneous
D: First In, then Out

Trial 3. **Enter on computer numbers 1;2;5**
Point to the images
In order for us to see, is it absolutely necessary for something to come into the eye, go out of the eye, or go in and out of the eye at the same time?

A: Incoming
B: Outgoing
C: Simultaneous

Trial 4. **Enter on computer numbers 1;2;3;4**
Point to the images
In order for us to see, is it absolutely necessary for something to come into the eye, go out of the eye, first come into the eye and then go back out, or first go out of the eye and then come back in?

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
In order for us to see, is it absolutely necessary for something to come into the eye, go out of the eye, or first go out of the eye and then come back in?

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

Trial 6. **Enter on computer numbers 1;2;3**
Point to the images
In order for us to see, is it absolutely necessary for something to come into the eye, go out of the eye, or first come into the eye and then go back out?

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

Trial 7. **Enter on computer numbers 1;2**
Point to the images
In order for us to see, is it absolutely necessary for something to come into the eye or go out of the eye?

A: Incoming
B: Outgoing

Trial 8. Now we are not going to show you anything on the computer. In order for us to see, is it absolutely necessary for something to:

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

SCORING CRITERIA FOR WRITTEN EXPLANATIONS

IN SCHEMA-ACTIVATION CONDITIONS

1. Brain

3: Brain's function as processor, interpreter, or organizer of information is mentioned, and no incorrect function is mentioned

2: Brain's function is mentioned, but incorrect information is also mentioned

1: No mention of brain's role is mentioned, or only mention is incorrect

2. Retina

3: Correct function is mentioned, i.e. that visual image or light is inverted, cast or focused on this spot; could also describe concept of photoreceptors; no incorrect function is described

2: Either only mentions part of the function (e.g. "retina helps determine colors that you see"), or mentions correct function along with incorrect information

1: No mention of function, or only description given is incorrect

3. Optic Nerve

3: Describes correct function, that optic nerve transmits a message or signal from the eye to the brain, and gives no incorrect description; mentioning blind spot acceptable as long as above function also mentioned

2: Describes blind spot without mentioning transmission of message, or describes primary function with incorrect information

1: No mention of function or only function described is incorrect

4. Lens

3: Describes correct function, i.e. that light passes through it and is focused, and mentions no incorrect information

2: Only mentions light passing through lens without the concept of focusing, or mentions correct function along with incorrect information

1: Either gives no function or only function described is incorrect

5. Light entering the eye

3: Concept is explicitly mentioned somewhere in explanation, and no incorrect information accompanies it

2: Concept is only implicit in explanation (e.g. "light waves are sent to the retina and up to the brain"), or concept is mentioned but so is incorrect information (e.g. "light enters eye through the retina")

1: Concept is not mentioned at all

6. Light reflects off object

3: Explicit mention of light waves or rays hitting the object (book) and bouncing into the eye

2: Process of reflection not stated but necessity of light is implicit (e.g. "what I see depends upon how much light there is"), so that whether subject knows concept is ambiguous

1: Concept is not mentioned at all

7. Pupil

3: Correct function is stated, that pupil allows light into the eye, and no incorrect information is mentioned; could mention pupil changing in size according to light intensity as long as above function also mentioned

2: Describes only pupil changing in size with light intensity but does mention that pupil allows light into eye, or gives incorrect information along with correct function

1: No function given, or only description is wrong

APPENDIX D

VISION TRIALS FOR PARTICIPANTS IN CONTROL

AND SCHEMA-ACTIVATION CONDITIONS

Nonecess.Rad

Testers: There are 8 trials. Use 7 for the number of repetitions.

Trial 1. **Enter on computer numbers 1;2;5;4**

Point to the images

When we see does something come into the eye, go out of the eye, go in and out of the eye at the same time, or first go out of the eye and then come back in?

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

When we see does something come into the eye, go out of the eye, go in and out of the eye at the same time, or first come into the eye and then go back out?

A: Incoming
B: Outgoing
C: Simultaneous
D: First In, then Out

Trial 3. **Enter on computer numbers 1;2;5**

Point to the images

When we see does something come into the eye, go out of the eye, or go in and out of the eye at the same time?

A: Incoming
B: Outgoing
C: Simultaneous

Trial 4. **Enter on computer numbers 1;2;3;4**
Point to the images
When we see does something come into the eye, go out of the eye, first come into the eye and then go back out, or first go out of the eye and then come back in?

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
When we see does something come into the eye, go out of the eye, or first go out of the eye and then come back in?

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

Trial 6. **Enter on computer numbers 1;2;3**
Point to the images
When we see does something come into the eye, go out of the eye, or first come into the eye and then go back out?

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

Trial 7. **Enter on computer numbers 1;2**
Point to the images
When we see does something come into the eye or go out of the eye?

A: Incoming
B: Outgoing

Trial 8. **Now we are not going to show you anything on the computer. But tell me, when we see does something:**

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