AN ABSTRACT OF THE THESIS OF

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Title: Development of a Two-Tiered Multiple Choice Test to Measure Misconceptions in Physics Among High School Students in Thailand

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The objectives of this study were to construct and develop a two-tiered multiple-choice test for the measurement of student misconceptions in optics at the level of secondary education in Thailand, as well as to investigate the effects of gender, grade level, and type of school upon levels of student misconceptions.

Misconceptions were measured by the Two-Tiered Optics Misconception (TTOM) test instrument developed for this study. Based upon criteria-evidence, the validity or appropriateness, meaningfulness, and usefulness of inferences derived from scores obtained from administration of the instrument was demonstrated at acceptable levels. The TTOM was administered to 932 high school subjects from randomly selected all-male, all-female, and coeducational 10th through 12th grade classes in Bangkok, Thailand.

A mixed analysis of variance model was used to investigate the effects of gender, grade level, and type of school upon subject misconception scores in the field of optics. Analysis of the data revealed the following: 1) a paper-pencil test based upon a pattern of two-tiered multiple-choice questions and reasons developed for this study provided a valid and reliable measure of student misconceptions in optics at the level of secondary education in Thailand; 2) gender, grade level, and type of school did not have significant effects upon subject misconception scores among Thai high school students; 3) the subgroup school within type was found to have a significant effect upon subject misconception scores; 4) when fixed grade levels were considered for type of school, there were significant differences in misconceptions among 12th grade subjects from different types of schools; 5) certain consistent misconceptions in the area of optics, related to the properties of a converging lens, images from a plane mirror and a converging lens, light rays, regions of light travel, shadow formation, and lightning flashes, existed among Thai physics students at the level of secondary education.

Development of a Two-Tiered Multiple Choice Test to Measure Misconceptions in Physics Among High School Students in Thailand

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Redacted for Privacy

Director, School of Education

Redacted for Privacy

Dean of Graduate School

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CHAPTER 1

INTRODUCTION

In the past, science educators have assumed that students enter physics classrooms with an absence of knowledge, i.e., the "empty-vessel" theory of education, and that learning thus begins from the zero point. In accordance with this theory, students do not reflect preconceived notions of prior knowledge that would cause them to resist or to fight what they are about to learn, and thus learn only as much as may be expected of them in the new classroom. However, recent findings in cognitive research have caused a movement away from the empty-vessel theory toward "naive theories," or the supposition that students usually bring informal ideas or knowledge with them into the classrooms they enter to formally encounter the phenomena of physics (Mestre & Touger, 1989).

The informal ideas that students bring with them into the classroom have been described or defined differently. From efforts to summarize the barriers placed before an accurate conceptual knowledge of physics, a useful and common working language may be based upon the term "misconceptions" (Amir, Frankel & Tamir, 1987). Other terms that have been used to describe this phenomenon include semi-autonomous schemes (Clement, 1982), erroneous concepts (Stepans & Dyche, 1987), misunderstandings (Perkins & Simmons, 1987), preconceptions (Brown & Clement, 1987), alternative ideas (Haslam & Treagust, 1987), conceptual stumbling blocks (Narode, 1987), spontaneous conceptions (Mestre & Touger, 1989).

The term "misconception" has many definitions. Fowler and Jaoude (1987) defined misconception as an inaccurate understanding of a concept, the misuse of a concept name, the incorrect classification of concept examples, confusion between differing concepts, improper hierarchical relationships, or over- or under-generalizing of concepts. Wandersee (1985) defined a misconception as a concept often used to describe an unaccepted (though not necessarily "incorrect") interpretation of a concept by the learner. Duit (1987) stated that "misconceptions are conceptions which are incorrect viewed from the standpoint of science" (p. 154). For the present study, the definition provided by Narode (1987) is sufficiently comprehensive to provide practical and useful guidelines:

> Misconception is a person's conceptualization of a problem or phenomenon that generally is reasonable to themselves but at variance from the conceptualization of an "expert" in the field from which the problem came. (p. 322)

Abimbola (1988) stated that the problem of selecting the most meaningful and useful terminology to define misconceptions remained unresolved even after a conference on misconception was held at Cornell University in 1983. Science educators placed themselves within two differing perspectives of conceptual change or terms. Advocates of the "revolutionary" perspective defined misconceptions as misunderstandings or erroneous ideas, whereas those who favored the "evolutionary" perspective preferred the use of the terms existing concept, preconceptions, alternative framework, or alternative conceptions. Subject to even further division, the term "alternative conception" was regarded to be more inclusive than "alternative framework" and had gained wider application.

For purposes specific to the present study, the practical focus for a concept of misconceptions is adapted from Narode (1987): Individual conceptualizations of a problem or phenomenon of optics that are self-evidently reasonable, but which differ from conceptualizations established by "experts" in the field of optics.

During the last three decades, misconceptions in science have been extensively investigated and have been reported to exist among students in many grade levels in the United States (Bar, 1987; Brown & Clement, 1987; McDermott & Goldberg, 1986), and as well in South Africa (Helm, 1980), Nigeria (Adeniyi, 1985; Ivowi, 1984), the Netherlands (Bouvens, 1987), India (Mohapatra, 1988), Australia

(Haslam & Treagust, 1987), Taiwan (Dai, 1991), and Thailand (Sangsupata, 1976, 1984). Predominantly, investigations of the existence and nature of these misconceptions has been conducted in the field of physics, but in recent years there has been a considerable increase in studies in the fields of biology and chemistry as well as in those areas of physics, including force and movement, that received relatively little attention in the past (Duit, 1988).

At the same time, during at least the past decade, it has become evident to educators in Thailand that many Thai high school students completed physics courses without developing an adequate understanding of the concepts and theories which they had been taught. One of the results of the identification and investigation of this problem has been increased focus upon student misconceptions in relation to physics. This problem has in the past been cloaked by several factors specific to the Thai educational setting, including problems in the identification of student cognitive stages of development, the widespread habit of learning textbook information by rote memorization, and a focus upon teacher-centered learning. The result is that research information on student misconceptions in Thailand is not readily available, and an instrument for the analysis of patterns of misconception in physics has not been developed. Thus, there is a need to develop a valid and reliable instrument for the analysis of Thai student misconceptions in physics.

Theoretical Framework and Rationale for the Study

The theoretical framework for the proposed study was derived from six areas of inquiry: a) existence of misconceptions, b) constructivism and misconceptions, c) measurement of misconceptions, d) consideration of related variables, and d) Thai students and the educational system.

Existence of Misconceptions

Misconceptions about scientific principles are widespread and have a tenacious hold on student patterns of thinking (Ridgeway, 1988). Bodner (1986) stated that the misconceptions that students bring into science and mathematics classes are remarkably resistant. Moreover, misconceptions interfere with ability of students to understand concepts presented in the classroom (Mestre & Touger, 1989). Halloun and Hestenes (1985b) stated that:

> if such misconceptions are not corrected early in the course, the student will not only fail to understand much of the material, but worse, he is likely to dress up his misconceptions in scientific jargon, giving the false impression that he has learned something about science. (p. 1048)

Driver (1981) had found that many students passed science courses without acquiring adequate understanding of their underlying concepts and theories. Idar and Ganiel (1985), who examined learning difficulties in physics among Israeli high school students, found that preconceptions affected ability to learn.

Duit (1988) stated that among students, alternative frameworks (i.e., misconceptions) were frequently found in the field of physics (Idar & Ganiel, 1985). Misconceptions among students had been determined to exist at the elementary level (Bar, 1987; Dai, 1991; Stavy, 1991), the secondary or high school level (Brown & Clement, 1987; Bouvens, 1987; Helm, 1980; Ivowi, 1984; Ivowi & Oluotun, 1987; Mohapatra, 1988; Shepherd & Renner, 1982; Stepans, Beiswenger, & Dyche, 1986), and at the college or university level (McDermott & Goldberg, 1986; Smith, 1987).

The preference topics of cognitive researchers were force and motion, but investigations of misconceptions in optics had been conducted for light, light propagation, vision, and color. McDermott and Goldberg (1986) examined problems in understanding image formation by plane mirrors among physics students at the University of Washington. Bouvens (1987) used a multiple choice test designed for a rating scale format to investigate misconceptions regarding geometric optics among high school students, and Mohapatra (1988) investigated misconceptions regarding the second law of light reflection. Thus, research findings indicated that physics misconceptions existed at all educational levels. In addition, Treagust (1988) and Haslam and Treagust (1987) determined that parallel misconceptions could be found to exist in the fields of, respectively, chemistry and biology.

Constructivism and Misconceptions

Constructivism, the lineage of which can be traced to Immanuel Kant through an early 20th century German philosopher of science, Hugo Dingler (Butts & Brown, 1989), became a prominent educational approach during the early 1980s. Bodner (1986) stated since Piaget's theory that knowledge was constructed in the minds of learners was based upon actual research in how children acquired knowledge, Piaget (1974) should be identified as the first constructivist. Piaget stated that knowledge was acquired as the result of a life-long constructive process in which we organize, structure, and restructure our experiences in light of existing schemes of thought, thereby gradually modifying and expanding upon these schemes. Thus, from the concept that "knowledge can be transferred intact from mind of the teacher to the mind of the learner," the constructivist model focused rather upon the learner; that is, "knowledge is constructed in the mind of the learner" or "knowledge is assumed to fit reality the way a key fits a lock." (Bodner, 1986, pp. 874)

From the point of view of science, the constructivist model helps to explain why students bring misconceptions that are remarkably resistant to instruction into chemistry, physics, and mathematics classrooms. Science educators have sought to reduce misconception in a variety of ways, including the use of computer programs in the classroom (Brown & Burton, 1978; Brown & Vanlehn, 1980; Stewart, Streibel, Collins, & Jungck, 1989; Tatsuoka, 1983). However, changes in the technology of classroom instruction have seemingly had little effect upon the nature of student misconceptions. Bodner (1986) stated that simply telling students that they were wrong was not sufficient to modify the degree to which students could overcome their misconceptions. Driver (1981) maintained that in the absence of knowledge of student misconceptions prior to entering the classroom, even well-prepared and effective teaching would not assure that all students would absorb new and correct concepts.

In the constructivist approach, human learning is viewed as a process in which the learner actively constructs knowledge based upon the application of existing conceptions (Duit, 1989). Based upon this model, the most feasible means to replace prior misconceptions is to construct new concepts that provide more appropriate explanations of individual experience and/or knowledge (Bodner, 1986). From classroom observations, Narode (1987) determined that student misconceptions must be addressed and overcome before more accurate conceptual understanding could be attained. This was the approach adopted by Dai (1991), who found evidence to support the need to diagnose student misconceptions before any specific teaching strategy could be successfully adopted for the classroom.

Measurement of Misconceptions

Since the mid-1970s research interest in student conceptions in science has increased to the extent there has been a conjunction of interests in the role of preconceptions upon ability to learn between the otherwise separate fields of science education and cognitive psychology (Duit, 1988). Science educators have sought to determine the nature of the principal preconceptions which influence students' pathways to accepted scientific knowledge. From a basic and general point of view, the interest of cognitive psychologists is directed toward the role of preconceptions in the learning and problem solving processes.

Since this conjuncture of interests, standard psychometric procedures have been employed by science educators for the investigation of student preconceptions or misconceptions. The usual means to obtain information about student misconceptions has been through individual student interviews and/or responses to open-ended questions about specific scientific topics. While interviews can be a fruitful means to provide in-depth information about the state of student misconceptions (Trembath, 1980), it is time-consuming process that provides which are difficult to categorize or evaluate by statistical methods. Moreover, the process requires substantial training and must be limited to small groups of students (Amir et al., 1987; Haslam & Treagust, 1986; Treagust, 1987). Thus, interviews are not a convenient means for use by instructors within classrooms.

The use of open-ended short essays allows students to express their ideas freely, but for reason of this same freedom of expression are also difficult to assess. Moreover, in an open-question format, language difficulties interfere with the identification of real misconceptions (Bouvens, 1987). One alternative that teachers can use to identify student misconceptions is to administer a pencil-and-paper multiple choice test, wherein items are specifically designed to identify misconceptions within a limited and clearly defined content area (Haslam & Treagust, 1986).

Multiple Choice Testing

Multiple choice testing has been a long-established and even dominant technique of evaluation. Accompanying growth in emphasis upon the development of intellectual skills and the mastery of major principles, as replacements for the principle of education by rote memorization, multiple choice test items have been designed to measure factual knowledge as well as to assess various higher cognitive abilities (Tamir, 1971; West & Pines, 1985). Specific to the present study, Amir et al. (1987) stated that "carefully constructed multiple choice items are by themselves efficient in corroborating our knowledge about existing misconceptions. Bar (1987) reported that misconceptions that were rarely detected from either oral or written open-ended test essays, had been recorded in considerably high percentages in the multiple choice tests.

Ease of administration, accompanied by the use of objective scoring procedures, has been an inducement for researchers to develop multiple choice test measures of formal reasoning ability and misconceptions (Tobin & Capie, 1981). Thus, multiple choice tests to measure student misconceptions in the classroom have been constructed and administered as reported in the conference on misconception at Cornell university. The regular pattern of questions presented for science misconception test formats has been based upon either four or five optional responses (Dai, 1991; Doran, 1972; Fisher, 1985; Griffiths, Thomey, Cooke, & Normore, 1988; Helm, 1980; Ivowi, 1984; Lawson & Weser, 1990; Linke & Venz, 1979; Stavy, 1991; Wandersee, 1985) or upon two-tiered tests (Haslam & Treagust, 1987; Treagust, 1988).

Two-Tiered Multiple Choice Testing

When measuring logical thinking and misconceptions, it is difficult to assure that subjects use formal reasoning abilities to solve the various test items. Thus, the necessity that subjects justify problem solutions has been a characteristic of clinical procedures that has not been generally incorporated into pencil-paper tests. Therefore, Lawson (1978) and Lawson, Adi and Karplus (1979) employed this technique as the basis for the development of a two-tiered multiple choice test in which subjects were required to provide written justifications for problem solutions.

Tobin and Capie (1981) used the same procedure to develop a multiple choice measure of logical thinking abilities, establishing construct-related evidence for validity. Subjects were asked to select a correct response from a number of alternatives, and then to provide written justification of their selection. From the results of test administration, it was determined that many high school students were unable to formulate clearly written justifications for the selection of particular responses. Thus, the test was modified to include multiple justification options as well as multiple solutions for each problem. A correct solution then required selection of the correct response and the best justification for that response. Consequently, the two-tiered test represents the techniques of both the subjective test (i.e., the clinical interview) and the objective test (i.e., the multiple choice test).

According to Haslam and Treagust (1987) and Treagust (1988), the two-tiered test is based upon a multiple choice format, consisting of problem and lists of suggested solutions. In turn, the list of suggested solutions consists of two parts or tiers, the first of which for each item is a multiple choice content question with from two to three response choices. The second part contains a set of four possible reasons for the response given to the first part. The reasons consist of the correct answer, one or more identified misconceptions, and frequently a clearly incorrect reason. The second part was developed from student responses to open-ended questions, as well as from information gathered from the interviews and the literature of testing procedures.

Tamir (1989) stated that the advantages of a two-tier item, with respect to traditional multiple choice, consisted of the following:

> 1) It provides all the benefits of an objective item, such as quick, easy, and even desired machine scoring, economy of response time, it is not dependent on students' writing skills, and 2) it enables the inclusion of specific misconceptions and provides detailed information about the frequency distribution of these misconceptions in a given student population.

Although the two-tiered multiple choice test based upon the integration of objective and subjective test procedures has been considered to be an appropriate alternative for the determination of misconceptions in science (Haslam & Treagust, 1986; Tobin & Capie, 1981; Treagust, 1988), a valid and a reliable two-tiered multiple choice test for the determination of the effect of misconceptions in physics education has not been previously developed or tested.

Validation of Test Instruments

Although multiple choice tests have been widely used to diagnose scientific misconceptions, the reliability and the validity of only a few studies using paper-and-pencil methods have been reported. Helm (1980) claimed criterion referenced validity and internal consistency for his instrument, while Adeniyi (1985) reported an acceptable level of validity for an essay test method. From clinical interviews, Wandersee (1985) reported test validity and a reliability coefficient of 0.62.

Four research investigations have included reports on the process of instrumental development. Bouvens (1987) used factor analysis to categorize test items, and reported acceptable reliability and Pearson *r*-correlation coefficients. Dai (1991) reported acceptable reliability and validity as well as item discrimination and item difficulty for a test instrument based upon a multiple choice pattern. Haslam and Treagust (1987) established the validity of 13 two-tiered items, formulated in consultation with five experienced secondary biology teachers, two science educators, and two college biology lecturers. Moreover, the Cronbach's coefficient alpha, difficulty indices, and discrimination indices were also reported favorably. Hsiung (1989) constructed a 22-item two-tiered test for physical science and reported that the instrumental had been established as reliable, with acceptable difficulty and discrimination indices, but did not report that the validity of the instrument had been determined. Thus, review of the literature revealed that a valid and reliable two-tiered multiple choice test instrument was not available in the field of physics or in the specific subject area of optics.

Consideration of Related Variables

A number of variables have been investigated for the possible degrees of influence they exercise upon student misconceptions in science. These variables have been considered in two basic categories, including classroom or source of misconceptions variables and surroundings variables. Classroom variables which have been investigated include textbooks (Barrow, 1990; Cho, Kahle & Nordland, 1985; Stepans et al., 1986), instruction (Benbow, 1988; Rogan, 1988; Smith, 1988; Wells, 1988), and instructors (Ivowi & Oludotun, 1987; Nussbaum, 1981). The surroundings variables include gender, age or grade level, type of school, and home background.

Research results for the second category have proved inconsistent. For example, neither Zerega, Haertel, Tsai, and Walberg (1986), Tobin and Garnett (1987), Lucas (1988) Becker (1989), or Jones (1991) found significant effects for gender in the case of science achievements. However, Bouvens (1987) found that gender had a significant effect upon misconceptions, but Haslam and Treagust (1987) found that gender had a significant effect upon misconceptions. Za'rour (1975) found that gender had a significant effect upon misconceptions only at the 11th grade level. The subjects of three types of investigations were high school students. In addition, when Dai (1991) examined the effect of gender upon lunar misconceptions among the elementary school students in Taiwan, she found that gender had no effect upon student misconceptions. The findings of these studies have resulted in speculation that differences in school levels and subject areas may have been a contributory cause to different effects by gender.

Differences have also been established for grade level Doran (1972), Haslam and Treagust (1987), Wandersee (1987), Dupin & Johsua (1988), and Stavy (1990) observed that student age/grade level had effects upon student misconceptions, whereas Westbrook (1988) reported negative effects for grade level. For the school type variable, Bouvens (1987) and Shepherd and Renner (1982) found that the type of school (i.e., a general high school or a preuniversity high school) had an effect upon misconceptions, whereas Dai (1991) reported there was no significant effect upon lunar misconceptions for student background (i.e., religious or nonreligious).

Thai Students and the Educational System

The educational system in Thailand consists of preschool, elementary, secondary, and higher education levels. Compulsory education is provided for all Thai students from the elementary level through the age of 14 years. Secondary education is divided into lower and upper levels, each consisting of three grades. Lower secondary consists of grades 7-9 and the upper level consists of grade 10-12. Approximately 50 percent of all Thai students, especially students from rural areas or from low income families, elect to leave school at the end of the 9th grade (Chantavanich & Fry, 1981).

There are three types of secondary schools in Thailand: schools exclusively for either males or females and coeducational schools. Although, the educational system and all schools are organized and administered by the Ministry of Education, there is significant competition among schools for reason of an entrance exam system. The number of students that secondary schools qualify for entrance into public universities is considered as a demonstration of school quality. For the greater part, qualified students usually come from the single-sex schools (Chantavanich & Fry, 1981).

Physics is the core subject of secondary science programs, and it has traditionally been difficult for students to demonstrate mastery of the subject to the extent that performance can be used to predict overall examination success. Recently, the number of high school students enrolled in science programs who have change enrollment to alternative programs has increased, largely due to the difficulty of successfully completing courses in physics. A variety of tools or methods to increase students' chances of success in physics have been investigated by Thai science educators. It has been found that science misconceptions are among the factors which may have an effect upon students' success in science (Sangsupata, 1984).

Summarization of the Theoretical Framework

From consideration of the theoretical framework for the present study, the following have been established:

1) Misconceptions in science and in the field of physics have been found to exist among students at all levels through secondary education (Bar, 1987; Bouvens, 1987; Brown & Clement, 1987; Dai, 1991; Helm, 1980; Ivowi, 1984; Ivowi & Oluotun, 1987; McDermott & Goldberg, 1986; Mohapatra, 1988; Shepherd & Renner, 1982; Stepans et al., 1986; Smith, 1987; Stavy, 1991).
2) Review of the principles of constructivism suggests that the diagnosis of previous misconceptions prior to the construction of appropriate or new educational concepts will effectively serve to reduce the persistence of misconceptions.
3) Misconceptions can be measured by means of either clinical interviews or paper-pencil testing methods (Bouvens, 1987; Dai, 1991; Doran, 1972; Fisher, 1985; Griffiths et al., 1988; Haslam & Treagust, 1987; Helm, 1980; Ivowi, 1984; Lawson, 1978; Lawson & Weser, 1990; Linke & Venz, 1979; Mohapatra, 1988; Stavy, 1991; Tobin & Capie, 1981; Treagust, 1988; Wandersee, 1985).

4) The use of two-tiered multiple choice testing provides an effective instrument for the measurement of misconceptions among students. However, a valid and reliable instrument has not developed for the area of optics in the field of physics education (Bouvens, 1987; McDermott & Goldberg, 1986; Mohapatra, 1988; Watt, 1985).

5) Examination of gender, grade level, and type of school variables have revealed inconsistent effects upon student misconceptions. It has been stated that these effects are perhaps dependent upon subject area as well as educational level, and that further investigation should be conducted to determine interactions among these factors.

6) The structure and traditions of science education in Thailand are such that student misconceptions are a possible source of student lack of success in science programs and declining student enrollments in these programs.

Significance of the Study

The procedures developed for the present study and the results obtained have provided benefits to science education in Thailand, as follows:

1) In science education, it is necessary to develop the means to allow instructors to assess student misconceptions in physics as well as in other

science disciplines. Teachers must begin to recognize misconceptions at an early stage since once misconceptions have become fixed in students' minds, they have proved difficult to correct and to change. This study provides a valid and reliable test for the identification of student misconceptions in the area of optics as a field of physics education.

2) The two-tiered multiple choice test developed for the present study can be applied to assess students' prior misconceptions about optics by both inservice and preservice teachers. Once misconceptions are diagnosed, teachers will be able to take remedial action to counteract their effects, employing effective instructional techniques based upon the problems identified.

3) Finally, the present study provides a pattern for the development of a two-tiered multiple choice based upon item analysis procedure. Development of a valid and reliable instrument supplements materials available for inservice teacher workshop programs. This contribution will encourage the development of new views of science instruction and of curriculum development in Thailand.

Statement of the Problem

The purpose of the present study is two-fold. The primary purpose is to develop a valid and a reliable two-tiered multiple choice test to measure the effects of misconceptions about optics in the field of upper secondary physics education in Thailand. This instrument will be identified as the "Two-Tiered Optics Misconception Test" (TTOM). The secondary purpose is to investigate the effects of a number of variables upon misconception scores, determining whether significant differences existed among the three types of schools from which the study population is selected.

Variable Factors

For the present study, the following factors were considered for their effects upon student misconceptions about optics in science education in upper secondary schools in Thailand.

Gender

Klainin, Fensham, and West (1989), in a study of physics achievements among high school students, found that female performances exceeded those of males. These results differed from the findings established in non-Asian countries. Due to these findings as well as inconsistent findings for the effect of gender from the previously conducted research, gender was investigated to determine its effect upon student misconceptions.

Grade Level

In his theory of cognitive development, Piaget (1974) stated his belief that cognitive and intellectual changes were the result of a developmental process consisting of a coherent process of successive qualitative changes in cognitive structures, or "schemata," changes to which were derived logically and inevitably from preceding structures. Thus, new schemata do not replace prior schemata, rather they incorporate them into new, qualitative, and cumulative logical changes (Wadsworth, 1979).

However, it has been determined that some students remain in an earlier stages (e.g., the concrete operational stage) throughout their school years, and even throughout their lives (Woolfolk, 1990). The first three stages of cognitive development, the sensori-motor intellectual, pre-operational, and the concrete operational, are forced upon most individuals by physical realities (Neimark, 1975), but the following stage, the formal operational, is not so closely tied to the physical environment. Neimark speculated that the last stage may be "a refinement of an advanced culture rather than a necessary condition for survival" (p. 556). Piaget (1974) suggested that most adults may be able to use formal operational thought in only a few areas, those in which they have the greatest experience or interest.

In this sense, science and mathematics are subjects which are particularly likely to require formal operations, especially in physics area: The formation and mental testing of hypotheses are important aspects of physics, and neither is free of misconceptions. Insofar as the stage of cognitive development of students may have an effect upon the existence of misconceptions, grade level (and indirectly, age in years) was examined to determine possible relationships to misconceptions in the science of optics.

Type of School

From previously conducted research, conclusions with respect to types of school in relation to misconceptions have been inconsistent. Therefore, based upon the assumption that enrollment in either male, female or coeducational institutions would have no effect upon misconceptions, type of school was a variable considered for the present study.

Methodology of Instrument Development

When tests are to be interpreted as measures of selected attributes or qualities that are not operationally apparent, the need to establish construct-related evidence for validity is implied. This safeguard provides a means to avoid the frustration of relating the data derived to each of the criterion considered (Cronbach & Meehl, 1955) as well as a framework for the development of an instrument. Insofar as this approach to instrumental validity has not been apparent in previously conducted research on the effect of misconceptions in science education, it has been adopted for the construction of the instrument prepared for the present study.

The methodology for the establishment of construct-related evidence for validity consisted of the definition of misconceptions, selection of the knowledge statements to match the definitions, consultations with an expert panel, as well as item analysis to determine internal consistency, determination of known-group differences, and interviews with a random sampling of subjects.

Assumptions for the Study

From the following assumptions, that:

1) prior misconceptions exist among optics students in secondary education in Thailand,
2) misconceptions among optics students in secondary education in Thailand may be measured by development and testing of a reliable and valid two-tiered multiple choice instrument,
3) gender, grade level, and type of school have no effect upon the existence of misconceptions among optics students in secondary education in Thailand, and

4) development of a reliable and valid two-tiered multiple choice instrument will provide knowledge that may be used to reduce misconceptions in science, as well as contribute to effective teaching and curriculum development in secondary education in Thailand,

the present study has been based upon the basic assumption that student achievements are inversely related to levels of misconception.

Research Hypotheses

For TTOM test scores among optics students in secondary education in Thailand, the following null hypotheses will be analyzed:

1) There will be no differences among types of schools (male, female, and coeducational);
2) There will be no differences among schools within types of schools;
3) There will be no differences among subjects for grade level (10th through 12th grades);
4) There will be no interaction effect between grade level and type of school;
5) There will be no interaction effect between grade level and schools within types of schools;
6) There will be no differences among 10th grade subjects for type of school;

7) There will be no differences among schools within type for 10th grade subjects;

8) There will be no differences among 11th grade subjects for type of school;

9) There will be no differences among schools within type for 11th grade subjects;

10) There will be no differences among 12th grade subjects for type of school; and

11) There will be no differences among schools within type for 12th grade subjects.

12) There will be no differences for grade level among coeducational schools;

13) There will be no differences for gender among coeducational schools; and

14) There will be no interaction effect for grade level and gender among coeducational schools.

Limitations of the Study

The present study is limited to:

1) Secondary school science students in Bangkok, Thailand, and

2) Selected misconceptions within the secondary school physics curriculum in Bangkok, Thailand.

Definition of Terms

The following definitions are relevant to the present study. Other terms or phrases used in this report are considered to be self-explanatory.

High academic achievement students: Students enrolled in 12th grade science programs, each of whom have achieved grade point averages above 3.5 (A=4.0).

High school students: Thai secondary school students attending grades 10 through 12 who are enrolled in science programs.

Low academic achievement students: Students enrolled in 12th grade non-science programs, each of whom have achieved grade point averages between 2.00 and 2.75 (A=4.0).

Misconception: Individual conceptualizations of a problem or phenomenon that are self-evidently reasonable, but which differ from expert conceptualization within the field from which the problem is derived (Narode, 1987).

Physics misconceptions: Misconceptions related to knowledge of optics composition and the structure of phenomena.

Schools within a type: Individual schools within each type, including four coeducational schools, and two each exclusively male and female schools.

Two-tiered multiple choice test: Multiple choice test format consisting of problems and a list of suggested solutions based upon two tiers. The first tier consists of choices of multiple choice responses in relation to individual questions; the second tier consists of multiple choice explanations of responses provided in the first tier (Treagust, 1988).

Types of schools: Either exclusively male or female schools or a coeducational school.

Organization of the Study

This study is presented in four additional chapters. Chapter 2 includes a review of the literature and the methodologies for the develop of the instrument and procedures for testing the hypotheses are summarized in Chapter 3. Chapter 4 summarizes the gathered data, and presents the results of data analyses. Chapter 5 concludes study with a summary, discussion of the results, conclusions, and recommendations for practice use of the instrument and future study.

CHAPTER 2

LITERATURE REVIEW

The purpose of this chapter is to review the literature pertaining to: 1) physics misconceptions among student subjects, 2) misconceptions specific to the study of optics, 3) other research related to the present investigation, 4) development of measurement instruments, and 5) test validation.

Physics Misconceptions Among Students

Za'rour (1975) investigated science factual misconceptions among selected groups of students in Beirut, Lebanon. The subjects were 1,444 9th and 11th grade students and university students, including 130 American 11th grade students from the American Community School, a part of the Lebanese educational system. A 40-item multiple choice test, for which reliability was not reported, was developed and administered, composed equally of questions from the physics area and a distribution among the earth and space sciences.

For physics results reported, distractors, selected by percentages greater than the expected (at the .05 level of significance) chance scores for each class, were labeled misconceptions and *t*-tests were used to test for significance. A Pearson's *r* was calculated between test scores for correct test responses and the science grades of the secondary students and verbal and quantitative scores for the Scholastic Aptitude Test (SAT) of 11th grade subjects from the American Community School. By these means, 20 distractors were labeled misconceptions (Za'rour, 1975).

Between the ninth grade subjects and the university group, there was a significant decrease in nine cases, an increase in one case (i.e., the weight of an object at the North Pole when compared to its weight at the equator is smaller), and no significant change in the remaining 10 items. The female held more misconceptions with percentages significantly higher than those of the males only at the 11th grade level, but there was little difference by gender for either the 9th grade and university subjects. There was no significant difference between types of schools (the American Community School and Lebanese schools), through different items were misconceptualized in each group. It was concluded that those differences could have been due to cultural differences and/or the use of different curricula and methods of teaching. The correlation coefficient between correct response scores and science grades were .51 for one school and .27 for the other, and the verbal and SAT scores were .41 and .68, respectively (Za'rour, 1975).

Helm (1980) conducted research on misconceptions in physics, sampling 460 South African physics students at levels 9 and 10, and 65 science and mathematics teachers. The instrument was a 20-item misconception test based upon multiple choice questions with four alternatives, as modified from an original test developed in 1975, and for which validity, criterion reference, and internal consistency were indicated. Results were expressed as percentages for the analysis of groups selecting particular options. From the test results, it was apparent that physics misconceptions were widespread among both South African students and teachers.

Shepherd and Renner (1982) measured understanding of concepts of matter and density in elementary schools placed in either middle or junior high schools. Subjects consisted of 74 and 61 students from, respectively, the 10th and 12th grades in three Oklahoma schools enrolled in English classes. The essay format instruments used were designed to evaluate the degree to which responses (i.e., "sound understanding") could be related to textbook answers. The acknowledged weaknesses of this format included: 1) the abstraction of key response ideas for evaluation against prototype answers derived from approved textbooks, and 2) an insufficient number of subjects.

Evidence was not presented that the two samples were similar with regard to other relevant variables. Although this research pattern reflected a number of errors, the reported results indicated that understanding of the two concepts tested has not been improved by schooling. From these results, it was inferred that misconceptions tend to persist, supporting the assumption that what schools think they are teaching students is not necessarily what is being learned (Shepherd & Renner, 1982).

Osborne and Cosgrove (1983) investigated conceptions of the changes of states of matter among subjects ranging from 7 to 17 years of age in coeducational and single-sex schools. Test procedures were based upon individual interviews and completion of a test instrument, wherein the results of the interviews were used to construct a paper-and-pencil survey. Interviews were conducted by an "interview-about-events" method and were taped. How the paper-and-pencil test was developed and its reliability were not reported, in addition to which information on how the tapes were analyzed was not presented.

Survey data were collected from tests administered to 725 subjects and were summarized in graphic form. Each point of view was plotted by percentage of responses and the age of subjects. Findings revealed that older students held views similar to those of younger students. Although views tended to change with age, some nonscientific ideas were more popular among older subjects than among younger subjects. In addition, it was determined that the subjects brought strongly held views into science classes, which views could either remain uninfluenced or could be influenced in unanticipated ways by science teaching (Osborne & Cosgrove, 1983).

Ivowi (1984) conducted an investigation similar to that reported by Helm (1980), in this case among Nigerian secondary school students aged 15-17 years and physics teachers in eight secondary schools. Selected multiple choice items (12) were modified from those of Helm, and the addition of new options was adjusted to the required format (i.e., the Ivowi test used five options, compared to four choices in the Helm test). Chi-square analysis was used to present selection frequency of particular options among both students and teachers, using a *t*-test to determine statistical differences. The results obtained from the administration of both 20-item tests were similar, from which it was apparent that physics misconceptions were as widespread among Nigerian secondary school students as they had been among previously tested South African students.

Halloun and Hestenes (1985a) examined common sense concepts of motion among college students enrolled in physics courses. A multiple choice mechanics diagnostic test was administered and interviews were conducted with a sample of 22 subjects within one month following administration of the tests. The test, consisting of questions readily classified as characteristic of either Aristotelian, Impetus, or Newtonian theories, was administered to 478 subjects enrolled in university physics classes at the beginning and at the end of the semester.

Comparison of pretest and posttest results indicated that some beliefs were decreased, while others were consistently held. Interviews with the sample of 22 subjects, accompanied by classroom demonstrations, were used to probe common sense beliefs more deeply. From interview results, it was apparent that the demonstrations had no more effect upon subjects' opinions than standard discussions of phenomena. It was suggested that demonstrations would not be effective unless performed in a context that elicited and helped to resolve conflicts between common sense and specific scientific concepts. After sustained discussions, subjects who had demonstrated obstinately incorrect beliefs were generally able to admit error as the inconsistency of their thinking was brought to their attention when they were asked to reflect on their own arguments (Halloun & Hestenses, 1985a).

Halloun and Hestenses (1985b) also surveyed the initial knowledge state of college physics students, using two multiple choice test. For pretest procedures, a physics diagnostic test was used to assess student qualitative concepts of common physical phenomena and to identify common misconceptions, whereas a mathematics diagnostic test was used to the student's mathematical skills. The mechanics (physics) diagnostic test, devised from a written-answer version, was used as a posttest to measure the effect of instruction.

The test development procedures were subject to the judgment of physics professors and graduate students (the total numbers were not reported). The test, as based upon interviews with 22 introductory physics students and observation of the answers of 31 students who received "A" grades in university physics, was administered to 11 graduate students to determine correct answers. By Kuder-Richardson coefficients, the reliability of the mechanics test was 0.86 for the pretest and 0.89 for the posttest (Halloun & Hestenses, 1985b).

The mathematics diagnostics test was revised from a written test of the first version and was judged by experienced physics instructors. Test reliability, without comment on the number of items or how the expert advice was used, was reported at 0.86 by the Kuder-Richardson formula. Results indicated that subjects' initial knowledge had a large effect upon performance in physics, but that conventional instruction procedures provided only comparatively small improvements in basic knowledge. Low physics test scores did not mean that basic concepts of Newtonian physics were missing, but that alternatives misconceptions about mechanics were firmly in place. It was stated that if misconceptions were not corrected early in the course, students would not only fail to understand much of the material, but would also be likely to dress up existing misconceptions in scientific jargon while providing the false impression that something had been learned about science (Halloun & Hestenses, 1985b).

Maloney (1986) sought to identify student problem-solving strategies for the evaluation of the effectiveness of a physics course in correcting erroneous strategies. Physics-current in a series circuit was used as the basis of study. Subjects, not identified by number, consisted of sophomores and juniors in college enrolled in algebra-based general physics. The researcher assessed student problem-solving strategies by means of a single ranking task and a task set consisting of 24 items, for which reliability was not reported. For the single task, subjects were requested to rank six simple series circuits. The specific resistance values of the circuit components were selected so that subject choices of a particular circuit ranking would reflect specific problem-solving strategies. Moreover, subjects were asked to explain their reasoning for solution of both the ranking task and the task set. Task performances were based upon both pre- and post-instruction. Results were reported in percentages, and it was found that more than half of the subjects used strategies that focused upon solutions based upon scientific misconceptions. However, the failure to access reliability for the test left even these results in doubt.

Brown and Clement (1987) used a multiple choice diagnostic test to determine misconceptions about Newton's third Law among 50 subjects from two high schools. The test was designed to appear as a rating scale, and was administered at the beginning of the year following instruction in mechanics. Instructors were not made aware of test contents since the subjects were asked to rate how confident they were in their answers. Options included a blind guess, not very confident, fairly confident, and completely confident. The process of instrumental development and scoring were not reported.

Results, expressed as percentages, indicated that high school students entered physics class with preconceptions in the area of Newton's third law. These preconceptions were not only persistent, but were also determined to be difficult to overcome by administration of traditional instructional techniques. The persistence of preconceptions may have resulted from the subjects' generally naive view of force as a property of a single object, rather than as a relation between objects. Since the number of subjects for this study was small, no generalized conclusions were provided (Brown & Clement, 1987).

Treagust (1987) administered a multiple choice test to measure student misconceptions among students of chemistry, biology, and physics. The subjects were 243 chemistry students from the 11th and 12th grades, 441 biology students from the 8th through 10th grades, and 113 physics students from the 10th grade. The instrument was designed as a two-tiered multiple choice test, the first tier based upon propositional statements answered by multiple choice options.

For the second tier, subjects were asked to select an option for their first tier option from a multiple choice list of reasons. It was reported that the instrument was validated by subject matter experts and educators, but reliability results were not indicated. Findings indicated that two-tiered multiple choice tests could be used to determine student misconceptions, but that this information could not be adapted easily by classroom practitioners.

Finegold and Tamir (1990) investigated physics curricula in Israel, as sponsored by the International Association for Educational Evaluation (IEA). Subjects from the 9th and 12th grades were administered the International Test for Assessment of Achievement. Results were reported as percentages of correct and incorrect answers, and demonstrated that subjects, even at the university level, reflected misconceptions that tended to diminish as the subjects increased in age.

Misconceptions About Optics

McDermott and Goldberg (1986) examined problems in understanding image formation from plane mirrors to determine the extent to which students connected formal concepts to real world phenomena. Individual demonstration interviews were used since the purpose was to determine student thought patterns. The instrument consisted of a set of four tasks, performance of which required subjects to predict how images were perceived under different circumstances, and then to provide explanations for their predictions. The subjects were students enrolled in introductory physics classes at the University of Washington, one-half of whom (i.e., 30) were interviewed prior to the start of a geometrical optics course and the remaining half interviewed following completion of a geometrical optics course.

Doubt about the accuracy of the findings was expressed insofar as two subjects were not examined for similarities, and reasons were not provided why only one-half of the subjects were interviewed. To examine the consistency of answers, group demonstration questionnaires were administered to an entire class (n=172) prior to start of the course. The number of items and the questionnaire format (i.e., rating scale or multiple choice) was not reported. Results revealed that the pattern of responses to the questionnaires and interviews were nearly identical. It was concluded that the use of individual demonstration interviews allowed the identification and the description of several of the problems students encountered (McDermott & Goldberg, 1986).

In the Netherlands, Bouvens (1987) administered a multiple choice test in a format similar to that of rating scales, investigating misconceptions regarding geometrical optics. In the pilot study, previous studies, interviews with preuniversity students, and the historical development of optics were examined. This experience was used to identify misconceptions for the development of the questionnaire. The 42 test items were designed for a five-point scale, and subjects were asked to determine right and wrong answers. Factor analysis was used to categorize the items.

Five variables, including school year, school type, gender, age, and curriculum, were investigated. Significant differences in subject misconceptions were determined by *t*-test (reliability = 0.79). Subjects consisted of 639 pupils from five schools, including general and preuniversity high school students. Results indicated the existence of misconceptions among subjects from both the general and preuniversity high schools for vision, interactions with surfaces, and image formation. There were no significant differences in the number of misconceptions by gender, rather the number of misconceptions was determined to be dependent upon the type of school and the number of years that the subjects had studied in school. It was also determined that misconceptions were not related to age group, and that improvement in the understanding of geometrical optics was due to educational effects and not to the higher abstraction level abilities of older students (Bouvens, 1987).

Mohapatra (1988) studied generative causation of misconception "Induced Incorrect Generalization" (IIG) in Indian schools, based upon a qualitative design. It was hypothesized that if the IIG phenomenon affected a group simultaneously, it would contribute to group misconceptions. Research was focused on science classroom teaching.

Since the study format required students who had completed 10 years of school, 200 students in grades 11 and 12 between the ages 15 to 16 years were selected as subjects. The formal concept tested involved the second law of light reflection and was based upon personal interview methods. Conversations with subjects were recorded and analyzed. It was observed that the student learning was based upon incorrect generalizations which could differ significantly from formal concepts. However, it was also determined that the IIG process was a possible cause of group misconception among students.

Watts (1985) studied concepts of light by the use of a case study. A subjects was a fourth year, single-sex, comprehensive school student in London enrolled in O-level physics. From interviews, the subject was unsure whether light was entirely a single composite. Waves were used to indicate the manner in which a strand might undulate as it threaded along a lengthy rope. To explain certain effects, subjects described light in such different forms as natural, electric, ultraviolet, or radioactive light.

Threads of light were separated from beams to provide different types of colored light. Natural light was an expression that covered sunlight, daylight, and candlelight; artificial light was reserved for sources clearly identifiable as man-made. Images, described as being on a mirror, rather than behind it or anywhere else, could be seen even in dark rooms when observers were close to the mirror.

The researcher commented that experiment performance led not only to the discovery of laws, it also provided practical activities that fostered discussion and challenge, allowing students to reach some resolution of discrepancies on their own.

Other Research Related to Misconceptions

Research related to misconceptions included investigations as follows: sources of misconception (Barrow, 1990; Ivowi & Oludotun, 1987); effect of test format on misconceptions (Bar, 1987); teachers and student teachers (Ameh & Gunstone, 1988; Nussbaum, 1981; Smith, 1987); teaching strategies for reduction of misconceptions (Idar & Ganiel, 1985); and effect of sex differences in science learning (Al Methan & Wilkinson, 1988; Kelly, 1987; Klainin et al., 1989; Zerega et al., 1986).

Ivowi and Oludotun (1987) investigated sources of misconceptions in physics, designing an open-ended essay instrument consisting of problem descriptions and tasks performed by students. The problems covered motion, conservation principles, and fields. Subjects were six physics students from 17 to 19 years of age drawn from 12 secondary schools. Validity and reliability were as established from a previous study. One problem consisted of two tasks, wherein odd-numbered tasks sought the same information by answer and explanation and even-numbered tasks consisted of the sources of information.

The Chi-square statistic was used to determine significant differences among possible sources, the results indicating that the most probable source of misconception was textbooks, followed by personal experience/intuition, and teachers. The influence of peers, other books, or instructional television/general television programs was found to be minimal. Moreover, it was determined that students who came from home backgrounds devoid of educational toys had limited experience with the scientific and technological world. Those students depended upon school teaching and very limited laboratory facilities. Under these types of conditions, proper understanding of concepts of physics may be impaired, giving rise to prevalent misconceptions (Ivowi & Oludotun, 1987).

Barrow (1990) confirmed the findings of Ivowi and Oludotun (1987), investigating misconceptions about magnets in elementary science textbooks. A list of eight magnet concepts for grades K-6, as validated by a panel of three science educators and two physicists, was used as a core. Interviews were conducted with 78 elementary students to ascertain their knowledge of magnets, then 10 textbook series were searched. Results indicated that a lack of consistency in the definition of poles existed in various textbook series. It was observed that it was possible to understand that elementary students may fail to see the value of studying standard magnets when ceramic magnets were those with which they were most familiar. It was recommended that teachers be made aware of student concepts in contrast to the presentation of the same concepts in textbooks (Barrow, 1990).

Bar (1987) examined the effect of three kinds of tests on misconceptions, including 1) an individual oral test, 2) a multi-choice test, and 3) an open-ended test. Two topics, evaporation and condensation, were chosen for examination among 83 students ranging in age from 5 to 12 years. The same number of students, aged 10 to 14 years, were chosen for five multi-choice tests. For the open-ended test, 240 students aged 10 to 14 years were examined. Validity and reliability were not reported for any of the tests. Results indicated that the testing format provided a significant but not conclusive effect since the subjects in each group were so markedly different. Moreover, it was determined that there was insufficient reason to conclude that the multi-choice test could be used to measure misconceptions more effectively than either the open-ended test or the oral test.

Recently, researchers have focused upon the content and structure of subject matter knowledge among teachers and its uses in teaching. Nussbaum (1981) investigated misconceptions among student teachers trained in science curricula. Subjects included majors in biology (n=52), chemistry (n=31), and graduate students (n=11) in science education in Israel. The instrument consisted paired contrasting explanations of given physical phenomena. It was stated that the instrument was constructed from the results of an investigation previously completed by the researcher.

Subjects were given a worksheet in which they were asked to read and respond to student responses. Each student teacher reported oral responses to each task. The results indicated considerable variance in analyses of student explanations, both within and between the three groups tested. Identified misconceptions included the tendency of students to relate animism to dynamic physical phenomena. Biology student teachers showed lower misconceptions for science laws as separate from nature. In addition, student teachers provided general remarks about student responses, rather than remarks which provided interpretive quality (Nussbaum, 1981).

In a related study, Smith (1987) found that teachers often expressed certain misconceptions of their own, and had difficulty in understanding student misconceptions, especially among pupils from the elementary grades. The misconceptions expressed by teachers were also examined by Ameh and Gunstone (1988), based upon a study of Nigerian science teachers. The research assumption was that teachers had an understanding of concepts which was congruent with the views of science. The purpose of the study was to explore the validity of assumptions about the nature of understanding among high school teachers. Teachers (N=251) were given a written test on concepts they regularly taught, and 45 of the subjects were interviewed following the test. The validity and reliability, however, of the instrument was not reported. The study concluded that teachers exhibited the same range of misconception as students. However, teachers tended to use more sophisticated terminology and had a generally lower frequency of misconceptions.

Within the context of an introductory physics course in Israeli high schools, Idar and Ganiel (1985) examined serious learning difficulties in physics. Following a detailed task analysis, the cognitive entry requirements for the course were identified. Based upon this information, a remedial teaching method was developed, consisting of supplying students with immediate and frequent feedback to reinforce understanding, correct misunderstanding, and to fill in gaps in necessary background skills. The whole process took place within the classroom setting. While they were not statistically significant, the results did indicate that background had an effect upon the ability to learn physics principles.

Zerega et al. (1986) studied the effect of sex differences in science learning. The subjects were 304 adolescent students in Denver, Colorado, each administered a general science multiple choice achievement test. Data were examined by three-way analysis of variance, and results indicated that at an early adolescent level, there were no significant sex differences in science achievement; that is, females performed as well as males. However, four years later, in late adolescence, female achievement levels were significantly lower than those for the males. It was concluded that the high school years, between the ages of 13 to 17, had an important differential effect. Tobin and Garnett (1987) also studied gender differences in general science. Their findings were similar to those obtained by Zerega et al. in that the mean scores for male achievement tests were higher than those for females. However, it was also concluded that this difference was not statistically significant.

Findings from research studies conducted in Kuwait and Thailand have resulted in findings contradictory to those from similar studies in western countries. Al Methen and Wilkinson (1988) focused on science and mathematics achievement among Kuwaiti students and found that females scored significantly higher than males for all science subjects. However, it was observed that these results may have been due more to sociological than to biological factors.

In Thailand, Klainin et al. (1989) tracked male and female achievements in physics and chemistry from grades 10 through grade 12. The studies were conducted in six government schools in Bangkok, including both coeducational and single-sex schools. Laboratory skills examined included problem solving, theoretical knowledge, and scientific attitudes. Two-way analyses of variance for gender by grade level were used to determine the gender main effect and the interaction terms for both chemistry and physics. Results indicated that female performance exceeded male performance in laboratory skills and problem solving, as well as in theoretical chemistry. However, this relationship was not consistent throughout the three periods examined. Moreover, in the area of theoretical physics knowledge, there was no difference between males and females.

Kelly (1987), directing attention at the issue of gender and science knowledge, provided at least a partial explanation for findings such as those obtained by Al Methen and Wilkinson (1988) and Klainin et al. (1989):

> Girls at a similar stage of development tend to avoid science because it is not a conventional choice. Girls who do choose science are likely to be more emotionally mature, and have considerable self-knowledge which helps them to sustain unusual choices.

Development of Measurement Instruments

Za'rour (1975) developed a 40-item multiple choice test to identify misconceptions among Lebanese students. The instrument was based upon a review of previous studies, interviews with teachers, and the reseacher's teaching experience. Two tests with 64 items in multiple choice, true-false and open-ended formats were piloted.

Options for multiple choice items were retained to the degree they provided distractors that proved more attractive from the pilot study results than the correct answers. The concepts of true-false and open-ended questions were retained if the majority of subjects responded correctly. Distractors which did not prove attractive were replaced and erroneous responses to the open-ended questions were transformed into distractors for the multiple choice questions. A new version of the tests was tested to check its language and construction. Final modification resulted in a 40-item multiple choice test, each with four alternatives, including 120 distractors of which 12 were "none of these" and "impossible to tell" options. About 20 items were concerned with physics (Za'rour, 1975).

Tobin and Capie (1981) developed the Test of Logical Thinking (TOLT) by selecting 10 items previously reported by Lawson (1978) and Lawson et al. (1979) in an initial version of the TOLT. It was claimed that this procedure assured that the TOLT would contain items that had been previously reported as valid measures of formal reasoning ability. Two items were selected to measure five modes of formal reasoning, including controlling variables, proportional reasoning, probabilistic reasoning, correlational reasoning, and combinatorial reasoning.

The test was presented in a multiple justification format (subjects selected correct responses from a number of alternatives and provided written justifications for their selections), but the number of subjects was not reported. Reliability was high (.74), but several factors served to reduce validity. Among these factors, subjects were unable to formulate clear written justifications for selecting particular responses, and rescoring the responses suggested a number of scoring inconsistencies. Thus, the initial version was modified to a revised test so that multiple justifications were provided as well as multiple solutions for each problem. In the revised version, correct solutions required selection of correct responses and most appropriate response justification. Moreover, the revised test also utilized a colored video-tape to present the context for each problem (Tobin & Capie, 1981).

Halloun and Hestenes (1985b) reported procedures for developing a mechanics test, using four different methods. First, early versions of the test were examined by a number of physics professors and graduate students, suggestions from whom were incorporated into the final version. Second, the test was administered to a group of graduate students to determine their agreement with the correct answers to each question. Third, interviews with physics students who had taken the test demonstrated that the questions and alternative responses were understood. Fourth, the answers of students who had received grades of "A" in the physics class in which the test was administered were scrutinized for evidence of common misunderstandings which could be attributed to question formulation. None were found.

The reliability of the mechanics test was established through interviews and by a statistical analysis of test results (test-retest effect, determined by the Kuder-Richardson formula). Interviews established that student answers reflected stable beliefs rather than tentative, random, or flippant responses. In addition, the possibility of relevant test-retest effects was eliminated by two procedures. First, the posttest results of one group of students who had not taken the pretest was compared to those of a larger group in the same class who had taken the pretest. Means and standard deviations for both groups were nearly identical. Second, a group of students was given the posttest shortly after midterm and again at the end of the semester. Mean test scores and standard deviations for this group differed. This change in score demonstrated the improvement between pretest and posttest scores that could have been anticipated (Halloun & Hestenes, 1985).

Treagust (1988) used a 10-step process to develop a diagnostic two-tiered multiple choice instrument. The first four steps defined the content, and steps five to seven obtained information about student misconceptions. The final three steps involved development of the diagnostic test. These 10 steps for instrument development were as follows:

1) Identify propositional knowledge statements, as described by Finley and Stewart (1982).
2) Develop a concept map, as described by Novak (1980).
3) Relate propositional knowledge to the concept map.

4) Validate the content by science educators, secondary science teachers and science specialists with a thorough knowledge of the subject matter.
5) Examine related literature.
6) Conduct unstructured student interviews.
7) Develop multiple choice content items with free response.
8) Develop the two-tiered diagnostic tests. The test was developed from the multiple choice items with a design comparable to the format established by Tobin and Capie (1981). The first part of each item on the test was a multiple choice content question with either two or three choices. The second part of each question contained a set of four possible reasons for the answer given to the first part. The reasons consisted of the correct answer and any identified misconception or misconceptions, together with a simple wrong answer, if needed. The second part of each item was developed from the student responses to reasons given for each open response question as well as information gathered from interviews and the literature.
9) Design a specification grid to ensure that the diagnostic test covers the propositional knowledge statements and concepts from the concept map.

10) Continue refinements with different classes to ensure that the test as a whole can be used for diagnosing student misconceptions in the topic under examination.

Dai (1991) developed a test using procedures consisting of try-out testing, first draft, second draft pilot studies, and final refinement. The process of test development started with the identification of various lunar concepts from a review of the literature and from discussions with teachers and students on the topic of the moon. These sources served as the raw material for the construction of a try-out draft. The test format combined an open-ended with a multiple choice justification test based upon 26 items. After sample testing, responses and comments were evaluated and used to construct the first draft.

The first draft was derived, modified and expanded from the try-out test. Non-pictorial questions were included in most of the items. Each item had one correct response and two distractors, one of which was a misconception and the other an equally plausible distractor. The findings from the item analysis of the first draft were used for the revision of test items (Dai, 1991).

The second draft (pilot study) was accomplished from revision of the first draft. There were 33 items with four alternatives choices for each item. Data collected from the pilot study was computed. Indices of item difficulty and discrimination were used to justify the suitability of each item. Finally, final refinement resulted in a 20-item multiple choice test in a format consisting mostly of pictorial items. Content and construct-related evidence of validity were used for test validation, the latter established by submitting draft items to a panel of five experts. The panel of experts judged the test items to determine that underlying concepts were adequately identified and were free of mechanical deficiencies. Dai (1991) reported that construct-related evidence of validity was evaluated by using an interview-about-events approach.

Test Validation

Validity is the most important consideration in test evaluation. Test validation is the process of accumulating evidence to support such an inference (American Psychological Association [APA], 1974). Construct validation is important for all types of psychological tests, including those for aptitude, achievement, or other interests. Construct-related evidence for validity must be investigated whenever other acceptable criterion or content universe cannot be accepted in their entirety (Cronbach & Meehl, 1955). The term "construct" refers to something that cannot be observed, but is rather constructed by the investigator to characterize and summarize regularities in individual behaviors (Mitzel, 1982).

Evidence for the construct interpretation of a test may be obtained from a variety of sources, and has been characterized from Cronbach and Meehl (1955), Mitzel (1982), and the APA (1974) as follows:

1) Intercorrelation among items and factor analysis may be used to support the assertion that a test measures primarily a single construct.
2) Group differences. A construct theory often suggests that certain groups should score high or low on a measure. By administering a test to two differing groups, the investigator should be able to determine whether scale predictions are consistent with expectations. Results in accordance with expectations contribute to the construct validation of the measure.
3) Evidence derived from analysis of individual responses can yield hypotheses that enrich the definition of a construct.
4) Internal structure. For many constructs, within test evidence of homogeneity is relevant for judging validity. Item-test correlation and certain reliability formulas describe internal consistency, thus contributing to construct-related evidence for validity.
5) The stability of test scores may be relevant to construct validation. Whether a high degree of stability is encouraging or discouraging for the proposed interpretation is dependent upon the theory defining the construct.

6) To observe the performance process is a means to informally determine which sources account for test variability, thus providing evidence for construct validation.

7) Theories about the effects of particular constructs may suggest that the construct or the expression of it could be modified by some intervention. Performance under the different conditions may be expected to vary markedly.

8) Evidence from content and criterion-related evidence validation studies contribute to construct interpretations.

However, the manner in which the instrument is developed can be used to contribute to the construct validation of the measure. For the present study, this consisted of the method of test construction, including definitions of misconceptions, selection of the knowledge statements to match the definitions, consultation with experts as well as demonstration of internal consistency, and item analysis.

Validation of a particular test usually requires the integration of evidence (APA, 1974). Typically, there is no single acceptable criterion measure against which construct validity may be measured (Mitzel et al., 1982). However, Cronbach and Meehl (1955) have stated that no test developer could present validity for all possible criterion, nor could any test developer run all of the possible experimental tests of a proposed interpretation.

However, this recommendation is more subtle in nature than the simple statement that a lot of validation is better than a little. The choice of which of one or more approaches to use to gather evidence for the interpretation of constructs is dependent upon the specific validation problem, and the extent to which validation has been focused upon construct meaning (APA, 1974).

CHAPTER 3

METHODOLOGY

This chapter is presented in three principal sections. The first section summarizes the procedures for development of a valid and a reliable two-tiered multiple choice test for the measurement of misconceptions about optics among Thai high school physics students. The second section discusses the selection of the subjects, and the final section presents a summary of procedures for administering the instrument and testing the hypotheses, including consideration of the methods of data analysis.

Development of the Survey Instrument

An instrument, the Two-Tiered Optics Misconception Test (TTOM), was constructed and developed for use in secondary education physics classes in Thailand. Items were derived from a review of the literature and from interviews with selected science educators, secondary and university level physics instructors, and a random sampling of high school science students. The procedure for the development of the TTOM consisted of (1) the development of an open-ended test and (2) the development of the Two-Tiered Optics Misconception Test.

Development of an Open-Ended Test

The process of test development was initiated with the identification of varied interpretations of the principles of optics, based upon science curriculum in use in Thailand (Ministry of Education, 1989). This was performed through a review of the literature, and interviews with four Thai high school science students (from grades 10-12) and four physics teachers. Each teacher was asked such questions as: What kind of mistakes do your students make about optics concepts? From your experience, what causes your students to make these mistakes? Each student was asked such questions as: Which optics concepts are difficult for you to understand? Do you have problems when you study the concepts of light, shadow, and image formation from a plane mirror or a converging lens? Why do you have these problems?

The instructor responses indicated that students reflected certain misconceptions between light and the sources of light. The underlying factor was that students paid less attentions to learning a concept and more to arriving at a solution. Since they would face university entrance exams in the near future, student responses indicated a greater need to learn to solve problems than to learn concepts. Thus, when the students were asked about the definition of light, their answers focused upon the sources of light. Interview data were tape recorded and were recorded by handwritten notes, two sources which served as the raw material for constructing open-ended test items.

Question items, as derived from previous investigations of optics misconceptions (McDermott & Goldberg, 1986; Mohapatra, 1988; Smith, 1987) and the aforementioned interviews with physics teachers and students, were prepared (Appendix B) and were then translated into the Thai language by the researcher. An open-ended 30-item test was constructed and presented to three Thai language experts, one with mastery of the Thai language, one with mastery of translations from English to Thai, and with mastery of both English and principles of optics, to assure that the test language was understandable.

The Thai language experts suggested some changes in wording for purposes of clarity. For example, "warm" as used in item #8 indicates "hot" in Thai, and "warmth" in item #9 (Appendix B) indicates "heat." Upon correction of the test language, the open-ended test was administered to 30 students in grade 9, 70 non-science students in grades 11 and 12, and 76 science students in grades 10-12. None of these students were included in either subsequent field testing or in the administration of the final instrument.

The format of the open-ended test consisted of problem statements, and space for both answers and reasons (Appendix B). No time limit was set for completion of the test. Correct responses to questions as well as incorrect responses by students were maintained for subsequent use as provided answers and the reasons for development of the TTOM, as described in the following section.

Development of the Two-Tiered Optics Misconception Test

Optical phenomena and light are apparent in everyday life. However, the relationships among facts, events, and concepts of optic phenomena may differ in explanation from accepted scientific theories. Thus, the concepts which were selected for the basis of testing were optical instruments and light. Optics concepts included reflections and images from plane mirrors, the properties of a converging lens, and real and virtual images. Light concepts consisted of light and heat, light and perception, definitions of light, light rays, the sources of light, scattering and reflection, diffraction, light and shadowing, and color filtration.

Test items were again derived from review of studies by McDermott and Goldberg (1986), Mohapatra (1988), and Smith (1987) and from interviews with Thai physics teachers and students. These items were combined with selected examples from the open-ended test and were prepared as an item pool (Appendix C). To prevent the construction of a test measuring only rote learning, Bloom's taxonomy of the cognitive domain (Gronlund, 1985) was used. Test items 10-22 and 26 (14 items) were designed to measure objectives in the knowledge category, and items 1-9, 23-25, and 27-30 (16 items) were designed to measure objectives in the comprehensive category.

The format of the instrument was designed as a 30-item, two-tiered multiple choice test (Appendix C); the first section consisted of choices of content responses, and the second section included choices of reasons for the responses given in the first section. In addition, the test provided space for students to present their own ideas to the extent they differed from the provided responses or reasons. Following translation of the 30-item pool into Thai, three Thai language experts checked the language to assure that it was understandable. Following language adjustments, a selected expert panel, consisting of three professors of optics, three physics educators, and two high school physics teachers, each with more than 15 years of teaching experience (Appendix A), was asked to determine whether each first tier item choice was either Correct, a Misconception, or a Wrong answer by placing a C, M or W in the space provided for each choice. A wrong answer at this stage indicated that the item answer was either not a reasonable answer or that it had no relation to the question. The expert panel was also asked to choose one reason, from among four provided reasons, to support correct answers. Space was also provided for suggestions, recommendations, or corrections. Items that received agreement from at least six of the eight experts for correct answers were maintained.

From consultation with the expert panel, items 10 and 14 (Appendix C) did not receive minimum support and were eliminated from the item pool. The provided correct answers were then determined to be correct. None of the student responses as derived from the open-ended test, and provided as incorrect answers, were determined by the experts to be the wrong answers. This checking process was necessary to assure that the TTOM distractors were misconceptions rather than simple mistakes.

To increase test understandability, certain changes and/or modifications were suggested and then adopted for selected items prior to proceeding to the next step. For example, in item 5 (Appendix C), the experts suggested drawing a picture of a cardboard DE close to a converging lens to prevent confusion; for item 6, it was suggested that the picture should display the experiment from two angles; for item 20, it was suggested that to set a situation before asking a question was to be preferred to only asking a question; and for item 27, it was suggested that a diagram of light diffraction should be included with the question. The test was then presented for readability analysis prior to field testing.

Readability

Eight science students, selected from grades 9, 10, 11, and 12, were asked to assess the readability of the items. The students were asked to identify items that they could not understand clearly. The discussion was recorded by the researcher and by tape recorder. The time for students to complete the test varied between 30-70 minutes; with an average of 50 minutes. The records were used for revising the test before administering to the subjects in the field study.

Field Study

The TTOM, consisting of the instructions, a 28-item two-tiered multiple choice test, and an answer sheet, was administered to 190 high school science students at the Kasetsart Demonstration School in Bangkok, Thailand. For each statement, subjects were asked to select correct responses and reasons from, respectively, the first and second tiers of choices. Subjects completed the test in 60 minutes. The responses were collected for purposes of item analysis and to establish reliability.

Field test results were scored as follows:

1) For correct selections of both first and second tier item choices, one point was awarded.
2) For selection of a correct answer from the first tier, followed by selection of an incorrect reason or no selection from the second tier, zero points were awarded.
3) For selection of an incorrect answer from the first tier, regardless of whether the reason

selected from the second tier was correct or incorrect, zero points were awarded.

4) For selection of a correct answer from the first tier and no selection from the second tier, wherein subjects indicated their own responses in the space provided, one point was awarded if the reason was judged to be correct by two physics professors; otherwise, zero points were awarded..

Validation

Validity is defined as the appropriateness of inferences from test scores or other forms of assessment (APA, 1985). Validity is influenced by uniform aspects of measurement, including the test format, conditions of administration, and language levels in use. For the present study, construct-related evidence for validity was established. Content-related evidence for validity could not be established because the procedure demonstrates the degree to which the sample of items, tasks, or questions on a test are representative of some defined universe or domain of content (APA, 1985). Misconceptions are not a domain of content. They are rather the psychological characteristics of interest (APA, 1985). Thus, misconceptions are constructs. Construct-related evidence for validity for this study was determined by 1) the manner in which the instrument was developed, 2) determination of known-group differences, and 3) interviews with a random selection of subjects, as given below:

1) The manner in which the instrument was developed included the method of test construction, internal consistency, and item analysis.

   a) The method of test construction included the definition of misconceptions, selection of knowledge statements to match the definitions, and consultation with experts prior to field study administration of the pilot test to a selected group of subjects.

   b) Internal consistency: Reliability, as indicated by the internal consistency of the test items, is concerned with item homogeneity (Gronlund, 1985; Mehrens & Lehmann, 1991). The Kuder-Richardson formula 20 (KR-20) and the method for increasing the reliability of a short multiple choice test (Serlin & Kaiser, 1978) were used to determine internal consistency. The reliability of the instrument for the field study was found to be .81.

   c) Item analysis: The total item scores for the highest 27 percent and the lowest 27 percent were used to establish item analysis, item difficulty, and item discrimination (Mehrens & Lehmann, 1991). Based upon this procedure, the number of items was reduced from 28 to

25. An item-total score correlation was used to establish the correlation between individual test items and the total test score, providing construct-related evidence for validity. The item-total score correlation was found to be .20 for the field study.

2) Determination of differences between means of known-groups was used to provide evidence of validity. Field test subjects in the 12th grades with grade point averages in excess of 3.5 were selected as a known high achievement group and, to control for the effects of variation, 12th grade non-science subjects were selected to represent a low achievement group. The TTOM scores were analyzed to determine score differences within these two known-groups. The statistical *t*-test was used to determine the significance of the difference between the two samples and the results of this analysis are provided in Chapter 4 (Table 4.1).

3) Following administration of the field test. 14 students were randomly selected from the 10th through the 12th grades at the Kasetsart Demonstration School, Bangkok, Thailand, for interviews regarding test items. The interview questions, some of which were accompanied by drawings, were drawn from the TTOM and presented to

the subjects one at a time. Subjects were provided with paper and pencils to be used to sketch or describe their ideas. The following statement is an example of an interview question (i.e., from items 1 to 4 of the final instrument, Appendix H):

Statement/Question: The optical instrument as shown in this picture consists of an object (the filament of an unfrosted light bulb), a converging lens, and a screen. Suppose we removed the lens, leaving an object and a screen where they are. Would anything change on a screen? And why?

Responses: Ten students responded that the image on the screen would become erect, smaller than an object, and unclear, noting that the property of a converging lens was to invert and change the size of the image. These responses were based upon textbook information. However, four subjects responded that without a lens, there could be no screen image because a converging lens would be required to focus the light. The light ray would be converted after passing through the lens and only then would a real image appear.

The remainder of the questions were presented to the subjects following an identical procedure. After completing an interview, subjects turned in written explanatory comments to the interviewer for consideration with the answers. In addition, interviews were tape recorded. Scores were obtained from the number of correct answers and correct reasons, and interview results are provided in Table 3.1.

The mean score was 8.21 for the field study interviews, in contrast to a mean score of 8.4 from administration of the test. The two mean scores were comparable, though not statistically identical. In this case, testing for significant differences between two means did not result in identical scores for reason of the assumptions of the statistical testing (Devore & Peck, 1986). Thus, it was determined student misconceptions about optics were accurately identified from a combination of field study testing of the item pool and the interviews with a random selection of subjects from the same population. These results were considered to provide construct-related evidence for validity.

Table 3.1. Summary of interview with random selection of subjects.

ID	Grade	Gender	Correct item responses:	Score
1	10	M	1,2,5,6,8,16,17, 18,21,23	10
2	10	F	10,14,15,18,20	5
3	10	M	13,15,19,20	4
4	10	F	10,11,15,18,19,20, 21,22,23	9
5	11	M	1,2,3,10,11,14, 15,16,18,20	10
6	11	M	1,2,9,10,15,19,20	7
7	11	M	10,12,14,15,17, 18,21,22,24	9
8	11	F	1,4,5,6,14,15,21,24	8
9	11	F	1,2,7,8,10,18,20,21,25	9
10	12	F	1,2,7,10,14,15,16, 17,20,21,23,25	12
11	12	M	10,12,14,15,17, 18,19,23,24	9
12	12	M	1,10,12,14,15, 16,25	7
13	12	M	11,13,14,19,20, 21,24,25	8
14	12	M	1,2,3,8,10,15,18,20	8

Selection of Subjects

Two schools for males, two schools for females, and four coeducational schools were randomly selected from among the number of larger secondary schools in Bangkok, Thailand (i.e., schools with enrollments greater than 2500 students). The types of schools selected usually offered from four to eight science classes at each grade level. One class from each grade at each school was then randomly chosen, and all students in the selected classes were included as subjects of the study. The number of subjects by gender and grade level are shown in Tables 3.2 and 3.3. From Table 3.2, there was a total of 932 subjects, consisting of 238 students from all-male schools, 246 students from all-female schools, and 448 students from coeducational schools.

Table 3.2. Participants by type of school and grade level.

Type	No. of Schools	Level 10	Level 11	Level 12	Totals
Male	2	100	87	51	238
Female	2	98	91	57	246
Coed	4	154	159	135	448
Total	8	352	337	243	932

The numbers of male and female subjects from coeducational schools, by grade level, are shown in Table 3.3. There were 75 male and 79 female students from grade 10, 79 male and 80 female students from grade 11, and 55 male and 80 female students from grade 12. The ratio of males to females for each grade level was approximately 1:1.

Table 3.3. Male and female participants at coeducational schools.

	Level 10		Level 11		Level 12	
School	Male	Female	Male	Female	Male	Female
1	26	15	17	23	8	26
2	21	27	24	26	12	16
3	13	19	19	21	20	17
4	15	18	19	10	15	21
Total	75	79	79	80	55	80

Administration of the Instrument

In its final form (Appendix H) the TTOM was used to investigate physics misconceptions about optics held by high school science students in Bangkok, Thailand. The instrument was distributed during the fourth week of September, 1992 and the first week of October, 1992 and administered to 932 students from 24 randomly selected classes from among eight high schools. The instrument asked subjects to provide information on grade and gender, and provided instruction how each respondent was to mark responses to each of first page items on the answer sheet as well as how the test should be completed. Subjects were allowed 50 minutes to complete the tests and all tests were administered by the research to all classes. Responses were collected and scored for item analysis, reliability, and analysis of variance. The collected data were then subject to analysis with respect to the hypotheses.

Item Analysis and Reliability of the TTOM

The procedures used for item analysis and to establish item difficulty, item discrimination, item-total score correlation, and reliability were identical to procedures used for the field study tests.

Testing the Hypotheses

Data for three variables were analyzed for their effect upon student misconceptions, including grade level, type of school, and gender. Grade levels considered included the 10th, 11th, and 12th grades; types of schools considered include all-male, all-female, and coeducational schools. Statistical analysis procedures were applied to scores for the TTOM in the form of a three-factor analysis of variance (ANOVA) based upon a randomized block design procedure. Table 3.4 provides a representation of the three-factor ANOVA used for the present study:

Table 3.4. Random-block design for three-factor analysis of variance.

Gender		Female	Male
Grade Level	10th	11th	12th
Type of School	Female	Male	Coed

Statistical Models

From the ANOVA three-factor design, statistical models are as outlined below.

Model One

For the variables type of school, school within type, and grade level,

$$Y_{ijkl} = \mu + T_i + S_{ij} + L_k + LT_{ij} + EU_{ijk} + ES_{ijkl} ,$$

where

Y_{ijkl} is the score for the l^{th} student in the class, corresponding to cells i, j, and k,

μ is the fixed constant representing the overall mean,

T_i is the fixed effect corresponding to type of school,

S_{ij} is the fixed effect corresponding to school within type,

L_k is the fixed effect corresponding to grade level,

LT_{ij} is the interaction effect corresponding to grade level and type of school,

EU_{ijk} is the random residual (error) associated with a class of students (the mean square of the residual is estimated as the interaction between the grade level by school within type interaction mean square, and

ES_{ijkl} is the random residual (error) associated with a student within a class.

The research hypotheses, in the form of null hypotheses, were tested and were as follows for Model 1:

Ho_1 There will be no differences among types of schools (male, female, and coeducational);

Ho_2 There will be no differences among schools within types of schools;

Ho_3 There will be no differences among subjects for grade level (10th through 12th grades);

Ho_4 There will be no interaction effect between grade level and type of school;

Ho_5 There will be no interaction effect between grade level and schools within types of schools;

Ho_6 There will be no differences among 10th grade subjects for type of school;

Ho_7 There will be no differences among schools within type for 10th grade subjects;

Ho_8 There will be no differences among 11th grade subjects for type of school;

Ho_9 There will be no differences among schools within type for 11th grade subjects;

Ho_{10} There will be no differences among 12th grade subjects for type of school; and

Ho_{11} There will be no differences among schools within type for 12th grade subjects.

For testing the principal hypotheses, Ho_1 through Ho_3 and Ho_6 through Ho_{11}, Model 1 terms included, T_i, S_{ij}, and L_k. To test for interaction effects, Ho_4 and Ho_5, the terms included LT_{ij} and EU_{ijk}. For computation of the *F*-values for the fixed model, the two residual terms, EU_{ijk}

and (ES_{ijkl}) were denominators for the calculation of each of the five *F*-values used to test null hypotheses for the three-variable fixed design.

The design for the ANOVA procedure is shown in Table 3.5 for all variables. For variables analyzed by fixed model for the 10th, 11th, and 12th grade level subjects, the design for the ANOVA procedure is as shown in Tables 3.6-3.8, respectively.

Table 3.5. Design for analysis of variance, all variables.

Source of Variation	df	MS	*F*-value
Among Classes:	23		
Type	2	MS_T	$MS_T/MS_{S(T)} = F_1$
School (Type)	5	$MS_{S(T)}$	$MS_{S(T)}/MS_U = F_2$
Level	2	MS_L	$MS_L/MS_U = F_3$
Type × Level	4	MS_{TL}	$MS_{TL}/MS_U = F_4$
Unit error (Classes) (Level × School (Type))	10	MS_U	$MS_U/MS_E = F_5$
Subject within classes error	908	MS_E	
Total	931		

Table 3.6. Design for analysis of variance, fixed model for 10th grade subjects.

Source of Variation	df	MS	F-value
Among Classes:	7		
Type	2	MS_{T10}	$MS_{T10}/MS_{S(T10)} = F_6$
School (Type)	5	$MS_{S(T10)}$	$MS_{S(T10)}/MS_{E10} = F_7$
Student within classes error	344	MS_{E10}	
Total	351		

Table 3.7. Design for analysis of variance, fixed model for 11th grade subjects.

Source of Variation	df	MS	F-value
Among Classes:	7		
Type	2	MS_{T11}	$MS_{T11}/MS_{S(T11)} = F_8$
School (Type)	5	$MS_{S(T11)}$	$MS_{S(T11)}/MS_{E11} = F_9$
Student within classes error	329	MS_{E11}	
Total	336		

Table 3.8. Design for analysis of variance, fixed model for 12th grade subjects.

Source of Variation	df	MS	F-value
Among Classes:	7		
Type	2	MS_{T12}	$MS_{T12}/MS_{S(T12)} = F_{10}$
School (Type)	5	$MS_{S(T12)}$	$MS_{S(T12)}/MS_{E12} = F_{11}$
Student within classes error	235	MS_{E12}	
Total	242		

Model Two

For the variables school, gender, and grade level for coeducational schools,

$M_{ijkl} = \mu_1 + S_i + G_j + L_k + GL_{jk} + EU_{ijk} + ES_{ijkl}$,

where;

M_{ijkl} is the score for the l^{th} subject in the class, corresponding to the cells j, k, and l,

μ_1 is the fixed constant representing the overall mean,

S_i is the fixed effect corresponding to school,

G_j is the fixed effect corresponding to gender,

L_k is the fixed effect corresponding to grade level,

GL_{ij} is the random residual (error) associated with a class of subjects (the mean square for the residual is estimated as the interaction between the grade level by gender interaction mean square),

EU_{ijk} is the random residual (error) associated with a class of subjects (the mean square for the residual is estimated as the interaction between the levels of the variables grade level, school, and gender), and

El_{ijkl} is the random residual (error) associates with a subject within a class.

The following null hypotheses were tested for Model 2:

Ho_{12} There will be no differences for grade level among coeducational schools;

Ho_{13} There will be no differences for gender among coeducational schools; and

Ho_{14} There will be no interaction effect for grade level and gender among coeducational schools.

To test the principal null hypotheses Ho_{12} and Ho_{13}, the terms included, S_i, G_j, and L_k. For the subsidiary hypothesis Ho_{14}, the term GL_{jk} was used to test for an interaction effect. When computing the *F*-values for the fixed model, the residual terms EU_{ijk} and ES_{ijkl} were denominators for the calculation of each of the four *F*-values used to test the null hypotheses for the three-variable fixed design. The design for the ANOVA procedure is shown in Table 3.9 for variables for coeducational.

Table 3.9. Analysis of variance for coeducational schools.

Source of variation	df	MS	*F*-value
School	3	MS_S	MS_S / MS_{UE} = F
Gender	1	MS_G	MS_G / MS_{UE} = F_{12}
Level	2	MS_L	MS_L / MS_{UE} = F_{13}
Gender × Level	2	MS_{GL}	MS_{GL} / MS_{UE} = F_{14}
Unit error	15	MS_{UE}	MS_{UE} / MS_{SE}
Subsampling Error	439	MS_{SE}	
Total	447		

Each of the ANOVA performed was tested at the .05 level of significance. All data were computed using SAS (1987).

Summary

The purpose of this chapter was to describe the methodology used to develop the Two-Tiered Optics Misconception Test for high school students in Bangkok, Thailand. Development of the instrument, the selection of subjects, and the administration of the instrument and testing of the hypotheses, to include the means of statistical analysis, were described.

For field testing, the subjects consisted of 190 science students from the 10th, 11th and 12th grades from the Kasetsart Demonstration School. Data from item analysis, item-total score correlation, and internal consistency were analyzed for test revision. The final instrument, consisting of 25 items in form of a two-tiered multiple choice pattern, was administered to 932 high school science students in the 10th, 11th, and 12th grades at eight high schools in Bangkok, Thailand.

CHAPTER 4
RESULTS OF DATA ANALYSIS

The results of data analysis are presented in this chapter, organized in three sections. The first section provides the findings with respect to instrument development, including consideration of item analysis, item difficulty, item discrimination, item-total score correlation, and the results of statistical data analysis of differences between the means of known-groups. The second section summarizes the results of statistical data analysis with respect to the research hypotheses. The third section provides a consideration of research findings from analysis of data unrelated to the research hypotheses.

Two-Tiered Multiple Choice Optics Instrument

The instrument was constructed in a two-tiered format, the first tier with multiple choice questions and the second tier with multiple choices of reasons for responses given to first tier questions. The area considered to be appropriate for testing generalized concepts of physics for secondary education in Bangkok, Thailand during the first semester 1992 was misconceptions in concepts of optics. The Two-Tiered Optics Misconceptions Test (TTOM) consisted of 25 items (Appendix H), for which there were four options for each of the questions and responses in the first and second tiers.

Item analysis procedures consisted of determination of item difficulty, item discrimination, and item-total score correlation. The item difficulty index shows the percentage of students who have answered an item correctly. Item discrimination is used to indicate the degree to which test results effectively separate subjects with high total test scores from subjects with low total test scores (Wiersma & Jurs, 1985). Results of the item difficulty and item discrimination calculations, as well the item-total score correlation, which expresses the relationship between the total test and item scores (Magnusson, 1967), are shown in Figure 4.1.

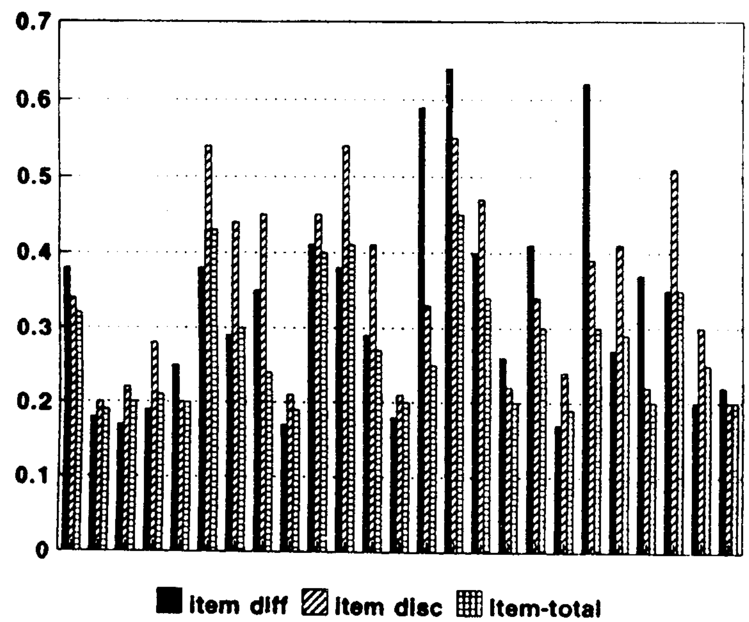


Figure 4.1. Item difficulty, discrimination, and total score correlation.

Figure 4.1 shows the item difficulty, item discrimination, and the item-total score correlation for each item. It may be noted that these values for items 2-4, 9, 13, 19, and 25 were all in an approximate range of 0.2.

Determination of differences between the means of known-groups was used to provide evidence of validity. The TTOM scores were analyzed to determine score differences within two known-groups, 12th grader subjects with grade point averages in excess of 3.5 (A=4.0) who were selected as a known high achievement group, and 12th grade non-science subjects who were selected to represent a low achievement group. The statistical *t*-test was used to determine the significance of the difference between the two samples and the results of this analysis are provided in Table 4.1.

Table 4.1. Comparison of means, high and low achievement groups.

Group	N	Mean	Variance	SD	*t*
High	41	9.61	7.29	2.70	6.43*
Low	49	5.75	8.65	2.94	

Note: * = $p < .05$.

Table 4.1 shows that there were significant differences between the mean scores of known high achievement and low achievement groups. It may be stated that a significant difference existed at the .05 level of significance for the mean misconception scores of the two known-groups.

Statistical Data Analysis

Statistical analysis procedures were applied to the data to determine: 1) mean scores for type of school, grade level, and school within type and 2) ANOVA scores for gender, grade level, and type of school. For each test, statistical significance was set at the .05 level.

Mean Scores

Figures 4.2-4.6 provide comparisons of mean scores by type of school, all schools by grade levels, grade levels, schools within a type, and gender, respectively. A complete listing of all mean scores is provided in Appendix E.

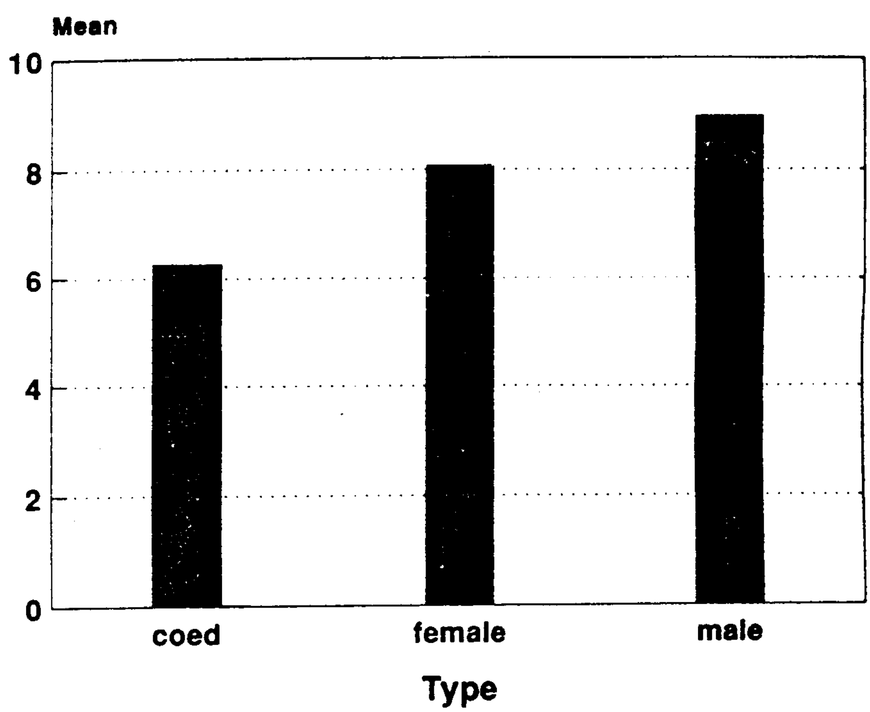


Figure 4.2. Mean scores by type of schools for male, female, and coeducational schools.

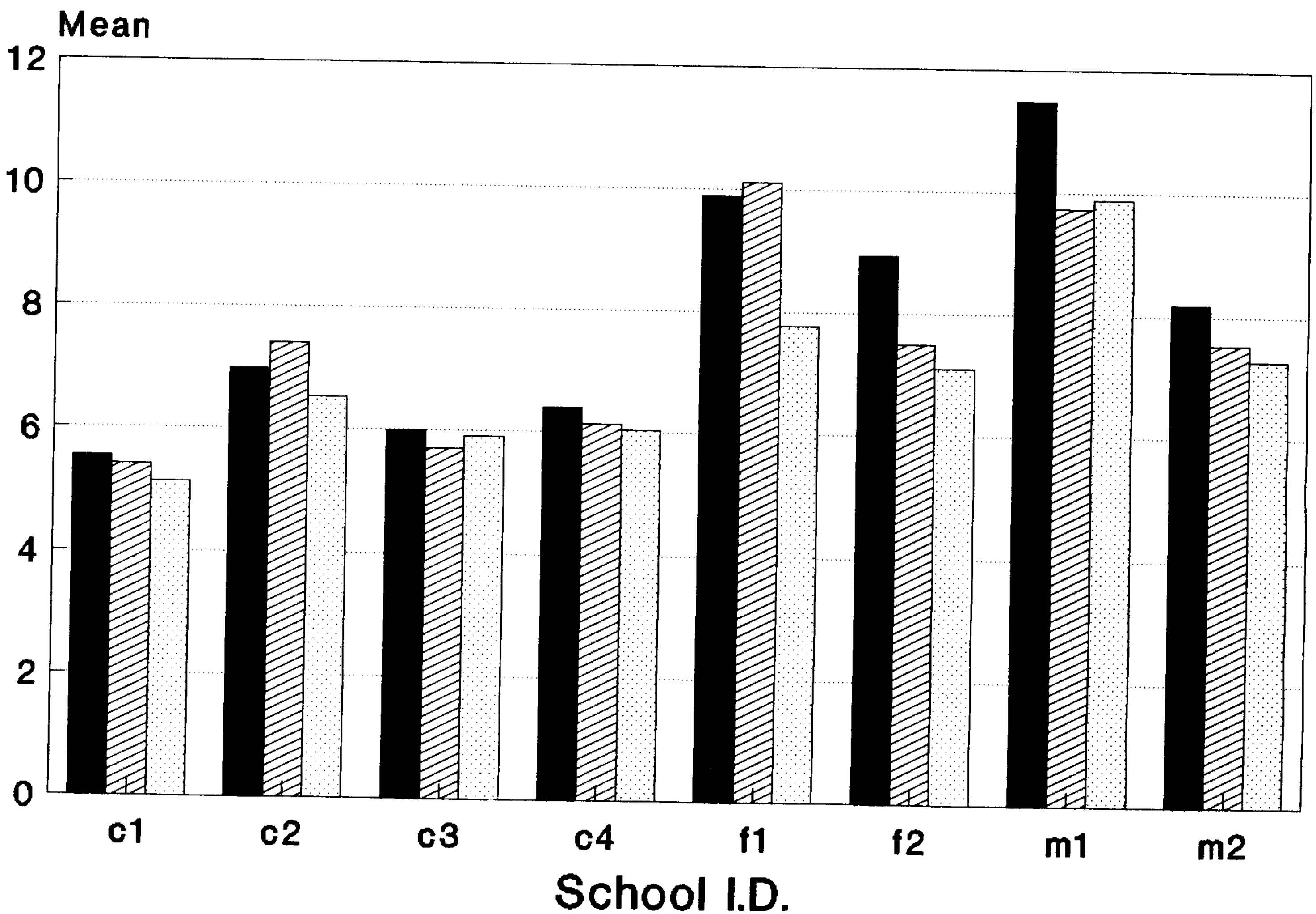


Figure 4.3. Mean scores for all schools by grade level.

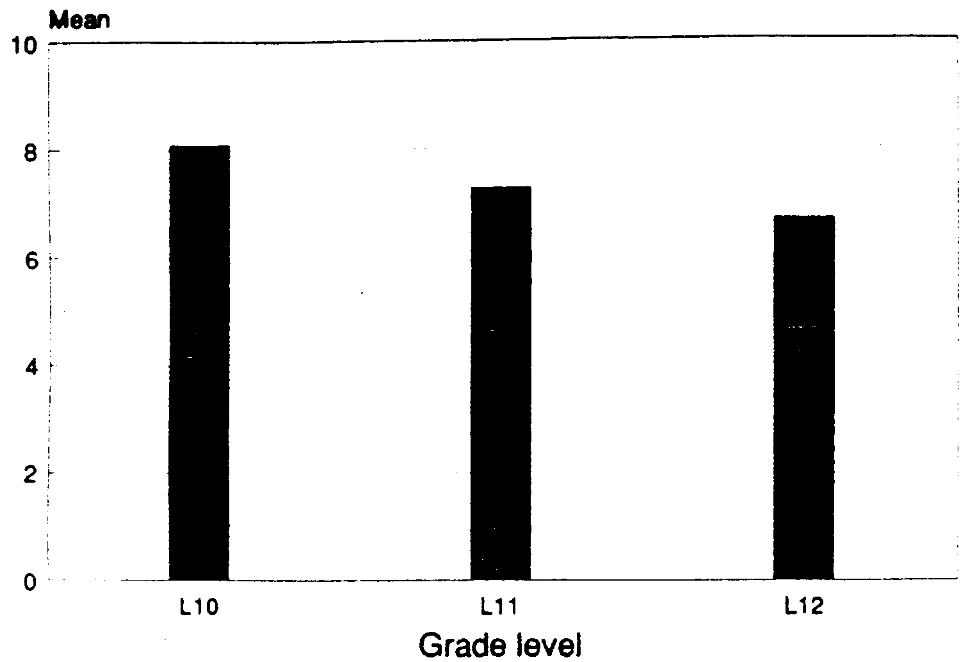


Figure 4.4. Mean scores by grade level for all school types.

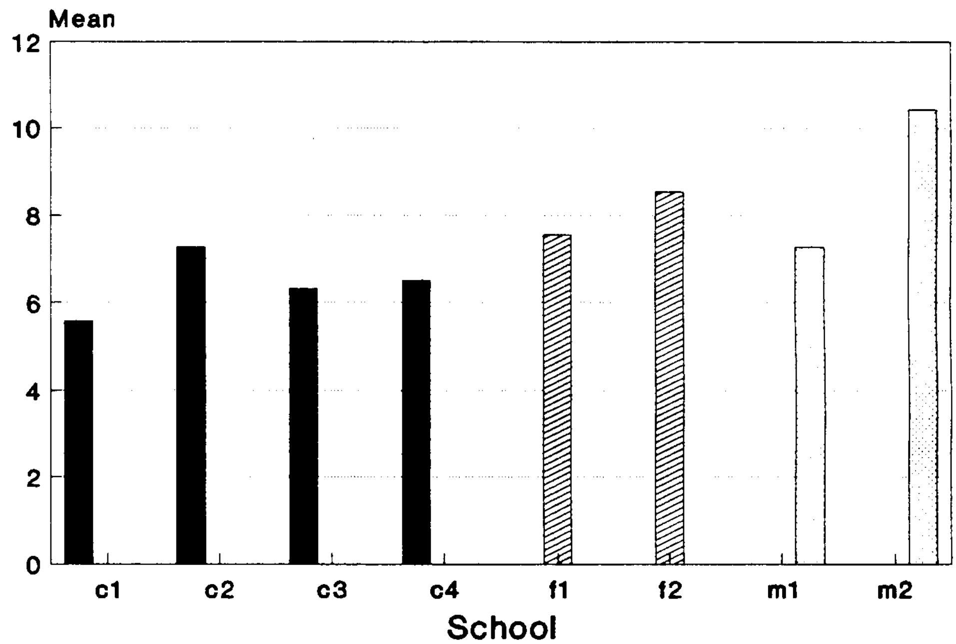


Figure 4.5. Mean scores for subjects by schools.

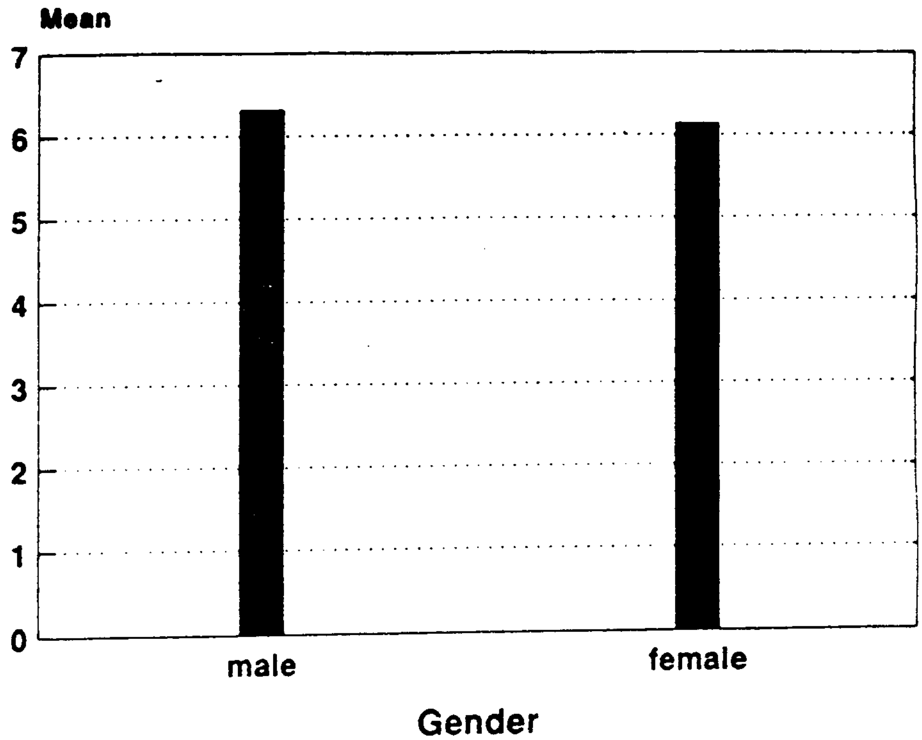


Figure 4.6. Means scores by gender for coeducational schools.

As indicated in Figure 4.2, subject mean scores for the male schools were higher than for either the female schools or the coeducational schools, thus indicating that the subjects from male schools had fewer misconceptions about optics than the subjects of either the female or co-educational schools. From Figure 4.3, mean scores for 10th grade level subjects were higher than for the subjects of either levels 11 and 12, indicating that subjects from level 10 had fewer misconceptions about optics than either of the other two grade levels.

In Figures 4.3 and 4.5, which indicate subject mean scores for each school, columns 1-4 indicate subject mean scores for coeducational schools, whereas comparative scores for exclusively female and male schools are given in, respectively, columns 5-6 and 7-8. Figure 4.3 shows comparative mean scores for fixed grade levels. The highest mean scores for the 10th, 11th, and 12th grades were for male schools (column 7), female schools (column 5), and male schools (column 7), respectively. From the mean scores given in Figure 4.5, subjects from a single male school (column 8) reported the highest score, followed by the subjects from a single female school (column 6). The lowest mean score recorded was for one of the coeducational schools (column 1). Note that the mean score for male subjects was nearly identical to the mean score for female subjects (Fig. 4.6).

Results for the Research Hypotheses

A three-factor ANOVA procedure was used to assess the effects for gender, grade level, and type of school upon misconceptions in optics among high school students in Bangkok, Thailand. Fourteen research hypotheses were tested.

Hypotheses One to Five

The variables considered include three types of schools (male, female, and coeducational), eight schools within types (two male, two female, and four coeducational), and three grade levels (10, 11, and 12), tested for TTOM scores for the following null hypotheses:

Ho_1 There will be no differences among types of schools (male, female, and coeducational);

Ho_2 There will be no differences among schools within types of schools;

Ho_3 There will be no differences among subjects for grade level (10th through 12th grades);

Ho_4 There will be no interaction effect between grade level and type of school;

Ho_5 There will be no interaction effect between grade level and schools within types of schools;

Based upon a 3 × 3 × 6 matrix for type of school (type), grade level (level) and school within type (school (type)), the summary for the ANOVA for Ho_1-Ho_5 is given in Table 4.2. (Note: For Table 4.2, the level of significance used was .01.)

Table 4.2. Summary analysis of variance for Hypotheses One through Five.

Source of Variation	df	SS	MS	*F*
Among Classes:	23			
Type	2	1256.66	628.33	3.71
School (type)	5	847.92	169.58	6.40**
Level	2	166.57	83.29	3.14
Type x Level	4	214.46	53.61	2.02
Error (classes)	10	265.10	26.51	3.65**
Subjects Within Classes	908	6597.03	7.26	
Total	931	9347.74		

Note: ** = $p < .01$.

Analysis of the data for Ho_1 and Ho_3-Ho_5 indicated that these hypotheses were not rejected at the .05 level of significance, and that significant effects for misconception scores were demonstrated only for schools within type. Therefore, among the types of schools, there were no significant differences among subjects for optics. Moreover, there was no interaction effect between type of school and grade level, whereas the results indicated that there was an interaction effect between grade level and school within type.

Hypothesis Six-Eleven

For the grade levels 10-12, Ho_6-Ho_{11} scores were analyzed for the effects of type of school and school within type, as follows (the level of significant, where appropriate for purpose of illustration, is given as .01.):

Ho_6 There will be no differences among 10th grade subjects for type of school;

Ho_7 There will be no differences among schools within type for 10th grade subjects;

Ho_8 There will be no differences among 11th grade subjects for type of school;

Ho_9 There will be no differences among schools within type for 11th grade subjects;

Ho_{10} There will be no differences among 12th grade subjects for type of school;

Ho_{11} There will be no differences among schools within type for 12th grade subjects;

As shown in Table 4.3, Ho_6 and Ho_7 scores indicated that there was a significant difference for school within type at the .01 level of significance for 10th grade subjects, but that there was no significant effect for type of school. Therefore, it was determined that for 10th grade subjects, there were no significant differences for misconceptions in optics by type of school, but that the differences for schools within types among subjects was significant.

Table 4.3. Analysis of variance by type of school and schools within type among 10th grade subjects.

Source of Variation	df	SS	MS	*F*
Among Classes:	7			
Type	2	704.36	352.18	2.25
School(type)	5	783.51	156.70	18.89**
Students Within Classes	344	2854.04	8.30	
Total	351	4341.91		

Note: ** = $p < .01$.

As shown in Table 4.4, Ho_8 and Ho_9 scores indicated that there was a significant difference for school within type at the .01 level of significance for 11th grade subjects, but that there was no significant effect for type of school. Therefore, it was determined that for 11th grade subjects, there were no significant differences for misconceptions in optics by type of school, but that the difference for schools within types among subjects was significant.

Table 4.4. Analysis of variance by type of school and schools within type among 11th grade subjects.

Source of Variation	df	SS	MS	*F*
Among Classes:	7			
Type	2	311.64	155.82	4.69
School(type)	5	166.01	33.20	4.76**
Students Within Classes	329	2294.89	6.97	
Total	336	2772.54		

Note: ** = $p < .01$.

As shown in Table 4.5, Ho_{10} and Ho_{11} scores indicated that there were significant differences for both type of school and school within type at the .05 level of significance for 12th graders. Therefore, it was determined that for 12th grade subjects, there were significant differences for misconceptions in optics for both type of school and school within type.

Results of the analysis, as given in Tables 4.2-4.4, indicated significant effects for type of school for 12th grade subjects, and for school within type for all grade levels. In addition, the results indicated that type of school did not have a significant effect upon grade levels

Table 4.5. Analysis of variance by type of school and schools within type among 12th grade subjects.

Source of Variation	df	SS	MS	F
Among Classes:	7			
Type	2	359.61	179.80	7.11*
School(type)	5	126.52	25.30	4.11**
Students Within Classes	235	1448.10	6.16	
Total	242	1934.23		

Note: * = $p < .05$; ** = $p < .01$.

10 and 11, whereas there was a significant effect for grade level 12. Therefore, from the results of the present study, type of school (i.e., all male, all female, or coeducational) did not have a significant effect upon TTOM scores for grade level and Hypotheses 7, 9, 10, and 11 were rejected.

Hypothesis Twelve to Fourteen

The variables for gender (male and female) and grade level (grades 10-12) were tested for an interaction effect with respect to misconceptions about optics among all subjects. Null hypotheses were as follows:

12) There will be no differences for grade level among coeducational schools;

13) There will be no differences for gender among coeducational schools; and

14) There will be no interaction effect for grade level and gender among coeducational schools.

Table 4.6 presents the ANOVA for the interaction effect among coeducational schools by grade level and gender. There was a significant effect for all coeducational schools (1-4) for grade level, indicating that subjects in each grade level had differing misconceptions about optics. However, there were no significant differences or interaction effects for gender and grade level, indicating that male and female subjects experienced parallel misconceptions about optics. Moreover, misconceptions among subjects for all grade levels were approximately equivalent. Therefore, Hypotheses 12-14 were not rejected.

Table 4.6. Analysis of variance for type of school, grade level, and gender for coeducational schools.

Source of Variation	df	SS	MS	*F*
School	3	204.25	68.08	6.10**
Grade Level	2	52.27	26.14	2.34
Gender	1	2.95	2.95	0.26
Gender × Level	2	8.78	4.39	0.39
Unit Error	15	167.41	11.16	1.63*
Subsampling Error	424	2895.73	6.83	
Total	447	3331.39		

Note: * = $p < .05$; ** = $p < .01$.

Findings Unrelated to the Research Hypotheses

From item analysis, it was found that there were high percentages of certain misconceptions about optics held by both subjects in the highest scored group (27%) and the lowest scored group (27%). Table 4.7 displays the percentage of misconceptions for each item and for each reason by grade level (10-12), gender, and type of schools (male, female, and coeducational). Those misconceptions which were scored for greater than 10 percent for each answer and each reason are shown. A complete listing of percentages for each item is given in Appendix D.

From Table 4.7, there were seven misconceptions selected by subjects by percentages greater than 20 percent.

1) For item 2 (properties of a converging lens), more than 62 percent of all subjects selected the answer which stated when the converging lens was removed, there would be no image if an unfrosted bulb was replaced by a frosted bulb since the filament passing through a frosted bulb could not be seen.
2) For item 4 (images viewed through converging lens), more than 40 percent of all subjects stated that it may be possible to see an image on a wall beyond the screen, and along the lens axis, because once the image visibly appeared, since

Table 4.7. Misconceptions selected for answers and responses for each item, by percentages (greater than 10%).

Item	A	R	L10	L11	L12	F	M	C	S
1	D	4	25.85	24.63	25.51	18.35	32.89	19.42	30.79
2	B*	4	67.05	65.88	62.14	65.15	65.55	64.73	65.91
3	B	1	20.45	12.76	12.76	15.05	16.33	14.06	17.15
	B	4	19.03	19.29	19.34	22.27	15.88	18.08	20.25
	D	3	19.89	21.07	18.93	13.20	27.52	18.30	21.69
4	A	3	18.47	15.13	13.58	11.96	20.36	17.63	14.46
	B*	4	45.45	51.63	46.09	54.43	40.72	47.10	48.55
5	C*	3	26.14	42.14	47.33	38.35	36.47	31.70	42.77
	D	4	28.13	29.97	20.58	28.04	25.50	27.23	26.45
7	C	3	13.07	12.76	16.87	17.32	10.29	17.41	10.74
	C	4	16.19	11.87	17.28	14.43	15.44	16.29	13.64
8	A	1	14.20	14.24	13.58	13.61	14.54	13.17	14.88
9	A*	1	22.44	25.82	28.40	27.22	23.04	26.12	24.38
	B	2	19.32	22.26	20.99	23.09	18.34	20.98	20.66
10	B	2	17.33	19.29	10.70	20.82	11.41	20.09	12.81
11	C	2	15.91	22.55	19.75	16.49	22.37	22.10	16.74
12	C	2	19.03	22.85	30.04	23.30	23.27	26.12	20.66
13	B*	4	47.44	48.96	46.50	49.69	45.64	47.10	48.35
	C	3	19.89	10.68	16.87	18.97	12.30	12.72	18.60
16	C	3	10.80	14.24	13.58	15.05	10.29	13.39	12.19
	D	1	15.63	19.29	17.70	15.05	20.13	17.41	17.56
17	C	2	16.76	23.44	14.81	18.97	18.34	19.20	18.18
18	D	1	20.45	18.69	13.99	19.18	17.00	18.08	18.18
19	A*	4	42.61	36.50	37.86	39.79	38.48	36.16	41.94
21	D	1	18.18	19.29	21.40	20.41	18.34	22.77	16.32
	D	2	13.92	15.13	14.81	16.91	12.08	15.63	13.64
	D	4	18.75	18.99	24.28	23.30	17.00	18.75	21.69
23	D	4	15.34	18.10	15.64	16.91	15.88	19.20	13.84
24	A*	2	50.28	63.80	55.56	62.47	50.11	52.23	60.54
25	A	2	18.47	17.21	18.52	20.82	14.99	19.42	16.74

Note: * = items with percentages greater than 20%.

the eye is not a screen, the actual image would appear only on the nearest surface.

3) For item 5 (light rays), at least 26 percent of all subjects answered that half of the image would disappear, but that the amount of light from the object was not changed since, if half the light was blocked from passing through the lens, half the image and half the brightness would vanish. However, more than 20% of the students also responded that half of the image would disappear and the amount of light from the object also diminish since the piece of cardboard would block both light rays and the amount of light.

4) For item 9 (images from the plane mirror), at least 22 percent of all subjects responded that if we moved backward so that angle of view at the mirror became wider, we would be able to see a whole body from a small rectangular mirror.

5) For item 13 (regions of light travel), more than 45 percent of all subjects responded that light could travel infinitely if it did not encounter an opaque object since light could not pass through opaque objects.

6) For item 19 (shadow formation), at least 36 percent of all subjects responded that shadow formations on a cloudy day were difficult to form or

to observe, compared to clear days during which light intensity was decreased.

7) For item 24 (lightning flashes), at least 50 percent of all subjects responded that lightning flashes were an example of the refraction of light in the atmosphere, due to a different amount of ions among the clouds.

There were four items for which the percentage of misconceptions among all subjects was less than 10 percent, including item 6 (reflections on a plane mirror), item 14 (colored light), item 15 (sources of light), item 20 (shadow sizes), and item 22 (light refraction). See Appendices D and G for detailed information.

Summary of Results

This chapter included a presentation of the results of the study, organized in three sections, the development of the instrument, statistical data analysis of the research hypotheses, and findings unrelated to the research hypotheses. For development of the instrument, results of item analysis indicated that the mean scores for item difficulty and item discrimination were .32 and .35, respectively, whereas the item-total score correlation coefficient was .28.

Findings related to consideration of the hypotheses were as follows:

1) The null hypotheses 1, 3, 4, 6, 8, 13, and 14 were not rejected.

2) The null hypotheses 2, 5, 7, and 9-12 were rejected.

Among the findings not directly related to the research hypotheses, there were seven misconceptions that were held by greater than 20 percent of all subjects. The concept areas which reflected the highest degree of misconception included properties of a converging lens, images from a converging lens, plane mirror, light rays, the region of light travel, shadow formation, and lightning flashes.

CHAPTER 5

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

The final chapter is presented in three sections, including a summary of the study, a conclusion with discussion of the findings, and recommendations. The final section includes recommendations for the design of instruments similar to that developed for the present study as well as recommendations for future research.

Summary

The objectives of this study were to construct and to develop a two-tiered multiple choice test for the measurement of student misconceptions in optics at the level of secondary education in Thailand, as well as to investigate the effects of gender, grade level, and type of school upon levels of student misconceptions. To meet these objectives, an instrument was developed, field tested, and then administered to 932 high school subjects from randomly selected 10th through 12th grade classes in Bangkok, Thailand. These classes included all-male, all-female, and coeducational classes.

A mixed analysis of variance model, developed according to guidelines suggested by Milliken and Johnson (1984), was used to investigate the effects of gender, grade level, and type of school upon subject misconception scores in the field of optics.

Findings of the Investigation

A two-tier multiple choice test was developed to measure optics misconceptions of secondary students in Thailand.

Testing hypotheses, findings directly related to hypotheses were as follow:

1) There were no significant differences among types of schools (male, female, and coeducational);
2) There were significant differences among schools within types of schools;
3) There were no significant differences among subjects for grade level (10th through 12th grades);
4) There was no interaction effect between grade level and type of school;
5) There was an interaction effect between grade level and schools within types of schools;
6) There were no significant differences among 10th grade subjects for type of school;
7) There were significant differences among schools within type for 10th grade subjects;
8) There were no significant differences among 11th grade subjects for type of school;
9) There were significant differences among schools within type for 11th grade subjects;

10) There were significant differences among 12th grade subjects for type of school; and

11) There were significant differences among schools within type for 12th grade subjects.

12) There were no significant differences for grade level among coeducational schools;

13) There were no significant differences for gender among coeducational schools; and

14) There were no significant interaction effect for grade level and gender among coeducational schools.

Therefore, for the research hypotheses, a summary of findings is as follows:

1) The null hypotheses 1, 3, 4, 6, 8, 13, and 14 were not rejected.

2) The null hypotheses 2, 5, 7, and 9-12 were rejected.

Findings Not Directly Related to the Hypotheses

Findings from item analysis, and not directly related to the hypotheses, revealed that more than 20 percent of the subjects commonly held seven misconceptions. These misconceptions were derived from concepts of the properties of a converging lens, images from a converging lens, plane mirrors, light rays, regions of light travel, shadow formation, and lightning flashes.

Conclusions

The following conclusions were derived from the findings of the investigation as directly related to the research hypotheses:

1. Testing of the instrument: The paper-pencil test, based upon a pattern of two-tiered multiple choice questions and reasons developed for this study, confirmed the validity, or the appropriateness, meaningfulness and usefulness, of inferences from scores obtained from the administration of the Two-Tiered Optics Misconception (TTOM), based upon acceptable levels as demonstrated by criteria-evidence.

2. Testing the hypotheses: Three variable factors, gender, grade level, and type of school, were measured for their effect upon student misconception scores in the area of optics within the field of physics. It was determined that gender, grade level, and type of school did not have significant effects upon subject misconception scores among Thai high school students. However, the subgroup school within type (i.e., two male, two female, and four coeducational schools) was found to have a significant effect upon subject misconception scores. In addition, when fixed grade levels were considered (Ho_6-Ho_{11}), it was determined that there were significant differences in misconceptions among 12th grade subjects from different types of schools (male, female, or coeducational).

Conclusions Not Directly Related to the Hypotheses

From the findings derived from item analysis, it was concluded that certain consistent misconceptions in area of optics existed among Thai physics students at the level of secondary education. These misconceptions were related to the properties of a converging lens, images from a plane mirror and a converging lens, light rays, regions of light travel, shadow formation, and lightning flashes. However, these conclusions were limited to the high school science students in Bangkok, Thailand.

Discussion Relative to the Conclusions

Discussion of relevant conclusions is presented in three parts. The first is related to instrument development. The second part concerns variables that possibly have an effect upon misconceptions among science students. The third part is confined to misconceptions among science students in the area of optics.

Development of the Instrument

The findings of the present investigation reveal that the validity, or the appropriateness, meaningfulness and usefulness, of inferences from scores obtained by administration of the TTOM were at acceptable levels, based upon criteria-evidence. From item analysis determination, the item difficulty index ranged from 0.17 to 0.64 and the discrimination index ranged from 0.20 to 0.55. The item-total score correlation ranged from 0.19 to 0.45, and reliability was established as .85. These findings were in agreement with those of Tobin and Capie (1981), Haslam and Treagust (1987), and Hsiung (1989).

The findings for tests of the TTOM contribute to the conclusion that it was a difficult test for Thai high school science students insofar as the two-tiered test format did not encourage guessing at correct responses. That is, from a multiple choice range of options, subjects had to consider both the correct answer and a relevant response to demonstrate the accuracy of answers. In addition, Thai high school science students were more familiar with physics tests that required calculation procedures to determine solutions than they were to tests which measured the accuracy of their conceptions in the physics area of optics. This factor provides one explanation for the high difficulty index of the TTOM (.32). At the same time, reliability of the field study and the TTOM were established at .81 and .85, respectively, indicating that the instrument was internally consistent in the measurement of misconceptions about optics.

Effect of Variables Upon Misconceptions

The effects of gender, grade level, and type of school were the variables considered for this investigation, and the effects for each variable is discussed in the following paragraphs.

1. Gender: In Thailand, the three types of schools in secondary education are all-male, all-female, and co-educational institutions. From the findings of the present study, gender did not have a significant effect upon misconceptions among high school students. This finding is in agreement with those of Dai (1991), Zeraga et al. (1986), Klainin et al. (1989), Bouvens (1987), and Tobin and Garnett (1987). The means for female and male students for misconceptions were 6.13 and 6.31, respectively, or comparable values. From checking percentages across all distractors for each item (Appendix G), it was determined that female and male students responded similarly to most of the distractors, indicating the existence of similar misconceptions about optics for gender. However, this finding differed from those of Za'Rour (1975), who found that males held fewer misconceptions in science than did females, and Al Methan and Wilkinson (1988). For the latter study of Kuwait students, females scored significantly higher than males for all science subjects.

2. Grade level: Students in Thailand are instructed in the properties of optics, light, the lens, mirrors, and colors beginning in grade 9 in integrated science classes and continued in the 11th grade in physics classes. Thus, for the present study it was assumed that 12th grade subjects would have fewer misconceptions about optics than

those from either the 10th or 11th grades. However, findings indicated no significant difference in misconceptions about optics among subjects in either the 10th through the 12th grades. From consideration of mean scores by grade level (Figure 4.3), 10th grade subjects scored higher than either of the higher two grades (i.e., 10th grade subjects had fewer misconceptions than subjects of either grade 11 or 12), a finding not in agreement with the assumption of this study with respect to grade level. In addition, this finding was not in agreement with results obtained by Stepan et al. (1986) and Westbrook (1988), both of whom concluded that grade level/age had an effect upon the state of misconceptions. Moreover, this finding stands in contrast to the Piaget (1974) concept of cognitive stages.

The exceptional nature of the finding with respect to grade level may be related to the structure of education in Thailand. University education in Thailand is available only to students who have completed the upper secondary level of education. To cope with university applications in excess of space, admissions are based upon competitive national university entrance examinations. A high school certificate (*Matayom-suksa-torn-ply*) is required to take these examinations. Certificates may be obtained only by completing the secondary 12th level, or by passing the adult education comprehensive exam, a non-formal educational process provided to the out-of-school population.

It has thus become practical and traditional for Thai students in the 10th and 11th grades of the formal system to attempt to pass the comprehensive exams for non-formal education. If both the comprehensive and university entrance exams are passed, no matter the grade level of the individual, the right is obtained to a place in the university system. Thus, high achievement students who pass the exams can enter as university students as early as the completion of the 10th grade.

This means that the 11th grade consists of students who have been unable to pass the necessary entrance examinations, or who have passed the university exam but who are otherwise unsatisfactory to the faculty in which they have chosen to enroll, or students who are still preparing to pass exams to enter medical school or an engineering faculty. In the end, 12th grade students are those who have failed the necessary university exams, or who want to continue in the vocational education. For example, the grade point averages of these students are in the range from 1.00 to 2.80. This highly competetive situation provides at least a partial explanation why 10th grade subjects had fewer misconceptions than subjects from either the 11th or 12th grades.

3. Type of school: In Thailand, the earliest formal education was conduced in Buddhist monasteries. This sole source of semi-public education was further restricted only to males. Female schools were confined to the palace and

then largely to the daughters of the aristocracy and the clergy, who studied the arts of cooking and crafts.

When public schools were established for both boys and girls, the educational patterns were derived from the English educational system. By the early 20th century, owing to the influence of American educational systems, coeducational schools were established, but the traditional schools (i.e., female and male schools) were the first choice of those parents who wished further schooling for their children. If children failed to pass the entrance examinations for traditional schools, they would then be enrolled in the coeducational schools. This meant that the traditional schools had greater opportunity to screen students than did the coeducational schools. As a result, it may be presumed that the average mean scores for traditional schools and coeducational schools should differ.

From the findings of the present study, the average mean scores of male schools were higher than those for either female or coeducational schools (Figures 4.5 & 4.6), but there were no significant differences in misconception scores among the three types of schools. These results were not in agreement with the findings of Bouvens (1987). Thus, from the examination of specific variations within types of schools, it was found that schools within type had a significant effect upon student misconceptions. This could imply that the state of misconceptions among students was specific to the quality of education offered by individual schools.

Misconceptions in Optics

Misconceptions in the area of optics for certain concepts were consistently held by Thai high school science students in all grade levels. This finding was in agreement with those reported by McDermott and Goldberg (1986), Mohapatra (1988), Smith (1987), and Brown and Clement (1987). It is assumed that these misconceptions were consistent to the degree they were related to the events of daily living. For example, when subjects were asked how to expand the range of vision of a mirror image (item 9, Appendix H), a high percentage responded by indicating backward movement, just as they would when standing in front of a mirror.

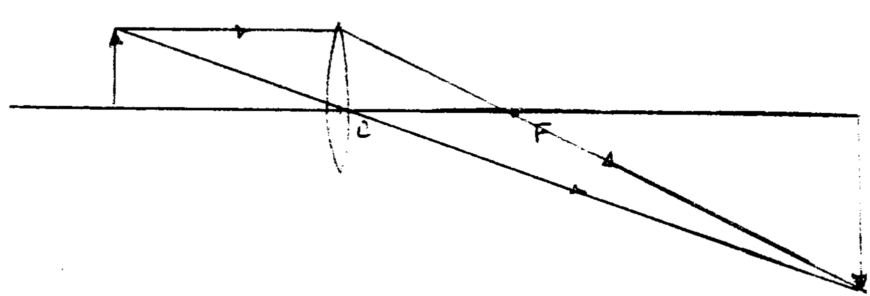
Recommendations

Recommendations from the present study are presented in two parts: (a) recommendations for practice, and (b) recommendations for future research.

Recommendations for Practice

From review of the literature of misconceptions experienced by students in high school science classes, and as a general recommendation for Thai Ministry of Education, the use of textbooks, the techniques of instruction appropriate to secondary education in Thailand as well as to physics teachers should be subject to serious review.

1) Textbooks: If science textbooks are based upon inquiry-oriented learning, whereas instruction is based upon a lecture approach, students will tend to acquire short-term knowledge rather than the procedural knowledge required to interpret long-term concepts (Dai, 1991). Thus, it brings to misconceptions easily. This is an appropriate situational description of physics instruction in Thai classrooms. For example, TTOM item 5 (Appendix G), as derived from a textbook, is based on a simple method of locating an image from a converging lens (Figure 5.1):



Starting from the first line, draw a straight line parallel to the axis until it meets the lens surface, then draw it through the focal lens. Draw a second straight line past the center of the lens. The location of the image of a converging lens is at the connection of two lines.

Figure 5.1. Diagram for light rays for a converging lens.

Based upon this example, most students will believe that only two lines are necessary to locate an image from a converging lens, demonstrating why high percentages of subjects in the present study experienced misconceptions in concepts of a converging lens.

2) Instruction: Two of the most important factors which affect instruction in Thailand are the background of the teachers and methods of instruction (Sangsupata, 1982, 1984). In Thailand, the background preparation of science instructors is generally inadequate. Sangsupata (1982) investigated science misconceptions (i.e., biology, chemistry, and physics) among preservice teachers in Thailand (i.e., senior class majors in science) and 12th grade science students. Findings revealed that numerous misconceptions were widely held by preservice teachers. These were students who, within one to two years, could be expected to find places in science classrooms, and who then could be expected to provide instruction based upon their own misconceptions. From the second factor, most physics instructors in Thailand teach physics concepts as they would those of mathematics. As previously reviewed, the highly competition system of university entrance examinations causes physics teachers to concen-

trate upon calculation exercises and problem solutions. In this situation, students practice problem solutions for complicated questions at the cost of neglecting basic conceptual knowledge. For example, in item 1 of the TTOM, when students are asked to find the focal length of a lens, the exercise they learn can be completed in less than one minute.

3) Physics teachers: Since the best means to replace misconceptions is to construct new concepts which provide better explanations of preexisting concepts among learners (Bodner, 1986), physics instructors should be encouraged to construct a two-tiered multiple choice test for the diagnosis of student misconceptions both before and after conceptual instruction. Use of a two-tiered multiple choice format will provide not only the benefits of objective itemization, such as ease of machine scoring, economy of response time, or lack of dependency upon student writing skills, it also enables the inclusion of specific misconceptions and provides detailed information about the frequency distribution of these misconceptions for given student populations (Tamir, 1989). In addition, compared to a traditional multiple choice test, this format serves to reduce student guessing at answers.

However, it is quite difficult to construct two-tiered tests, especially the sets of reasons provided in the second tier of responses. Those who develop tests should pay attention to student errors to either clarify misconceptions or to avoid misunderstandings. Birenbaum and Tatsuoka (1987) found that incorrect responses were more important than correct responses, and that the more informative the responses, the better the performance. If students are to complete schooling free of misconceptions or with fewer misconceptions in the basic concepts of science, this success will be owed not only to student efforts, but also to the efforts of both teachers and the educational system.

Recommendations for Further Research

The followings recommendations for future research are specific to the findings of the present investigation:

1) This study was conducted among secondary schools in Bangkok, Thailand, and should be replicated for other provinces or in other educational regions to confirm the findings.
2) A two-tiered multiple choice pattern for the measurement of student misconceptions should be developed and investigated for additional conceptu-

al topics in physics and other science disciplines.

3) Additional research should be conducted to determine which teaching strategies serve most efficiently to reduce student misconceptions in specific content areas.

4) Additional research should be conducted to investigate other factors that may have an effect upon student misconceptions in science. These factors may include language difficulties or the degree of similarity among alternatives.

5) Since misconceptions among instructors may influence misconceptions among students, additional research should be conducted to identify misconceptions among physics teachers.

6) Since a principal advantage of the two-tiered multiple choice is the reduction of guesswork responses, research should be conducted to compare the degree of guessing between the use of traditional multiple choice group tests and the use of the two-tiered multiple choice group test.

For the following reasons, further study of the instrument developed for the present study is also recommended:

1) The TTOM test items are too difficult and there was a fairly low item-total score correlation.

Thus, additional study of the instrument is recommended.

2) Item analysis is an important procedure for instrument development, but the determination of item difficulty, item discrimination, and the item-total score correlation for a two-tiered multiple choice test are more complicated than for traditional multiple choice tests since second-tier reason choices must be provided. It is a questionable practice to analyze only the first-tier answer choices since ignoring the second-tier responses will affect not only item analysis, but instrumental reliability as well. A computer program for the analysis of two-tiered item tests is not currently available. For the present study, a two-tiered item analysis program was developed by the reseacher. In this area, further research is recommended to establish the validity of the approach developed to confirm item analysis and reliability data for the TTOM.

3) The present investigation also brings into issue the question of how many items are appropriate for a two-tiered multiple choice test? For reason of the structure of this type of test, subjects must seemingly complete 40 responses to complete a 20-item, two-tiered test. In general, longer tests provide greater reliability (Mehrens

& Lehmann, 1991), but tests which are too long tend to both bore and exhaust students. In addition, elementary students cannot be expected to undergo tests that are equally as lengthy as those administered to high school or college students. Moreover, testing time limitations are also a factor that must be considered. From previous research (Dai, 1991; Haslam & Treagust, 1987; Hsiung, 1989; Tobin & Capie, 1981; Treagust, 1988), it has been recommended that the maximum number of items should be from 20 to 30. This issue should be investigated for student groups at different age levels.

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APPENDICES

Appendix A

Expert Panel Members

PHYSICS PROFESSORS

Dr. Rachanee Rukveeradhum, Associate Professor
Department of Physics, Chulalongkorn University

Dr. Buncha Panacharoensawas, Assistant Professor.
Department of Physics, Kasetsart University

Mr. Piroj Uthrapong, Assistant Professor
Department of Physics, Kasetsart University

SCIENCE EDUCATORS

Dr. Pramuan Siripunkaew
The Institution for the Promotion of Teaching Science and Technology

Mr. Chaiyan Sirichote
Department of Physics, The Institution for the Promotion of Teaching Science and Technology

Dr. Chanpen Chuapanit, Associate Professor
Department of Secondary Education
Chulalongkorn University

HIGH SCHOOL PHYSICS TEACHERS

Mr. Pitak Sa-Ngiamsin
The Demonstration School, Pathumwan
Srinakharinwirot University

Mr. Sujin Lienjarunerat
Kasetsart Demonstration School
Kasetsart University

THAI LANGUAGE ADVISORS

Somchit Watanakulung, Assistant Professor
Specialist in Thai Language
Faculty of Education,
Kasetsart University

Dr. Mantmart Leesatayakun
Mastery in English to Thai translation
Faculty of Education
Kasetsart University

Dr. Rachanee Rukveeradhum, Associate Professor
Mastery in Physics (optics) and English
Department of Physics
Chulalongkorn University

Appendix B

Open-Ended Test for the Measurement of Misconceptions in Optics

MISCONCEPTIONS ABOUT OPTICS

INSTRUCTIONS:

This test consists of 30 questions which examine your misconceptions about optics. Read each question carefully and take your time to answer it. Don't forget to give reasons supporting your answers. Write your answer in the space provided.

1. What is your idea of the definition of light?

____

____

2. How far can the light travel?

____

____

3. "When the light source is switched on, a room is illuminated at the same time." From this sentence, can we say that light has infinite speed? Why?

____

____

4. Give me three examples of "light"

____

____

5. What are the differences between light and heat?

____

____

6. What should we call the following: the sun, a flashlight, a candle, a lamp?

____

7. Consider these sentences: "Light is something which is contained in atmospheric space as air. The amount of light will show as brightness." Are these sentences correct? Why?

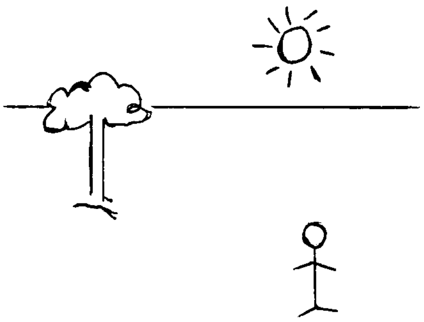
8. What happens when we hang a wet cloth outside in the light? Does the cloth become warm and dry? Why?

9. Do you believe that light contains warmth in itself? Explain.

10. Can we see an object colored black? Why?

11. Can we see an object colored white? Why?

12. How can we see objects? You can draw light rays on this diagram, if you prefer.



13. When you go for a vacation at the beach, if you observe the sky you can see a blue color similar to the color of the sea. Why are they the same? Explain.

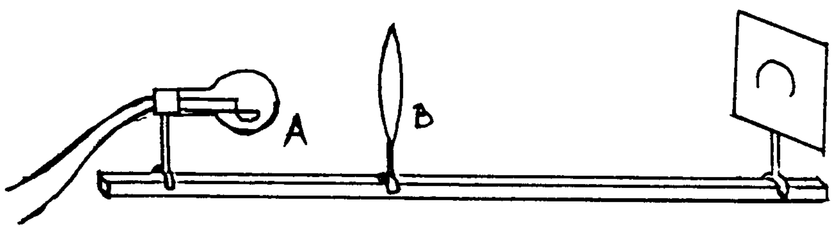
___

___

___

The following experiment is for questions 14 to 18.

The experimental kit consists of object A (an unfrosted light bulb with a horseshoe-shaped filament), a converging lens B, and a translucent screen C, all mounted on an optical bench. The converging lens is moved until a sharp image of the filament can be observed on the translucent screen, as shown below.



14. If the converging lens B is removed, and object A and screen C are left where they were, would anything be changed? Why?

___

___

15. If an unfrosted bulb is replaced by a frosted bulb, would anything be changed? Why?

___

___

16. What is the difference between a frosted bulb and an unfrosted bulb?

___

___

17. If we move screen C toward the lens, would anything change on the screen? Why?

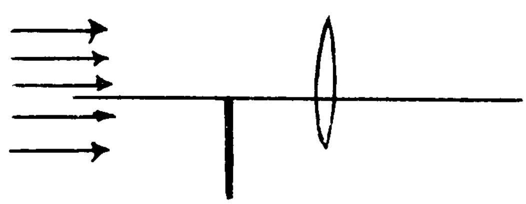
18. If the screen is removed, would anything be changed? Why?

19. Consider this situation. What will happen if a converging lens is covered by a black card, as shown in 19.1 and 19.2?

19.1

Answer

19.2



Answer

20. What kind of optical instrument provides only an erect image?

21. A small mirror is hung on the wall and the top of your head is level with the top edge of the mirror. One day you stand about 1 meter in distance in front of the mirror, and you find that your mirror image extends to about 20 cm below neck level. What should you do to see your whole body in the mirror? Explain.

22. Can humans see as well in the dark as animals? Why?

23. Explain your ideas about "no light" and "dark".

24. What is the definition of a shadow?

25. What is the relationship between shadow size, the source of light, the distance from and object to a screen, and from the source of light to the object?

26. Is it difficult or easy to form shadows on a cloudy day?. Explain.

27. What is the definition of the refraction of light?

____

____

28. If light travels toward a perpendicular line from air to water, will there be a refraction phenomenon? Why?

____

____

29. Why is light passing through a clear red glass red in color? Explain?

____

____

30. What does this sentence mean: Lightning flashes are an example of non-rectilinear propagation?

____

____

____

Appendix C

Item Pool for Two-Tiered Optics Misconception Test

MISCONCEPTIONS ABOUT OPTICS

INSTRUCTIONS

This test consists of 30 questions which examine your misconceptions about optics. Each question has two parts: a multiple choice response and a multiple choice reason. You are asked to make one choice from both the multiple choice response and one choice from the multiple choice reason for each question.

Answer all questions on the answer sheet.

1. Read each question carefully.

2. Take time to consider your answer and carefully select a reason which best represents your thinking.

3. Record your answer by placing an "X" over the letters which match your answer and your reason on the answer sheet.

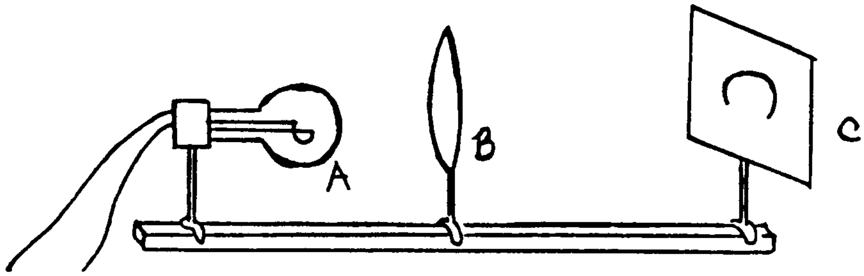
   e.g. A B C D a b c d

4. If you change your mind about an answer, cross out the old answer and add the new choice as shown

   e.g. A B C D a b c d

5. If the provided answers or the provided reasons do not represent your thinking, write your concept in the space provided at the right of each question.

DON'T FORGET TO RECORD YOUR DETAILS ON YOUR ANSWER SHEET.



For questions #1 to #4, the experimental kit consists of an object A (an unfrosted light bulb with a horseshoe-shaped filament), a converging lens B, and a translucent screen C, all mounted on an optical bench. The converging lens is moved until a sharp image of the filament can be observed on the translucent screen, as shown.

1. If the converging lens B is removed, and object A and screen C are left where they were, would anything be changed?

   A. The image on the screen would become erect and equal in size with the object.
   B. Without the lens there would be no image.
   C. The image on the screen will remain as before, but will become blurred.
   D. The image on the screen will become erect, but the image will be blurred.

   Reason:

   a. The property of a converging lens is to focus light. When there is a converging lens, the image will be clear.
   b. A converging lens flips the image over and an erect image will appear on the screen.
   c. If there is no a converging lens, light rays can't be focused and there will be no image on the screen.
   d. Both a and b

2. If an unfrosted bulb is replaced by a frosted bulb, would anything be changed?

   A. The image on the screen would become erect and equal to the size of the object.
   B. Without the lens there would be no image.
   C. The image on the screen will remain as before, but will become blurred.
   D. The image on the screen will become erect, but the image will be blurred.

Reason:

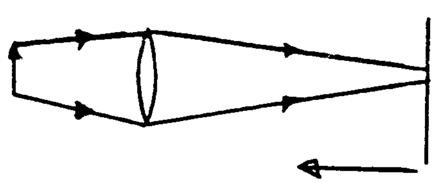
a. The property of a converging lens is to focus light. When there is a converging lens, the image will be clear.
b. A converging lens flips the image over and an erect image will appear on the screen.
c. The light rays become converging rays after passing through a converging lens and the real image will appear.
d. It does not a matter whether there is a converging lens or not. There will be no image on the screen because we can't see through a frosted bulb to the object, a horseshoe-shaped filament.

3. If we move screen C toward lens B, would anything change on the screen?

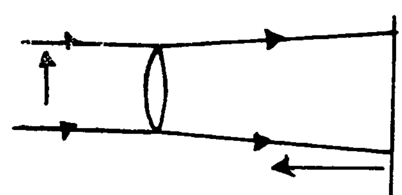
A. The image immediately becomes blurred and then quickly disappears.
B. The image becomes blurred because it is out of focus, and the size of the image will be enlarged.
C. The image becomes blurred because it is out of focus and the size of the image will be small.
D. The image will get smaller, go to a point, invert and then become enlarged.

Diagram supporting the answer above:

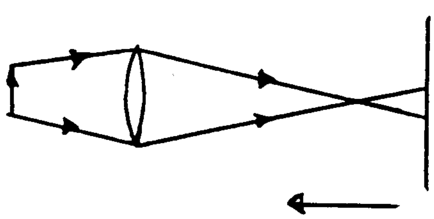
a.



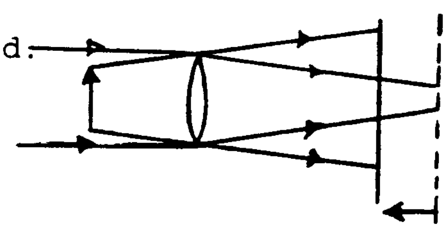
b.



c.



d.



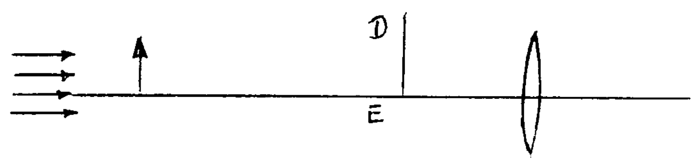
4. If the screen is removed, which of the following items is correct?

A. No image appears.
B. We might be able to see the image on the wall beyond the screen along the lens axis.
C. We might be able to see an image if we can place our eyes at the screen position.
D. If we move beyond the initial screen position and look along the lens axis toward the lens, we will be able to see an image.

Reason:

a. The image is located at the same position where the screen has been. We are able to see an image because our eye is in the position of the screen.
b. An image occurs in the lens.
c. An image occurs only on opaque surfaces.
d. An image appears in our vision, but since our eye is not a screen, the actual image will only appear on the nearest flat surface.

5. If we use a piece of cardboard DE to cover the upper half of the lens, leaving the lower half uncovered, would anything change on the screen?



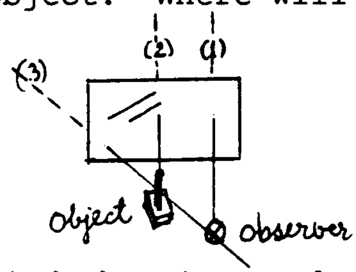
A. A whole image still appears on the screen but the brightness of the image is not changed.
B. A whole image still appears on the screen and the brightness of the image is diminished.
C. Half of the image will disapppear, but the amount of light from the object is not changed.
D. Half of the image will disappear and the amount of light from the object will also diminish.

Reason:

a. Light rays can go through the uncovered part, but this will diminish brightness.
b. Light rays can go through the uncovered part and its brightness will not change.
c. If half the light is blocked from passing through the lens, half the image and half the brightness will vanish.
d. If half the light is blocked from passing through the lens, half the image will vanish, but because

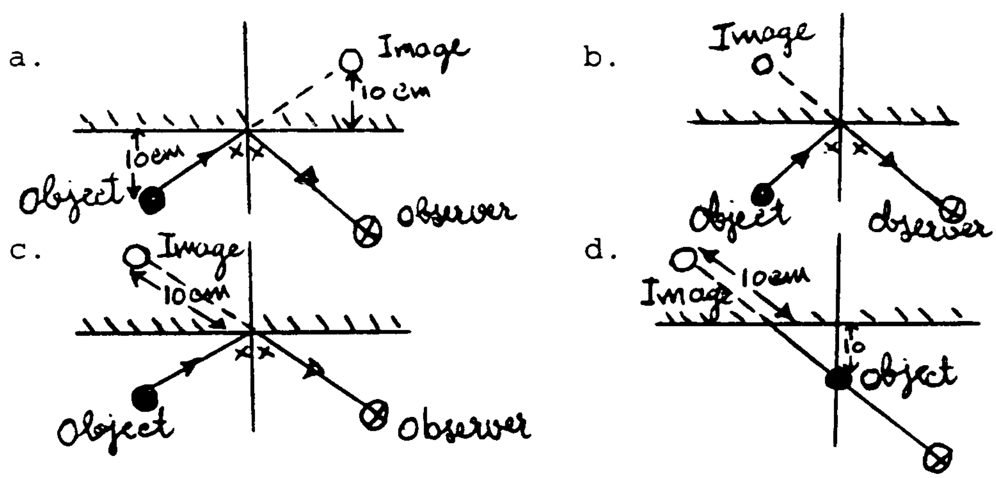
of the diffraction property its brightness will not change.

6. An experiment kit consists of a vertical plane mirror about 20 X 30 cm in size. An object is placed about 10 cm in front of the mirror. An observer is seated about 50 cm in front of the mirror, slightly to the right of the object. Where will an observer see an image?

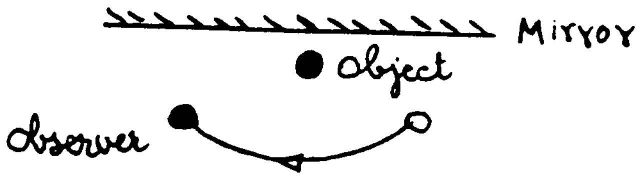


A. 10 cm behind the mirror along the perpendicular line between the mirror and the observer (line #1).
B. 10 cm. behind the mirror along the perpendicular line between the mirror and the object (line #2).
C. 10 cm behind the mirror along the line that passes between the observer and the object (line #3).
D. About 10 cm behind the mirror on a line of sight.

Reason: Because the diagram of light ray is...



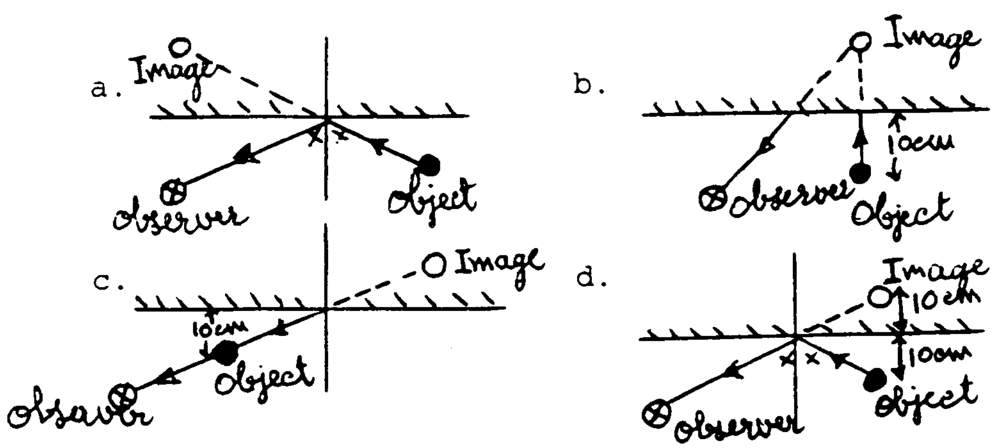
7. If an observer is moved to the left of the previous position, as shown below,



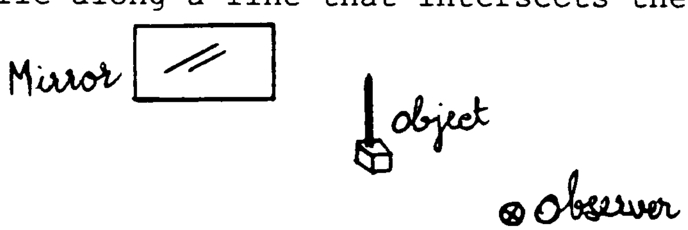
where will the image be located?

A. The image will shift its position to the left behind the mirror.
B. The image will be 10 cm behind the mirror along the line of sight between the observer's eye and the object.
C. The image will shift its position to the right side behind the mirror, along the line connecting the object and the observer.
D. The position of the image doesn't change. It still remains at the previous position, as in item #6.

Reason: Because diagram of the answer is...



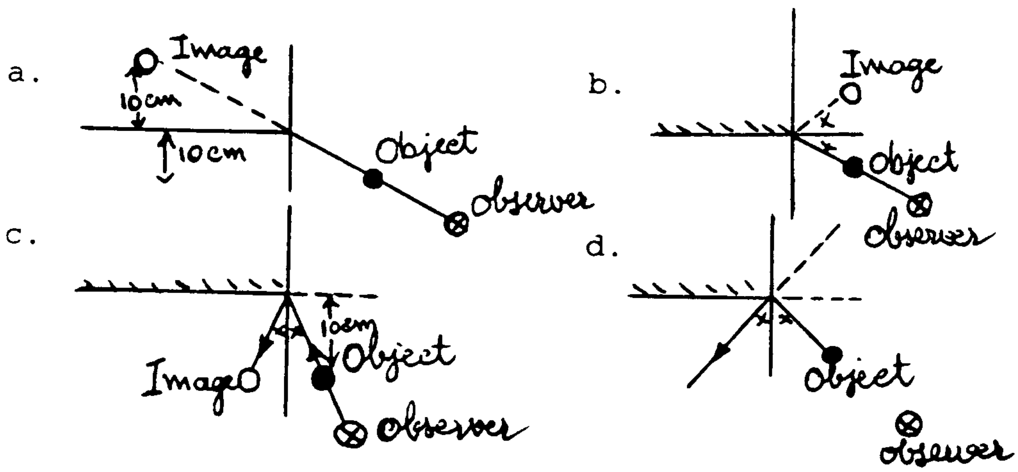
8. An observer is seated in a position that is no longer directly in front of the mirror, but is beyond the right edge. The object is also placed beyond the right edge so that the position of the object and the observer lie along a line that intersects the mirror, as shown.



Which statement is correct according to scientific principles?

A. An observer can see an image located on a line of sight.
B. According to the law of reflection, an observer can see an image located behind the mirror.
C. According to the law of reflection, an observer can't see an image because the image will be located in front of the mirror instead of behind the mirror.
D. An observer can't see an image because the observer is not in the path of the necessary light ray reflecting from the mirror.

A diagram for supporting this idea is...

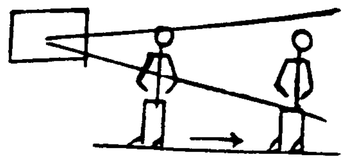


9. A small rectangular mirror is held vertically about one meter in front of the student. The mirror is positioned so that the top of the student's head appears at the top edge of the mirror. The student finds that the image in the mirror extends to about 20 cm below neck level. What can the student do to see more of himself in the mirror?

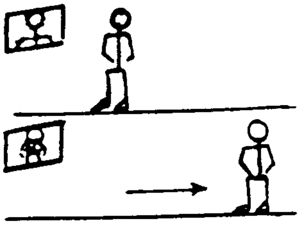
A. The student can see his whole body by moving backward so that the angle of view at the mirror becomes wider.
B. The student can see his whole body by moving away when more of his image will fit into the mirror.
C. A mirror's position must be vertical and below the student's head, then he will see his whole body.
D. There is nothing that can be done as long as the mirror is held and fixed in a vertical position and the size of mirror is not changed.

A diagram for supporting the answer is...

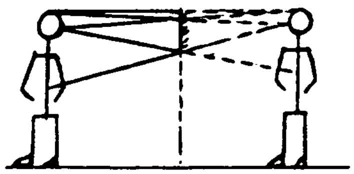
a.



b.



c.



d.

a and b

10. Which is the definition of light?

    A. Light is a form of energy.
    B. Light travels unlimited distance.
    C. Light is energy that stimulates a sense of seeing.
    D. Light is an electromagnetic wave.

    A supporting reason is...

    a. Light can go through space.
    b. Light has an infinite speed.
    c. The eye is a light receiver.
    d. We can see light even when it comes from the universe.

11. According to the scientific method, which sentence is correct?

    A. Light and heat are the same thing.
    B. Light contains warmth. We can prove this by hanging a wet cloth outside in the light. The cloth will become warm and dry.
    C. Light doesn't contain warmth in itself. Heat is radiated from a source of light.
    D. Light and heat are not the same thing, but are found in exact proportions.

    Reason:

    a. The more light, the more warmth.
    b. Light contains warmth and transfers it to any object that it hits.
    c. Both light and heat are energy, which can transform from one form to another.
    d. Light is an electromagnetic wave, but heat is an infrared wave.

12. If we shine a beam of light into a room that has no dust, describe the light beam that you can observe in that room?

    A. With no dust, we can see the light beam clearly.
    B. Light doesn't need a medium for traveling to the eye, so the dust doesn't effect sight.
    C. We cannot see the light beam. Light needs a medium to travel to the eye.
    D. We cannot see the light because there must be a reflector to get light to the eye.

    Reason:

    a. Light can travel through transparence, translucence, and space as well.
    b. Dust is a reflector. Light reflects dust to the eye.
    c. Light is an energy. It has no colors of its own so it required a medium to pass through.
    d. How clear one's vision is depends on the amount of dust in the air.

13. Why can an object be seen if it is black or white?

    A. Because there is a black light or a white light which enters the eyes.
    B. Because the object's color is black or white and the color shines into the eyes.
    C. Because if a light reflecting from the object doesn't enter the eye, we consider it to be black in color. On the other hand, if the reflection of a reflecting light enters the eyes, we consider it to be white in color.
    D. Because if a refracting light from the object doesn't enter the eyes, we consider it to be black in color. On the other hand, if a refracting light enter the eyes, we consider it to be white in color.

    Supportive details:

    a. To see any color is dependent on whether or not that color of light enters the eyes.
    b. Black objects obsorb all of the incident light and reflecting light cannot enter the eyes. But white color reflects all of the incident rays and enters the eyes.
    c. Color is purely a property of an object, not of the light itself.
    d. In the air, black color light refracts light at lower levels than white light.

14. How do we see objects?

A. The light reflection from an object enters the eyes.
B. Light from a source of light reflects from an object and enters the eyes.
C. The light rays from an object enter the eyes.
D. An image occurs at the retina.

Because:

a. This is a property of light reflection.
b. When the retina is stimulated, we see images.
c. Light from an object stimulates a sense of seeing.
d. If there is no light to reflect at an object, no image can be seen.

15. How far can light travel?

A. It can travel until the energy is dissipated.
B. It can travel infinitely if it doesn't encounter an opaque object.
C. Light can travel infinitely.
D. The distance light can travel is limited by the extent of its visible effect.

Reason:

a. Light is a kind of energy. When it travels distances, energy is transferred to the medium until it is dissipated.
b. Light is seen because the optical nerve is alerted. Thus, the distance that light can travel is limited by the vision.
c. Light is an electromagnetic wave. Because light travel is not dependent on the medium, light can travel infinitely.
d. Both b and c.

16. Which statement is correct?

A. The object that has a color, can be seen only if its color is different from the background.
B. All colors together form ranges of light with intensities from black to white.
C. A black colored light has the lowest effect on the optical nerve.
D. Sun light is a white light.

Reason:

a. Components of white light will range from ultraviolet to infrared. It can be confirmed by using a prism. A prism will disperse the white light into its components.
b. A black colored light has the lowest intensity.
c. The optical nerve can't separate a given color if it is alerted by a similar color.
d. The intensity of light is in proportion to its wavelength.

17. If we shine a green colored light onto a red colored light on a white surface, what color will be seen?

A. White
B. Yellow
C. Black
D. Magenta

Because:

a. It is a compound color.
b. It depends upon the surface.
c. A green colored light and a red colored light will mutually absorb until there is no light reflection to enter the eyes.
d. It depends upon the principles of color mixture.

18. Consider these given objects:

1. Sun, 2. Flashlight, 3. Lamp, 4. Candle.

Which one is a source of "light"?

A. #1 only
B. #2, #3 and #4
C. #1, #2, #3, and #4
D. Not any of these choices

Reason:

a. All of them are sources of light.
b. Sources of light and light have the same meaning.
c. These objects cannot light themselves.
d. Both b and c.

19. "When the light source is switched on, a room is illuminated immediately." From this sentence, can we say the light has infinite speed?

A. Yes, we can. The velocity of light is an approximate measure.
B. Yes, we can. The light has a speed faster than our eyes can detect.
C. Yes, we can. Light in this situation occurs by transformation from electrical energy.

D. No, we can't say that. We can measure speed of light even if its speed is faster than our eyes can detect.

Reason:

a. Light velocity is about 186,000 miles/sec.
b. High speed and infinite speed have different meanings.
c. Light is a kind of energy that is transformed from other energies.
d. Both a and b.

20. Why do the sky and the sea have the same blue colors?
A. Lights reflects from the sea to the sky.
B. It is the effect of the scattering of light.
C. In the afternoon, blue colored light can refract better than other colors.
D. It is the nature of the sky that it has a blue color.

Reason:

a. In the afternoon, blue color light reflects better than other colors, reflecting its color toward the sky.
b. The sea has a lot of space area, the reflection of light on the sea surface and the sky are close. As we have seen, it looks like the same colors.
c. The blue colored light can reflect up to the sky and refract it to the eye better than the other colors.
d. The blue colored light can scatter and enter the eye better than the other colors.

21. Which optical instruments provide only erect images?

A. a converging mirror B. a concave mirror
C. a plane mirror D. Both a and c

Reason:

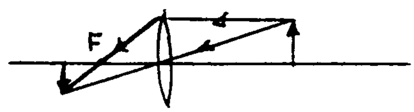
a. A property of a converging lens is that it disperses light. Light rays are supposed to focus only in front of the mirror.
b. A converging mirror or a concave mirror can provide a real image when an object is located near a surface mirror.
c. Depending on the position in which the object is located, all types of mirrors can provide real images.

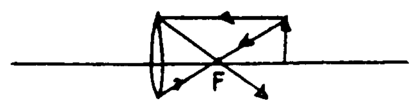
d. It is a property of a plane mirror that only erect images can form behind the mirror.

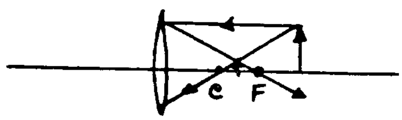
22. If an object is located in front of a converging lens, what kind of image will occur?

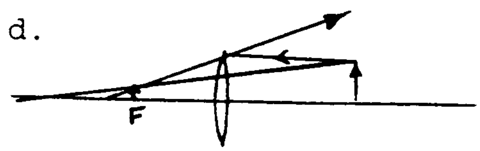
A. An real image behind a converging lens.
B. A real image in front of a converging lens.
C. An erect image behind a converging lens.
D. An erect image in front of a converging lens.

A diagram to support my answer is...

a.


b.


c.


d.


23. Which statement is correct?

A. Shadow formation on a cloudy day occurs with ease, but is difficult to observe compared to clear days.
B. Shadow formation on a cloudy day occurs with ease, but is hard to observe compared to cloudy days.
C. Shadow formation is not dependent on the condition of the sky.
D. On a cloudy day, shadow formation is not possible.

Reason:

a. Clouds absorb the sunlight.
b. Light rays passing clouds are a non-rectilinear propagation of light.
c. On a cloudy day, light intensity is higher than for clear days, but because of the diffuse light it will be hard to form shadows.
d. On a cloudy day, light intensity is lower than for clear days. Thus, no shadows will be formed.

24. The shadow size, bigger, smaller, or equal to an object depends on...

A. Distance of an object from a source of light and distance of an object from a screen.
B. The size of a source of light and an object.

C. The illumination of a source of light.
D. The size of a screen.

Reason:

a. The size of a shadow is large when the distance from an object to a screen is small. Simultaneously, if a screen is far from an object, the shadow will be large.
b. If the size of a source of light is large than an object, a shadow will be smaller than the object.
c. A larger surface for a big screen will provide a larger shadow on that screen.
d. A diminished illumination produces a big shadow. An example is that a shadow during the sunset is longer than at noon.

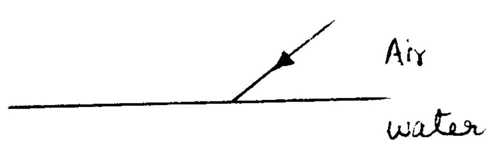
25. From the following statements, which one is correct?

A. Humans and animals can't see anything if there is no light available.
B. Humans can see everything in the dark.
C. Only animals can see in the dark.
D. Humans cannot see in the dark as clearly as animals.

Reason:

a. Animals have a special capability for seeing everything in the dark better than humans.
b. The human iris has vision limits.
c. Light is necessary for seeing. No light means nothing can be seen.
d. The iris can be adjusted by the condition of the light.

26. If light travels from air to water, as shown below,



which answer is correct?

A. The angle of incident will be larger than the angle of refraction.
B. The ratio of the sine of the angle of incident and the sine of the angle of refraction is an index of air.
C. We can't see a light reflection in this phenomenon.

D. The angle of refraction is bigger than the angle of incident.

Because:

a. Reflected light becomes refracted light.
b. Light travels from the thin medium to the thick medium, so the angles of refraction will be smaller than the angles of incident.
c. The angle of refraction is the angle between the water surface and refracted rays.
d. This is a definition of an index of refraction.

27. When light travels from one medium to another, a refraction phenomena occurs. If light travels toward a perpendicular line from air to water, which of the following is correct?

A. There is no refraction in this case because the incident ray is on the normal line.
B. There is no refraction because there is total internal reflection. The light goes backward until we can't see a refraction phenomena.
C. There is a refraction phenomena, but the light reflects backward so it is very hard to say that a refraction is not possible to observe.
D. There is a refraction phenomena because light travels through two media.

Reason:

a. Light travels in a straight line.
b. Light doesn't change its direction.
c. Refraction will occur when the direction or the velocity is changed.
d. Two phenomena, a reflection and a refraction, will occur simultaneously, but inclination toward one phenomena is dependent upon the medium.

28. Why will the light passing through a clear red glass be red in color?

A. Because light passing through a clear red glass is white light, but the red pigment in that glass activates red colored light entering the eye better than other colors.
B. The red color observed is the color of the object, not the color of light.
C. The red color that enters the eye is light reflected from red colored glass.
D. Clear red glass absorbs other colored lights and lets most of the red colored light pass through.

Reason:

a. A clear red glass acts as a red filter.
b. The light passing through colored glass will be changed by the pigment of the glass.
c. For light colors blue, red and green, red light has an intensity higher than the others. Thus, it can be observed easily and clearly.
d. A reflection and a refraction phenomena will occur simultaneously, but it will incline toward one of the phenomena, dependent on the medium.

29. Think about the lightning phenomenon which occurs before thunderstorms. Which statement is correct?

A. We can only see the part of the lightning flash that is reflected into the eye.
B. A lightning flash is an example of non-rectilinear propagation.
C. A flash is a kind of a light ray.
D. A lightning flash that enters the eye travels in a straight line.

Reason:

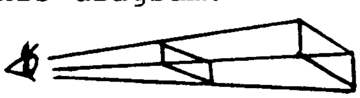
a. A flash is the product of ion exchange in the air.
b. The refracting angle of the light is necessary for vision. It must be an appropriate angle to enter the eye.
c. A flash is not a light ray.
d. There are two kinds of light propagation, rectilinear and non-rectilinear.

30. Half way between an observer and an object, what is the size of an existing image when compared to the object?

A. Half B. Larger
C. Equal D. The question is unclear.

Reason:

a. It follows from the law of perspective.
b. It follows from this diagram.



c. Both a and b.
d. The kind of optical instrument and distance from the object are not given in this question.

Appendix D

Percentages of Responses by Item, Scores for High and Low Groups

Item #	Ans	%Lower	Reason				
		%Higher	1	2	3	4	9
1	a	L	2.78	5.16	.79	5.56	-
		H	-	1.98	-	.79	-
	b	L	1.19	2.78	21.43*	7.14	-
		H	.40	1.98	55.56*	2.78	-
	c	L	13.89	.40	1.98	6.35	-
		H	1.59	-	.79	.79	-
	d	L	7.94	2.38	1.59	18.65	-
		H	4.76	.79	.40	27.38	-
	no ans	L	-	-	-	-	-
		H	.40	-	-	-	-

Item #	Ans	%Lower	Reason				
		%Higher	1	2	3	4	9
2	a	L	.40	.79	.79	.40	-
		H	-	.40	-	.40	-
	b	L	.79	1.19	7.94*	59.92	.40
		H	.40	.79	27.70*	62.00	.40
	c	L	3.57	.79	3.97	3.57	-
		H	1.59	-	.40	.79	-
	d	L	8.33	1.19	2.78	1.98	.79
		H	2.38	0.79	.40	.79	.40
	no ans	L	-	-	-	-	.40
		H	-	-	-	-	.79

* the correct answer and reason response.
\- no responses in this category.
9 no answer.

Item #	Ans	%Lower / %Higher	Reason 1	2	3	4	9
3	a	L	1.98	1.59	5.95*	2.38	.40
		H	5.95	.40	28.17*	1.19	-
	b	L	9.92	12.30	5.95	19.44	.79
		H	7.94	1.19	2.38	15.48	.79
	c	L	2.38	1.59	9.92	2.78	-
		H	3.57	.40	5.16	.79	-
	d	L	3.57	.40	16.27	5.56	.79
		H	.79	-	19.84	5.56	.40
	no ans	L	-	-	-	-	-
		H	-	-	-	-	-

Item #	Ans	%Lower / %Higher	Reason 1	2	3	4	9
4	a	L	1.59	1.19	15.87	4.76	-
		H	.40	.79	14.29	2.38	1.19
	b	L	1.19	.79	14.29	48.41	-
		H	.79	.40	4.76	37.62	.40
	c	L	.40	1.59	.79	.79	-
		H	-	.40	-	.40	-
	d	L	5.56*	-	1.19	1.59	-
		H	33.39*	.40	.40	1.59	-
	no ans	L	-	-	-	-	-
		H	-	-	-	.40	-

* the correct answer and reason response.
\- no responses in this category.
9 no answer.

Item #	Ans	%Lower / %Higher	Reason 1	2	3	4	9
5	a	L	.79	6.35	1.59	.40	-
		H	.79	1.59	.40	-	-
	b	L	14.65*	2.78	.40	.79	.40
		H	34.42*	0.79	.40	-	-
	c	L	1.19	2.78	34.13	2.78	-
		H	.40	.40	37.70	.40	-
	d	L	1.59	.40	2.78	25.79	-
		H	.40	-	.40	21.83	-
	no ans	L	-	-	-	-	.40
		H	-	-	-	-	-

Item #	Ans	%Lower / %Higher	Reason 1	2	3	4	9
6	a	L	7.94	2.78	3.57	2.38	.40
		H	2.78	3.57	1.19	-	-
	b	L	6.75	11.11*	8.73	3.97	.79
		H	.40	64.68*	2.38	.40	-
	c	L	2.38	7.54	9.13	11.11	.79
		H	.40	7.14	3.57	5.95	-
	d	L	3.17	2.38	6.75	6.35	-
		H	.79	3.17	1.19	1.98	-
	no ans	L	.40	-	-	-	1.59
		H	-	-	-	-	.40

* the correct answer and reason response.
\- no responses in this category.
9 no answer.

Item #	Ans	%Lower / %Higher	Reason 1	2	3	4	9
7	a	L	12.30	1.98	3.17	2.38	-
		H	5.56	.40	.40	1.98	-
	b	L	.79	5.56	2.38	4.37	.40
		H	.40	1.98	.79	7.54	-
	c	L	4.37	3.97	21.03	15.48	.40
		H	.79	2.78	5.95	11.11	-
	d	L	3.17	5.56	4.37	7.54*	.40
		H	.40	7.54	.40	51.19*	-
	no ans	L	-	-	-	.40	-
		H	-	-	-	-	.79

Item #	Ans	%Lower / %Higher	Reason 1	2	3	4	9
8	a	L	13.89	4.76	2.78	1.59	-
		H	9.52	1.19	.40	-	-
	b	L	7.94	4.76	3.97	1.19	-
		H	2.38	2.78	1.19	.40	-
	c	L	3.57	7.54	12.70	6.35	.40
		H	.79	.40	7.14	4.37	-
	d	L	1.98	8.73	4.76	12.70*	-
		H	.79	5.56	4.76	57.54*	-
	no ans	L	-	-	-	-	.40
		H	-	-	-	-	.79

* the correct answer and reason response.
\- no responses in this category.
9 no answer.

Item #	Ans	%Lower / %Higher	Reason 1	2	3	4	9
9	a	L	26.59	5.16	6.35	1.98	-
		H	23.02	2.78	2.78	-	.40
	b	L	13.10	20.24	5.16	3.57	-
		H	2.78	19.05	1.98	.40	-
	c	L	.40	.79	6.35*	2.38	-
		H	-	-	27.79*	8.33	-
	d	L	.79	1.19	4.37	1.59	-
		H	.49	.40	9.52	.40	-
	no ans	L	-	-	-	-	-
		H	-	-	-	-	-

Item #	Ans	%Lower / %Higher	Reason 1	2	3	4	9
10	a	L	1.19	.40	1.19	-	-
		H	-	.40	.40	-	.40
	b	L	1.59	23.41	3.97	1.59	-
		H	.40	11.90	1.59	.79	-
	c	L	2.38	20.24	4.76	18.65*	1.19
		H	-	2.78	3.57	63.49*	1.19
	d	L	1.98	3.57	9.92	3.97	-
		H	4.37	1.59	5.16	1.19	-
	no ans	L	-	-	-	-	-
		H	-	-	-	-	.79

* the correct answer and reason response.
\- no responses in this category.
9 no answer.

Item #	Ans	%Lower / %Higher	Reason 1	2	3	4	9
11	a	L	16.27	2.38	1.19	3.97	.40
		H	6.35	.40	.40	2.38	-
	b	L	7.54	2.38	1.59	3.17	-
		H	1.98	.79	-	1.98	-
	c	L	2.78	19.84	20.24	1.59	-
		H	-	12.30	6.75	-	.79
	d	L	1.59	10.32*	2.78	1.59	.40
		H	.40	64.68*	.40	-	-
	no ans	L	-	-	-	-	-
		H	-	-	-	-	.40

Item #	Ans	%Lower / %Higher	Reason 1	2	3	4	9
12	a	L	7.14	2.38	.79	-	.40
		H	6.35	.40	-	-	-
	b	L	7.14	13.49	8.73	2.38	-
		H	3.17	8.73	7.14	.40	.40
	c	L	1.19	26.19	2.38	7.14	-
		H	.79	14.29	.40	3.97	-
	d	L	2.38	8.73*	3.17	5.95	-
		H	1.19	50.00*	.40	1.98	-
	no ans	L	-	-	-	.40	-
		H	-	-	-	-	.40

* the correct answer and reason response.
\- no responses in this category.
9 no answer.

Item #	Ans	%Lower / %Higher	Reason 1	2	3	4	9
13	a	L	7.94*	.40	1.19	.79	-
		H	28.97*	-	-	-	-
	b	L	5.16	2.38	4.76	43.25	-
		H	1.19	.40	2.78	48.81	.40
	c	L	7.14	1.19	14.68	1.59	-
		H	1.19	.40	14.68	-	-
	d	L	1.59	6.75	.79	.40	-
		H	-	0.79	-	-	-
	no ans	L	-	-	-	-	-
		H	-	-	-	-	.40

Item #	Ans	%Lower / %Higher	Reason 1	2	3	4	9
14	a	L	6.75	1.19	12.30	.79	-
		H	1.59	-	10.71	-	.40
	b	L	5.56	2.38	3.17	3.57	.40
		H	1.19	.79	.40	1.19	-
	c	L	.40	9.52	3.97	1.19	-
		H	-	5.95	1.19	-	-
	d	L	42.46*	1.19	1.59	2.78	-
		H	75.79*	-	.79	-	-
	no ans	L	-	-	-	.40	.40
		H	-	-	-	-	-

* the correct answer and reason response.
\- no responses in this category.
9 no answer.

Item #	Ans	%Lower	Reason				
		%Higher	1	2	3	4	9
15	a	L	5.56	2.78	5.95	1.98	.40
		H	.79	-	1.59	-	.40
	b	L	1.19	1.19	5.16	.40	.40
		H	-	.40	.40	-	-
	c	L	5.16	10.71	1.98	8.33	.40
		H	.79	1.19	-	.40	-
	d	L	36.51*	3.57	1.98	5.95	-
		H	91.27*	.79	1.19	.40	.40
	no ans	L	-	-	-	.40	-
		H	-	-	-	-	-

Item #	Ans	%Lower	Reason				
		%Higher	1	2	3	4	9
16	a	L	3.17	1.59	3.17	4.37	-
		H	1.59	.79	-	-	-
	b	L	3.57	5.95	3.17	6.75	-
		H	1.59	1.98	-	1.19	.40
	c	L	.40	1.59	21.83	1.98	-
		H	-	.40	6.75	.40	-
	d	L	14.29	7.94	3.17	16.27*	-
		H	12.30	7.14	.79	63.49*	.79
	no ans	L	-	-	-	-	.79
		H	-	-	-	-	.40

* the correct answer and reason response.
\- no responses in this category.
9 no answer.

Item #	Ans	%Lower	Reason				
		%Higher	1	2	3	4	9
17	a	L	5.56	10.71	6.75	3.57	.79
		H	5.16	7.54	3.17	.79	.40
	b	L	1.98	6.75	5.95	15.08*	-
		H	1.19	3.17	3.97	37.30*	.40
	c	L	1.59	17.86	8.73	5.16	1.19
		H	.79	17.06	3.97	7.14	.79
	d	L	1.19	4.37	.79	1.59	.40
		H	1.19	3.57	-	1.59	.40
	no ans	L	-	-	-	-	-
		H	-	-	-	-	.40

Item #	Ans	%Lower	Reason				
		%Higher	1	2	3	4	9
18	a	L	3.57	.40	2.38	5.16	.40
		H	1.59	-	-	.79	-
	b	L	3.17	3.57	10.32	3.17	1.19
		H	.40	1.19	1.19	1.59	.79
	c	L	1.19	5.16	7.94	3.97	-
		H	.40	8.33	.79	1.59	.79
	d	L	15.48	3.97	4.37	23.81*	.79
		H	18.65	-	1.98	57.94*	.40
	no ans	L	-	-	-	-	-
		H	-	-	-	-	1.59

* the correct answer and reason response.
\- no responses in this category.
9 no answer.

Item #	Ans	%Lower	Reason				
		%Higher	1	2	3	4	9
19	a	L	3.57	2.78	9.52	47.22	-
		H	1.98	4.37	7.54	33.86	-
	b	L	1.98	3.57	5.16*	2.78	-
		H	2.38	1.59	29.22*	3.57	.40
	c	L	1.98	2.38	1.98	.79	-
		H	1.19	.79	.40	.40	.40
	d	L	8.33	1.19	2.78	3.97	-
		H	7.54	.40	.40	3.57	.40
	no ans	L	-	-	-	-	-
		H	-	-	-	-	.40

Item #	Ans	%Lower	Reason				
		%Higher	1	2	3	4	9
20	a	L	42.06*	2.78	5.16	14.68	2.38
		H	80.95*	.79	.40	.79	1.19
	b	L	3.97	5.95	1.59	3.57	-
		H	.79	6.75	-	.40	1.59
	c	L	2.78	1.19	1.19	7.14	-
		H	-	.40	.40	4.76	-
	d	L	1.19	.79	.40	1.98	-
		H	-	-	-	.40	-
	no ans	L	-	-	-	-	1.19
		H	-	-	-	-	.40

* the correct answer and reason response.
\- no responses in this category.
9 no answer.

Item #	Ans	%Lower	Reason				
		%Higher	1	2	3	4	9
21	a	L	1.19	2.38	6.35*	1.98	.79
		H	-	1.59	47.62*	1.19	-
	b	L	.79	3.17	1.98	.79	-
		H	-	-	-	-	-
	c	L	6.75	4.76	2.38	1.98	-
		H	5.16	4.76	.40	-	-
	d	L	18.25	18.65	3.17	23.81	.40
		H	15.48	5.95	-	17.06	.79
	no ans	L	-	.40	-	-	-
		H	-	-	-	-	-

Item #	Ans	%Lower	Reason				
		%Higher	1	2	3	4	9
22	a	L	5.16	2.38	5.16	1.98	-
		H	7.14	8.33	.79	2.38	.40
	b	L	4.37	6.35	6.75	5.95	-
		H	2.78	2.38	1.19	2.78	-
	c	L	3.97	3.57	9.92	3.57	-
		H	1.59	2.38	8.33	2.78	-
	d	L	2.38	2.38	27.38*	7.54	.40
		H	.40	3.17	49.60*	3.57	-
	no ans	L	-	-	-	.40	.40
		H	-	-	-	-	-

* the correct answer and reason response.
\- no responses in this category.
9 no answer.

Item #	Ans	%Lower	Reason				
		%Higher	1	2	3	4	9
23	a	L	3.97	2.78	5.16	6.75	-
		H	3.97	.79	-	2.78	.40
	b	L	1.98	3.97	2.38	2.38	-
		H	.79	1.59	.40	1.19	-
	c	L	3.97	1.59	4.76	14.68	-
		H	1.59	.40	.79	7.94	-
	d	L	9.52*	2.38	14.29	18.65	.40
		H	60.71*	3.57	2.38	10.32	.40
	no	L	-	.40	-	-	-
	ans	H	-	-	-	-	-

Item #	Ans	%Lower	Reason				
		%Higher	1	2	3	4	9
24	a	L	4.76	60.71	1.59	2.39	-
		H	3.17	45.63	.40	1.19	-
	b	L	1.19	3.57	2.38	1.59	-
		H	.40	1.59	.79	1.19	-
	c	L	4.37	1.98	1.59	2.38	.40
		H	5.95	.40	.40	.40	-
	d	L	1.19	1.98	4.76*	3.17	-
		H	.79	1.59	35.00*	1.19	-
	no	L	-	-	-	-	-
	ans	H	-	-	-	-	-

* the correct answer and reason response.
\- no responses in this category.
9 no answer.

Item #	Ans	%Lower / %Higher	Reason 1	2	3	4	9
25	a	L	9.52	19.44	3.17	1.19	-
		H	10.71	13.89	.79	-	-
	b	L	5.16	5.95	19.84	1.59	-
		H	1.59	3.57	25.00	-	.40
	c	L	4.37	4.76	4.37	2.78	-
		H	3.97	2.78	1.59	-	.40
	d	L	1.59	1.98	1.59	11.90*	-
		H	-	.40	1.98	32.14*	.79
	no ans	L	.40	.40	-	-	-
		H	-	-	-	-	-

* the correct answer and reason response.
\- no responses in this category.
9 no answer.

Appendix E

Subject Mean Scores by Variable

Type of school	Number of samples	Mean
Co-educational schools	448	6.27
Female schools	246	8.06
Male schools	238	8.95

Grade Level	Number of samples	Mean
10th graders	352	8.09
11th graders	337	7.26
12th graders	243	6.69

Gender	Number of samples	Mean
Male	209	6.31
Female	239	6.13

School Within Type I.D.	Type	Number of samples	Mean
1	C	115	5.58
2	C	126	7.27
3	C	108	6.32
4	C	99	6.51
5	F	122	7.56
6	F	124	8.55
7	M	111	7.28
8	M	127	10.42

Where C = coeducational school, F = female, M = male.

L	Mean scores for all schools by grade level.							
	1	2	3	4	5	6	7	8
10	5.53	6.98	5.98	6.40	9.89	8.94	11.47	8.19
11	5.40	7.40	5.70	6.14	10.11	7.50	9.74	7.53
12	5.12	6.52	5.92	6.05	7.78	7.10	9.88	7.27

Where L = grade level.

Appendix F

Item Difficulty, Item Discrimination and Item-Total Score Correlation

Item	Item Difficulty	Item Discrimination	Item-total score Corrrelation
1	0.38	0.34	.32
2	0.18	0.20	.19
3	0.17	0.22	.20
4	0.19	0.28	.21
5	0.25	0.20	.20
6	0.38	0.54	.43
7	0.29	0.44	.30
8	0.35	0.45	.24
9	0.17	0.21	.19
10	0.41	0.45	.40
11	0.38	0.54	.41
12	0.29	0.41	.27
13	0.18	0.21	.20
14	0.59	0.33	.25
15	0.64	0.55	.45
16	0.40	0.47	.34
17	0.26	0.22	.20
18	0.41	0.34	.30
19	0.17	0.24	.19
20	0.62	0.39	.30
21	0.27	0.41	.29
22	0.37	0.22	.20
23	0.35	0.51	.35
24	0.20	0.30	.25
25	0.22	0.20	.20

Appendix G

Distribution of Responses by Item
Two-Tiered Optics Misconception Test

					R1			
#	ANS	L10	L11	L12	F	M	C	S
1	a	.57	.89	1.23	1.24	.45	1.56	.21
	b	.28	1.19	.41	.82	.45	.67	.62
	c	5.68	9.79	7.00	7.84	7.16	9.60	5.58
	d	7.95	6.23	4.94	7.22	5.82	6.70	6.40
2	a	.00	.30	.41	.21	.22	.22	.21
	b	.28	.59	1.23	.82	.45	.45	.83
	c	1.42	3.56	2.88	1.86	3.36	2.90	2.27
	d	3.13	6.23	4.12	4.95	4.03	3.79	5.17
3	a	5.68	2.08	3.70	3.92	3.80	3.13	4.55
	b	20.45	12.76	12.76	15.05	16.33	14.06	17.15
	c	2.56	2.97	4.53	3.92	2.46	3.79	2.69
	d	1.42	.59	2.47	.82	2.01	2.01	.83
4	a	.57	.89	2.06	.62	1.57	1.12	1.03
	b	.00	1.19	2.06	1.24	.67	1.34	.62
	c	12.78	7.72	12.76	8.25	13.87	9.60	12.19
	d	2.27	3.26	.41	1.24	3.13	2.01	2.27
5	a	1.14	1.48	.00	.21	1.79	.67	1.24
	b	28.41	13.65	18.11	20.41	20.36	22.99	17.98
	c	.85	.59	.41	.62	.67	.67	.62
	d	1.70	.89	.41	1.24	.89	1.56	.62
6	a	5.97	6.53	5.76	6.39	5.82	7.81	4.55
	b	1.42	5.04	3.70	4.12	2.46	3.35	3.31
	c	1.14	.89	2.47	1.86	.89	2.46	.41
	d	1.14	2.37	1.23	1.65	1.57	1.79	1.45
7	a	7.67	8.90	9.88	8.04	9.40	10.71	6.82
	b	1.42	.89	.82	.62	1.57	.67	1.45
	c	2.27	2.67	1.65	3.30	1.12	3.35	1.24
	d	1.14	3.26	2.47	3.51	.89	2.68	1.86
8	a	14.20	14.24	13.58	13.61	14.54	13.17	14.88
	b	5.11	5.34	3.29	6.60	2.68	5.80	3.72
	c	.85	2.67	1.65	1.65	1.79	2.01	1.45
	d	1.99	2.08	1.23	1.03	2.68	1.34	2.27
9	a	22.44	25.82	28.40	27.22	23.04	26.12	24.38
	b	8.24	8.01	8.64	9.69	6.71	11.61	5.17
	c	.00	.00	.82	.00	.45	.45	.00
	d	.28	.89	1.65	.62	1.12	.67	1.03

#	ANS	L10	L11	L12	F	M	C	S
10	a	.00	.30	1.23	.62	.22	.89	.00
	b	1.70	1.19	.41	1.24	1.12	1.79	.62
	c	1.42	.30	1.65	.82	1.34	1.12	1.03
	d	4.55	3.26	4.53	3.51	4.70	3.79	4.34
11	a	9.09	12.17	17.70	15.67	8.95	13.62	11.36
	b	3.13	6.53	5.76	6.19	3.80	6.04	4.13
	c	1.42	2.37	2.47	1.86	2.24	2.90	1.24
	d	.85	.30	1.65	.41	1.34	1.12	.62
12	a	5.11	6.53	7.41	5.77	6.71	6.92	5.58
	b	7.10	4.15	4.53	6.39	4.25	5.80	4.96
	c	.28	.59	2.06	.82	.89	.89	.83
	d	2.27	1.48	2.06	1.86	2.01	2.23	1.65
13	a	16.19	19.29	17.70	15.88	19.69	16.96	18.39
	b	2.27	2.97	4.12	2.47	3.58	4.24	1.86
	c	4.26	2.97	2.88	3.30	3.58	3.57	3.31
	d	.00	1.48	.00	.41	.67	.67	.41
14	a	2.56	3.26	6.17	3.71	3.80	4.02	3.51
	b	1.14	4.45	3.70	2.68	3.36	3.35	2.69
	c	.28	.30	.83	.21	.67	.67	.21
	d	68.47	62.61	49.38	68.45	53.69	57.81	64.67
15	a	2.27	4.15	3.70	3.09	3.58	4.24	2.48
	b	.28	1.48	.82	.41	1.34	.89	.83
	c	1.99	2.67	1.65	2.06	2.24	2.46	1.86
	d	69.32	64.09	67.08	68.04	65.55	56.25	76.65
16	a	1.99	2.08	3.70	2.47	2.46	2.90	2.07
	b	1.70	2.67	2.88	2.06	2.68	3.35	1.45
	c	.28	.00	.00	.00	.22	.00	.21
	d	15.63	19.29	17.70	15.05	20.13	17.41	17.56
17	a	6.25	5.93	4.12	5.57	5.59	6.47	4.75
	b	2.27	1.78	2.06	1.44	2.68	2.23	1.86
	c	1.42	.59	2.06	1.24	1.34	1.79	.83
	d	.85	1.19	.82	.82	1.12	1.12	.83
18	a	1.99	3.26	2.88	2.68	2.68	3.13	2.27
	b	1.42	2.08	5.35	3.71	1.57	3.13	2.27
	c	.57	.89	2.06	.82	1.34	1.79	.41
	d	20.45	18.69	13.99	19.18	17.00	18.08	18.18
19	a	10.23	9.79	7.41	10.52	8.05	11.38	7.44
	b	1.99	.59	2.06	.82	2.24	.89	2.07
	c	.57	.59	1.23	.82	.67	.89	.62
	d	4.83	8.61	7.41	7.63	6.04	7.14	6.61
20	a	62.22	70.62	70.37	68.04	66.67	61.38	72.93
	b	1.99	1.78	.82	.62	2.68	1.34	1.86
	c	.85	.89	1.23	.62	1.34	.89	1.03
	d	.57	.30	1.23	.41	.89	1.12	.21
21	a	.85	.00	.41	.21	.67	.89	.00
	b	.28	.00	.41	.00	.45	.22	.21
	c	6.82	7.12	4.12	7.22	5.15	7.14	5.37
	d	18.18	19.29	21.40	20.41	18.34	22.77	16.32

#	ANS	L10	L11	L12	F	M	C	S
22	a	9.66	7.72	4.12	5.98	9.17	6.92	8.06
	b	1.99	4.45	4.12	2.89	4.03	4.46	2.48
	c	3.41	2.97	3.29	2.89	3.58	3.35	3.10
	d	2.27	.30	.82	.82	1.57	1.34	1.03
23	a	5.40	3.26	4.12	4.74	3.80	4.46	4.13
	b	1.42	2.08	1.23	1.44	1.79	1.79	1.45
	c	1.14	2.67	3.29	1.44	3.13	2.01	2.48
	d	40.63	34.72	17.70	32.16	32.89	26.12	38.43
24	a	12.22	8.31	11.11	12.78	8.05	12.95	8.26
	b	1.42	.89	2.06	1.44	1.34	1.34	1.45
	c	7.39	3.56	2.47	4.33	5.15	4.69	4.75
	d	.85	.89	.82	.82	.89	.45	1.24
25	a	10.23	7.42	11.52	9.07	10.07	7.81	11.16
	b	2.27	4.15	4.53	2.27	4.92	4.91	2.27
	c	4.55	4.75	2.06	4.33	3.58	3.13	4.75
	d	1.42	.30	1.23	1.03	.89	1.12	.83

R2

#	ANS	L10	L11	L12	F	M	C	S
1	a	1.99	3.86	2.06	2.89	2.46	2.68	2.69
	b	3.13	2.67	.00	1.86	2.46	2.90	1.45
	c	.28	.30	.00	.21	.22	.22	.21
	d	.57	1.19	3.29	1.86	1.12	2.23	.83
2	a	.85	.89	.41	.82	.67	.67	.83
	b	1.42	1.78	.41	.62	2.01	1.56	1.03
	c	.28	.30	.41	.62	.00	.22	.41
	d	.85	1.78	2.06	1.24	1.79	1.34	1.65
3	a	.57	1.48	.00	1.24	.22	.67	.83
	b	5.68	9.20	9.47	10.10	5.59	10.27	5.79
	c	.85	.59	.82	.62	.89	1.34	.21
	d	.00	.30	.00	.00	.22	.22	.00
4	a	.57	1.48	.00	.41	1.12	.67	.83
	b	.57	.89	.41	.62	.67	.89	.41
	c	.57	.89	1.65	.41	1.57	1.34	.62
	d	.57	.00	.00	.21	.22	.00	.41
5	a	6.25	1.78	6.58	4.33	5.15	4.46	4.96
	b	1.42	1.48	.82	.41	2.24	1.34	1.24
	c	1.42	2.08	1.23	1.24	2.01	2.46	.83
	d	.28	.59	.41	.21	.67	.89	.00
6	a	3.98	3.56	4.53	3.30	4.70	3.35	4.55
	b	43.47	36.50	27.57	30.31	43.85	25.00	47.73
	c	7.10	7.42	11.52	7.22	9.62	8.71	8.06
	d	2.27	3.86	3.29	3.92	2.24	2.68	3.51
7	a	1.42	1.19	1.65	2.68	.89	1.79	.21
	b	2.84	3.26	3.29	2.47	3.36	4.24	2.69
	c	1.99	5.04	16.87	17.32	2.68	4.02	2.48
	d	5.97	8.01	.82	7.42	5.82	5.58	7.64

#	ANS	L10	L11	L12	F	M	C	S
8	a	1.14	1.48	2.06	2.47	2.24	3.57	1.24
	b	5.11	4.75	3.70	4.95	3.58	4.24	4.34
	c	2.56	3.56	10.29	3.92	5.15	5.80	3.31
	d	5.40	6.82	4.12	6.60	8.05	8.26	6.40
9	a	4.26	4.45	9.47	3.71	4.70	4.24	4.13
	b	19.32	22.26	2.88	23.09	18.34	20.98	20.66
	c	.28	1.19	3.29	1.03	1.12	2.01	.21
	d	1.14	.59	5.76	.62	.89	.45	1.03
10	a	.00	.30	.82	.21	.22	.22	.21
	b	17.33	19.29	1.65	20.82	11.41	20.09	12.81
	c	11.93	13.65	3.70	12.58	14.32	18.08	9.09
	d	3.69	2.97	5.35	3.30	2.01	2.68	2.69
11	a	.85	.89	1.65	1.24	.89	2.01	.21
	b	.85	.59	3.29	1.86	.89	1.79	1.03
	c	15.91	22.55	19.75	16.49	22.37	22.10	16.74
	d	43.75	29.08	24.28	27.63	39.60	22.10	43.80
12	a	1.70	1.78	1.65	1.24	2.24	1.56	1.86
	b	17.05	15.13	7.00	14.64	12.75	16.29	11.36
	c	19.03	22.85	30.04	23.30	23.27	26.12	20.66
	d	26.42	25.52	18.93	21.03	27.52	18.75	29.13
13	a	.00	.30	.00	.00	.22	.22	.00
	b	1.14	.89	1.23	.62	1.57	1.12	1.03
	c	.57	.30	.82	.41	.67	.89	.21
	d	2.27	5.34	3.70	4.12	3.36	4.46	3.10
14	a	.28	.30	2.06	.82	.67	.89	.62
	b	1.70	2.08	2.06	1.86	2.01	2.68	1.24
	c	4.83	7.12	11.11	6.60	8.05	6.70	7.85
	d	.00	.89	.41	.00	.89	.45	.41
15	a	.57	1.19	.82	.82	.89	1.12	.62
	b	.57	.00	.82	.21	.67	.89	.00
	c	6.82	6.82	6.58	5.57	8.05	8.71	4.96
	d	1.14	2.08	.82	1.44	1.34	2.46	.41
16	a	.85	1.19	2.06	1.65	.89	1.12	1.45
	b	3.98	3.56	4.53	5.15	2.68	3.79	4.13
	c	.28	.59	1.65	.82	.67	.89	.62
	d	6.82	6.53	8.64	9.48	4.70	6.92	7.44
17	a	13.35	9.20	3.70	9.07	9.62	9.38	9.30
	b	4.55	6.23	7.41	6.39	5.37	7.14	4.75
	c	16.76	23.44	14.81	18.97	18.34	19.20	18.18
	d	4.26	2.37	1.65	2.06	3.80	2.23	3.51
18	a	.57	.30	.00	.21	.45	.45	.21
	b	1.70	1.78	2.88	2.06	2.01	2.90	1.24
	c	6.25	8.01	5.76	4.74	8.95	4.46	8.88
	d	1.14	1.19	2.06	1.03	1.79	2.46	.41
19	a	3.13	4.15	2.47	2.89	3.80	1.12	5.37
	b	1.42	3.86	3.29	2.06	3.58	3.13	2.48
	c	1.42	.89	1.65	1.24	1.34	1.12	1.45
	d	.28	1.19	1.23	1.24	.45	1.56	.21

#	ANS	L10	L11	L12	F	M	C	S
20	a	2.27	.89	3.70	2.47	1.79	2.90	1.45
	b	9.38	5.04	2.47	5.15	6.94	5.13	6.82
	c	.28	.59	.41	.41	.45	.67	.21
	d	.28	.30	.41	.21	.45	.22	.41
21	a	2.56	.30	2.06	1.24	2.01	2.01	1.24
	b	.85	1.19	2.06	1.24	1.34	1.34	1.24
	c	4.55	6.53	4.53	6.19	4.25	4.69	5.79
	d	13.92	15.13	14.81	16.91	12.08	15.63	13.64
22	a	7.67	5.93	2.06	3.71	7.61	3.35	7.64
	b	5.40	3.26	2.47	3.09	4.70	4.24	3.51
	c	2.27	2.67	2.06	2.06	2.68	1.34	3.31
	d	1.99	1.19	1.23	1.24	1.79	1.12	1.86
23	a	1.99	1.19	.41	1.86	.67	1.34	1.24
	b	1.70	2.37	2.88	2.27	2.24	2.68	1.86
	c	1.70	1.19	2.06	.82	2.46	1.56	1.65
	d	3.13	2.97	2.47	2.47	3.36	3.13	2.69
24	a	50.28	63.80	55.56	62.47	50.11	52.23	60.54
	b	3.41	4.15	7.00	3.71	5.59	6.47	2.89
	c	2.27	.59	.41	1.03	1.34	1.12	1.24
	d	.85	1.78	.82	1.03	1.34	1.34	1.03
25	a	18.47	17.21	18.52	20.82	14.99	19.42	16.74
	b	3.69	4.45	3.29	3.51	4.25	4.69	3.10
	c	3.13	2.97	3.29	3.09	3.13	3.57	2.69
	d	.57	1.19	.41	.21	1.34	1.12	.41

R3

#	ANS	L10	L11	L12	F	M	C	S
1	a	.00	.30	1.23	.41	.45	.89	.00
	b	40.63	38.87	37.04	44.12	33.56	37.05	40.91
	c	1.99	.59	.82	.82	1.57	1.79	.62
	d	.57	.30	1.65	.41	1.12	1.12	.41
2	a	.57	.00	.00	.41	.00	.45	.00
	b	17.05	13.35	12.76	15.05	14.09	13.84	15.29
	c	1.42	2.08	2.88	2.47	1.57	2.68	1.45
	d	.57	.59	3.70	1.86	.89	1.79	1.03
3	a	4.83	5.93	3.70	3.92	6.04	3.79	5.99
	b	2.84	6.82	4.12	4.95	4.25	4.91	4.34
	c	4.55	7.72	6.58	8.04	4.25	7.37	5.17
	d	19.89	21.07	18.93	13.20	27.52	18.30	21.69
4	a	18.47	15.13	13.58	11.96	20.36	17.63	14.46
	b	9.66	9.50	13.58	13.20	7.83	10.27	10.95
	c	.28	.30	.00	.41	.00	.45	.00
	d	.00	.59	.82	.41	.45	.22	.62
5	a	.85	.89	.82	1.44	.22	.89	.83
	b	.00	.30	.82	.00	.67	.45	.21
	c	26.14	42.14	47.33	38.35	36.47	31.70	42.77
	d	.57	2.08	.82	.82	1.57	2.01	.41

#	ANS	L10	L11	L12	F	M	C	S
6	a	1.99	1.19	4.94	2.47	2.46	3.35	1.65
	b	4.55	5.04	5.76	4.74	5.37	6.92	3.31
	c	2.84	8.31	9.05	8.04	4.70	7.59	5.37
	d	3.69	2.97	4.12	2.89	4.25	4.46	2.69
7	a	3.41	1.78	1.65	2.68	2.01	2.90	1.86
	b	2.56	.89	3.29	2.47	1.79	2.46	1.86
	c	13.07	12.76	16.87	17.32	10.29	17.41	10.74
	d	1.70	2.37	.82	1.44	2.01	2.46	1.03
8	a	.57	1.19	2.06	1.65	.67	2.01	.41
	b	1.14	1.48	3.70	2.27	1.57	3.35	.62
	c	7.39	12.76	10.29	12.16	7.83	10.94	9.30
	d	3.41	6.53	4.12	3.92	5.59	5.58	3.93
9	a	9.09	8.31	9.47	7.01	10.96	7.59	10.12
	b	3.69	5.93	2.88	5.77	2.68	5.13	3.51
	c	9.09	6.82	3.29	5.98	7.61	4.24	9.09
	d	11.36	5.64	5.76	5.15	10.74	5.36	10.12
10	a	.28	.30	.82	.41	.45	.67	.21
	b	1.70	2.08	1.65	1.65	2.01	2.23	1.45
	c	5.40	4.15	3.70	5.57	3.36	4.24	4.75
	d	8.24	3.56	5.35	4.74	6.94	4.91	6.61
11	a	1.14	.59	.00	1.03	.22	.67	.62
	b	1.14	.59	.41	.41	1.12	.45	1.03
	c	12.50	11.28	13.58	15.46	8.95	15.63	9.30
	d	1.99	3.26	1.23	1.65	2.91	2.23	2.27
12	a	.57	.00	.41	.21	.45	.22	.41
	b	9.38	8.01	7.82	8.25	8.72	6.47	10.33
	c	.85	.00	2.06	.82	.89	1.34	.41
	d	.57	1.78	1.23	1.24	1.12	1.56	.83
13	a	.57	.59	.00	.21	.67	.89	.00
	b	3.13	3.86	2.88	2.27	4.47	4.02	2.69
	c	19.89	10.68	16.87	18.97	12.30	12.72	18.60
	d	.28	.59	.41	.00	.89	.22	.62
14	a	8.81	10.98	13.58	8.04	13.87	10.94	10.74
	b	1.14	.89	1.23	.82	1.34	1.12	1.03
	c	2.56	1.48	2.47	1.44	2.91	2.68	1.65
	d	1.70	.00	.82	.82	.89	.67	1.03
15	a	3.69	2.08	5.76	4.33	2.91	3.79	3.51
	b	1.70	3.26	1.23	1.86	2.46	2.23	2.07
	c	1.14	1.19	2.06	1.44	1.34	2.46	.41
	d	.85	1.19	2.06	.82	1.79	1.12	1.45
16	a	.57	1.19	1.65	1.03	1.12	1.34	.83
	b	2.27	2.67	.00	1.65	2.01	2.90	.83
	c	10.80	14.24	13.58	15.05	10.29	13.39	12.19
	d	2.56	1.48	2.88	3.30	1.12	3.13	1.45
17	a	2.56	5.04	5.35	4.33	4.03	4.24	4.13
	b	3.69	4.75	4.12	4.95	3.36	3.79	4.55
	c	6.53	4.45	7.00	5.98	5.82	6.70	5.17
	d	1.42	.30	.41	.82	.67	.89	.62

#	ANS	L10	L11	L12	F	M	C	S
18	a	1.14	1.19	1.65	1.24	1.34	1.79	.83
	b	3.69	5.93	4.12	4.33	4.92	4.69	4.55
	c	1.42	4.75	5.76	3.92	3.58	5.36	2.27
	d	1.99	3.56	4.94	3.09	3.58	3.35	3.31
19	a	9.09	7.42	9.47	6.60	10.74	8.71	8.47
	b	8.52	10.68	14.40	9.07	12.75	10.04	11.57
	c	.85	1.48	.82	1.44	.67	2.01	.21
	d	3.13	1.19	1.23	2.47	1.34	3.13	.83
20	a	1.99	1.78	2.06	1.65	2.24	2.23	1.65
	b	1.42	.30	.82	.82	.89	1.12	.62
	c	.57	.89	.82	.41	1.12	1.12	.41
	d	.28	.00	.82	.21	.45	.22	.41
21	a	26.70	24.04	18.93	17.73	30.20	16.29	30.58
	b	.28	.89	.82	.62	.67	1.12	.21
	c	1.42	.59	1.65	.21	2.24	1.79	.62
	d	1.42	1.19	.82	.82	1.57	1.34	1.03
22	a	3.69	3.26	2.06	4.12	2.01	4.02	2.27
	b	4.26	2.37	4.94	4.12	3.36	4.91	2.69
	c	9.38	6.53	9.47	10.52	6.04	7.59	9.09
	d	34.66	40.95	42.80	38.97	39.15	39.51	38.64
23	a	2.84	2.37	3.29	2.89	2.68	3.35	2.27
	b	1.42	.30	2.47	1.03	1.57	1.12	1.45
	c	2.27	2.67	4.94	2.27	4.03	3.57	2.69
	d	7.95	10.09	12.76	11.96	7.83	12.28	7.85
24	a	1.14	.59	.82	.62	1.12	.89	.83
	b	2.56	1.19	2.06	1.03	2.91	2.23	1.65
	c	1.99	2.67	.41	1.03	2.68	2.90	.83
	d	9.66	6.23	9.05	4.95	11.86	5.80	10.54
25	a	1.70	.89	2.88	1.65	1.79	2.23	1.24
	b	17.61	26.11	26.34	21.44	24.61	21.43	24.38
	c	2.56	3.56	3.29	2.68	3.58	3.35	2.89
	d	1.42	1.78	1.65	1.24	2.01	1.56	1.65

R4

#	ANS	L10	L11	L12	F	M	C	S
1	a	1.42	3.56	3.70	3.30	2.24	4.02	1.65
	b	5.68	3.26	6.17	4.95	4.92	6.70	3.31
	c	2.56	1.48	4.53	3.09	2.24	2.01	3.31
	d	25.85	24.63	25.51	18.35	32.89	19.42	30.79
2	a	.00	.30	.41	.41	.00	.22	.21
	b	67.05	65.88	62.14	65.15	65.55	64.73	65.91
	c	2.27	1.78	1.65	1.03	2.91	2.90	1.03
	d	1.42	.59	1.65	1.03	1.34	1.34	1.03
3	a	2.27	1.19	4.12	2.27	2.46	2.90	1.86
	b	19.03	19.29	19.34	22.27	15.88	18.08	20.25
	c	1.14	1.78	1.65	1.03	2.01	1.34	1.65
	d	6.82	5.34	5.35	6.60	5.15	5.80	5.99

#	ANS	L10	L11	L12	F	M	C	S
4	a	3.69	3.56	3.70	3.09	4.25	5.36	2.07
	b	45.45	51.63	46.09	54.43	40.72	47.10	48.55
	c	.57	.89	.41	.41	.89	.45	.83
	d	2.56	.89	1.23	1.65	1.57	.89	2.27
5	a	.28	.00	.00	.00	.22	.22	.00
	b	.28	.30	.41	.62	.00	.00	.62
	c	1.70	1.19	1.23	1.24	1.57	2.01	.83
	d	28.13	29.97	20.58	28.04	25.50	27.23	26.45
6	a	.85	.00	2.06	1.44	.22	1.34	.41
	b	2.27	1.48	2.47	2.68	1.34	2.90	1.24
	c	10.51	7.42	8.23	11.75	5.59	10.94	6.82
	d	5.11	5.93	2.47	5.15	4.25	5.80	3.72
7	a	1.99	3.26	2.06	.62	4.47	3.13	1.86
	b	6.53	7.12	7.82	5.77	8.50	6.47	7.64
	c	16.19	11.87	17.28	14.43	15.44	16.29	13.64
	d	28.41	26.11	21.40	22.89	28.86	15.40	35.33
8	a	.85	.30	.00	.82	.45	.67	.21
	b	.28	.89	2.47	.82	1.34	.67	1.45
	c	4.55	4.75	7.82	5.57	5.37	4.69	6.20
	d	44.03	29.97	21.81	30.52	36.02	26.79	39.05
9	a	.00	.59	1.65	.82	.45	.89	.41
	b	1.42	2.37	2.06	2.27	1.57	1.79	2.07
	c	7.67	5.04	7.00	5.15	8.05	6.70	6.40
	d	1.14	1.19	1.23	1.24	1.12	1.34	1.03
10	a	.00	.00	.00	.00	.00	.00	.00
	b	.57	1.19	1.65	1.24	.89	1.34	.83
	c	40.06	43.92	46.09	38.56	47.87	33.71	51.65
	d	1.70	2.08	3.70	2.47	2.24	2.90	1.86
11	a	2.56	3.56	2.06	3.71	1.79	2.68	2.89
	b	1.99	2.97	1.23	2.47	1.79	2.01	2.27
	c	.57	.59	1.23	.62	.89	1.34	.21
	d	1.42	1.19	2.47	1.24	2.01	2.46	.83
12	a	.00	.00	.00	.00	.00	.00	.00
	b	1.14	1.78	.82	1.03	1.57	.89	1.65
	c	4.26	3.86	8.64	7.01	3.36	5.58	4.96
	d	2.27	4.75	1.94	4.74	2.91	4.69	3.10
13	a	.57	.30	.41	.41	.45	.45	.41
	b	47.44	48.96	46.50	49.69	45.64	47.10	48.35
	c	.85	.89	2.06	1.03	1.34	1.79	.62
	d	.28	.00	.00	.00	.22	.00	.21
14	a	.57	.30	.00	.00	.67	.45	.21
	b	3.13	2.37	2.06	2.47	2.68	2.46	2.69
	c	.85	.89	.82	.21	1.57	1.34	.41
	d	1.14	1.48	2.47	1.03	2.24	2.90	.41
15	a	1.14	2.08	.41	1.44	1.12	1.56	1.03
	b	.00	.00	.41	.00	.22	.22	.00
	c	4.26	2.97	3.29	4.12	2.91	6.03	1.24
	d	2.27	2.97	1.65	2.47	2.24	3.79	1.03

#	ANS	L10	L11	L12	F	M	C	S
16	a	3.13	2.67	4.53	3.71	2.91	4.69	2.07
	b	6.53	4.15	2.88	5.57	3.80	5.80	3.72
	c	.85	1.19	1.65	.82	1.57	1.79	.62
	d	39.20	35.31	31.28	30.72	41.16	29.46	41.53
17	a	1.14	2.37	2.47	1.65	2.24	2.90	1.03
	b	23.58	25.52	34.57	26.60	27.74	23.21	30.79
	c	5.68	3.86	5.76	5.36	4.70	5.13	4.96
	d	2.84	1.48	2.06	2.27	2.01	1.12	3.10
18	a	1.99	2.67	2.47	2.89	1.79	3.35	1.45
	b	1.42	2.97	3.70	2.06	3.13	3.35	1.86
	c	1.42	5.04	2.47	2.47	3.58	3.79	2.27
	d	50.28	32.64	37.04	41.65	39.15	33.93	46.49
19	a	42.61	36.50	37.86	39.79	38.48	36.16	41.94
	b	3.41	2.37	3.29	3.09	2.91	2.23	3.72
	c	.57	.89	.00	.41	.67	.67	.41
	d	6.25	9.20	5.76	8.87	5.37	8.93	5.58
20	a	4.26	7.42	7.82	7.63	4.92	8.71	4.13
	b	3.69	.30	1.23	2.06	1.57	2.23	1.45
	c	6.25	4.15	3.70	5.57	4.03	6.92	2.89
	d	.00	1.19	.82	.62	.67	1.12	.21
21	a	1.99	1.78	2.06	2.27	1.57	2.46	1.45
	b	.00	.89	.00	.41	.22	.67	.00
	c	.28	1.48	.82	.41	1.34	1.56	.21
	d	18.75	18.99	24.28	23.30	17.00	18.75	21.69
22	a	2.84	2.08	4.12	2.68	3.13	2.68	3.10
	b	5.11	3.56	3.70	4.74	3.58	4.02	4.34
	c	1.42	4.45	5.35	3.71	3.36	2.68	4.34
	d	3.69	5.93	7.00	7.22	3.36	7.14	3.72
23	a	2.84	5.34	5.35	4.33	4.47	4.46	4.34
	b	1.99	1.19	2.06	2.27	1.12	2.01	1.45
	c	5.97	9.50	18.52	10.31	10.74	9.60	11.36
	d	15.34	18.10	15.64	16.91	15.88	19.20	13.84
24	a	1.14	2.08	1.23	1.03	2.01	1.56	1.45
	b	1.70	.89	.00	.41	1.57	.67	1.24
	c	.57	.59	1.23	.82	.67	1.34	.21
	d	1.42	1.48	2.88	1.44	2.24	2.01	1.65
25	a	.57	.59	.00	.41	.45	.22	.62
	b	1.70	.59	.00	.41	1.34	1.12	.62
	c	2.84	1.19	.41	1.24	2.01	2.46	.83
	d	26.14	21.07	20.58	24.74	20.81	20.54	25.00

Appendix H

Two-Tiered Optics Misconception Test
(Final Version)

MISCONCEPTIONS ABOUT OPTICS

INSTRUCTIONS

This test consists of 25 questions which examine your misconceptions about optics. Each question has two parts: a multiple choice response and a multiple choice reason. You are asked to make one choice from both the multiple choice response and one choice from the multiple choice reason for each question.

Answer all questions on the answer sheet.

1. Read each question carefully.

2. Take time to consider your answer and carefully select a reason which best represents your thinking.

3. Record your answer by placing an "X" over the letters which match your answer and your reason on the answer sheet.

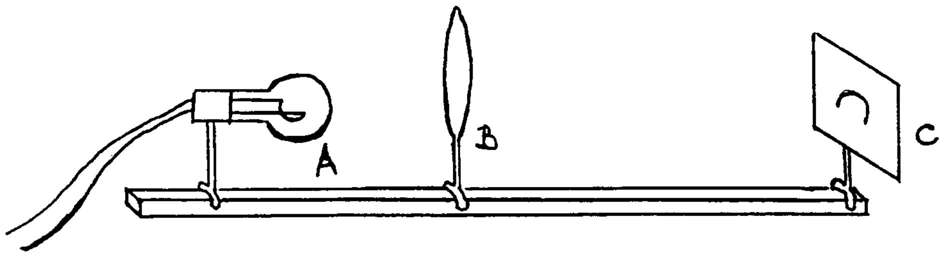
   e.g. A B C D a b c d

4. If you change your mind about an answer, cross out the old answer and add the new choice as shown

   e.g. ~~A~~ B C D a b c d

5. If the provided answers or the provided reasons do not represent your thinking, write your concept in the space provided at the right of each question.

DON'T FORGET TO RECORD YOUR DETAILS ON YOUR ANSWER SHEET.



For questions #1 to #4, the experimental kit consists of an object A (an unfrosted light bulb with a horseshoe-shaped filament), a converging lens B, and a translucent screen C, all mounted on an optical bench. The converging lens is moved until a sharp image of the filament can be observed on the translucent screen, as shown.

1. If the converging lens B is removed, and object A and screen C are left where they were, would anything be changed?

   A. The image on the screen would become erect and equal in size with the object.
   B. Without the lens there would be no image.
   C. The image on the screen will remain as before, but will become blurred.
   D. The image on the screen will become erect, but the image will be blurred.

   Reason:

   a. The property of a converging lens is to focus light. When there is a converging lens, the image will be clear.
   b. A converging lens flips the image over and an erect image will appear on the screen.
   c. If there is no a converging lens, light rays can't be focused and there will be no image on the screen.
   d. Both a and b

2. If an unfrosted bulb is replaced by a frosted bulb, would anything be changed?

   A. The image on the screen would become erect and equal to the size of the object.
   B. Without the lens there would be no image.
   C. The image on the screen will remain as before, but will become blurred.
   D. The image on the screen will become erect, but the image will be blurred.

Reason:

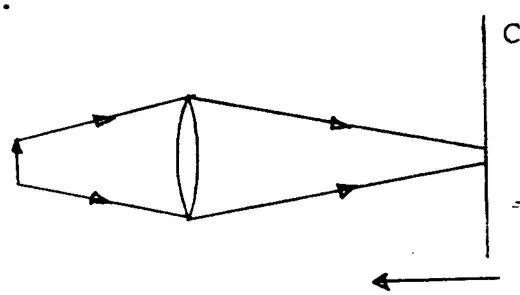
a. The property of a converging lens is to focus light. When there is a converging lens, the image will be clear.
b. A converging lens flips the image over and an erect image will appear on the screen.
c. The light rays become converging rays after passing through a converging lens and the real image will appear.
d. Both a and b.

3. If we move screen C toward lens B, would anything change on the screen?

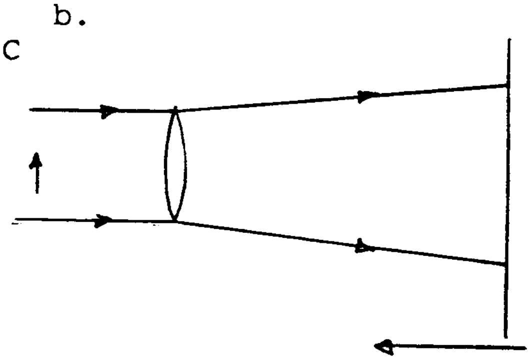
A. The image immediately becomes blurred and then quickly disappears.
B. The image becomes blurred because it is out of focus, and the size of the image will be enlarged.
C. The image becomes blurred because it is out of focus and the size of the image will be small.
D. The image will get smaller, go to a point, invert and then become enlarged.

Diagram supporting the answer above:

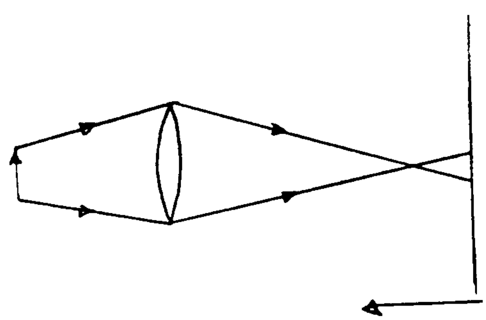
a.



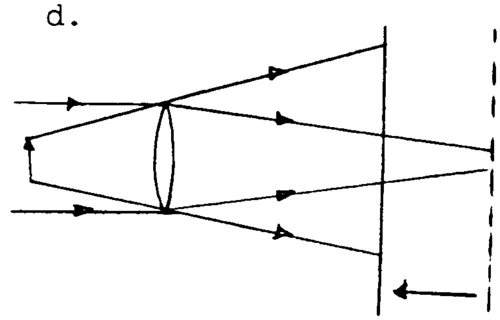
b.



c.



d.



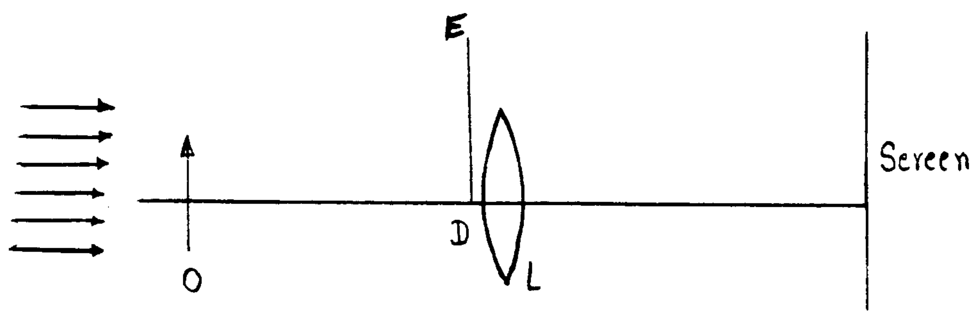
4. If the screen is removed, which of the following items is correct?

A. No image appears.
B. We might be able to see the image on the wall beyond the screen along the lens axis.
C. We might be able to see an image if we can place our eyes at the screen position.
D. If we move beyond the initial screen position and look along the lens axis toward the lens, we will be able to see an image.

Reason:

a. The image is located at the same position where the screen has been. We are able to see an image because our eye is in the position of the screen.
b. An image occurs in the lens.
c. An image occurs only on opaque surfaces.
d. An image appears in our vision, but since our eye is not a screen, the actual image will only appear on the nearest flat surface.

5. If we use a piece of cardboard DE to cover the upper half of the lens, leaving the lower half uncovered, would anything change on the screen?

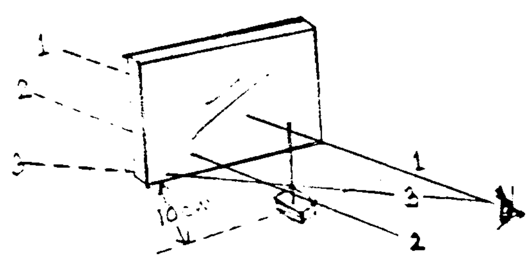


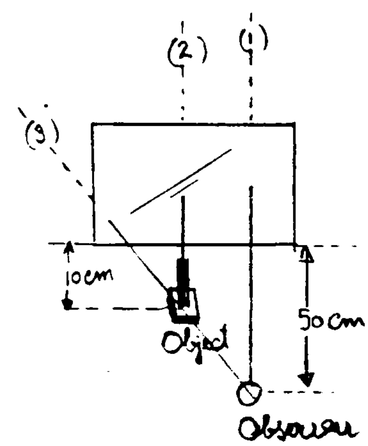
A. A whole image still appears on the screen but the brightness of the image is not changed.
B. A whole image still appears on the screen and the brightness of the image is diminished.
C. Half of the image will disapppear, but the amount of light from the object is not changed.
D. Half of the image will disappear and the amount of light from the object will also diminish.

Reason:

a. Light rays can go through the uncovered part, but this will diminish brightness.
b. Light rays can go through the uncovered part and its brightness will not change.
c. If half the light is blocked from passing through the lens, half the image and half the brightness will vanish.
d. If half the light is blocked from passing through the lens, half the image will vanish, but because of the diffraction property its brightness will not change.

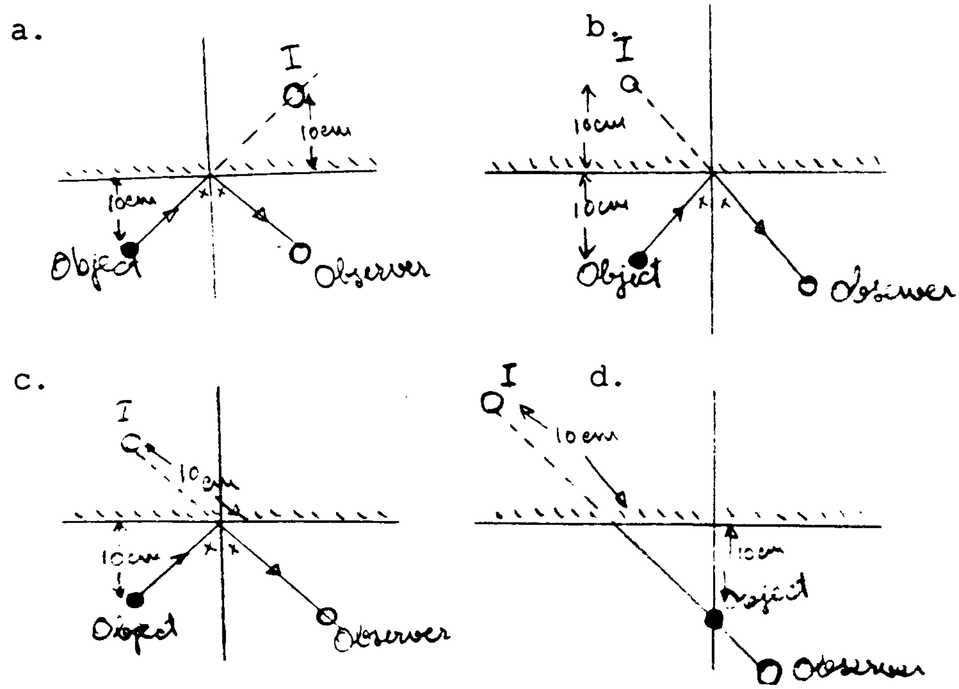
6. An experiment kit consists of a vertical plane mirror about 20 X 30 cm in size. An object is placed about 10 cm in front of the mirror. An observer is seated about 50 cm in front of the mirror, slightly to the right of the object. Where will an observer see an image?



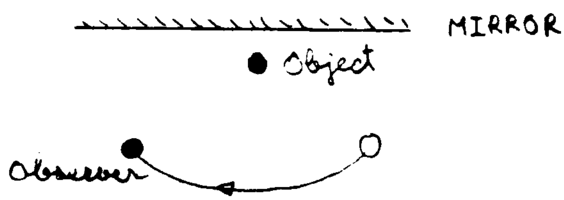


A. 10 cm behind the mirror along the perpendicular line between the mirror and the observer (line #1).
B. 10 cm. behind the mirror along the perpendicular line between the mirror and the object (line #2).
C. 10 cm behind the mirror along the line that passes between the observer and the object (line #3).
D. About 10 cm behind the mirror on a line of sight.

Reason: Because the diagram of light ray is...



7. If an observer is moved to the left of the previous position, as shown below,

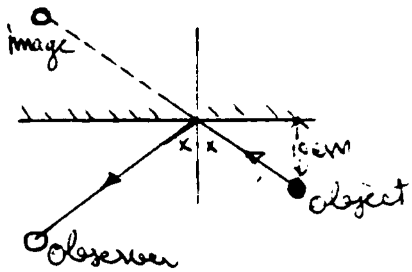


where will the image be located?

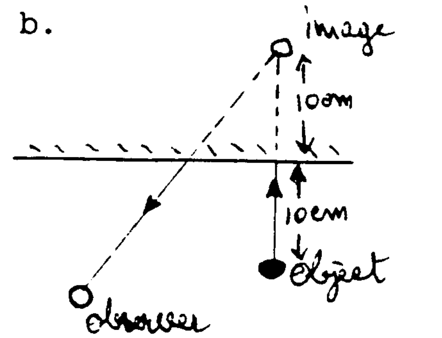
A. The image will shift its position to the left behind the mirror.
B. The image will be 10 cm behind the mirror along the line of sight between the observer's eye and the object.
C. The image will shift its position to the right side behind the mirror, along the line connecting the object and the observer.
D. The position of the image doesn't change. It still remains at the previous position, as in item #6.

Reason: Because the diagram of the answer is...

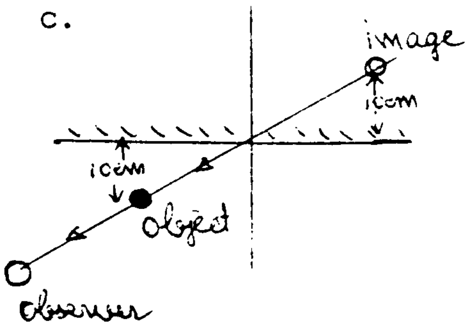
a.



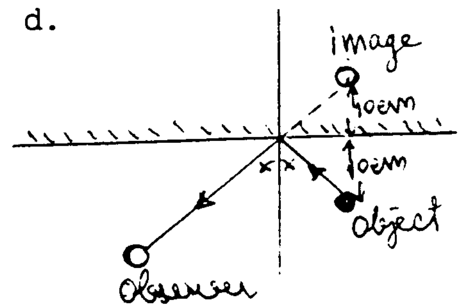
b.



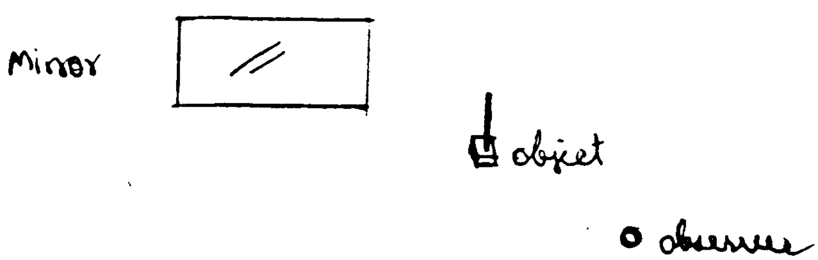
c.



d.



8. An observer is seated in a position that is no longer directly in front of the mirror, but is beyond the right edge. The object is also placed beyond the right edge so that the position of the object and the observer lie along a line that intersects the mirror, as shown.



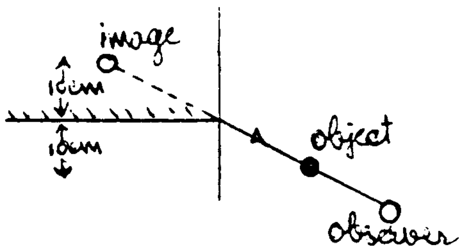
Which statement is correct according to scientific principles?

A. An observer can see an image located on a line of sight.
B. According to the law of reflection, an observer can see an image located behind the mirror.
C. According to the law of reflection, an observer can't see an image because the image will be located in front of the mirror instead of behind the mirror.

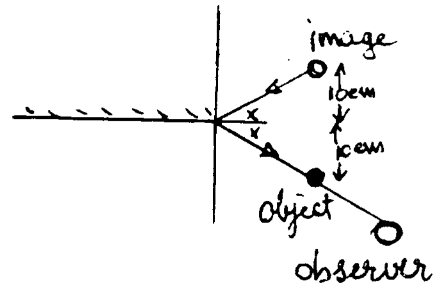
D. An observer can't see an image because the observer is not in the path of the necessary light ray reflecting from the mirror.

A diagram to support this idea is...

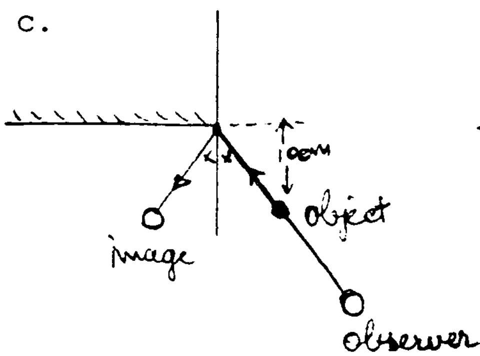
a.



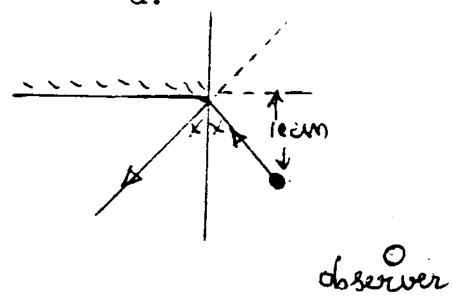
b.



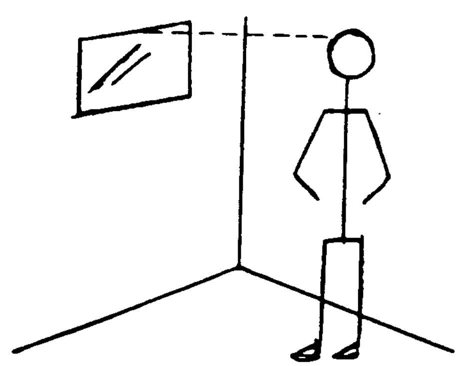
c.



d.



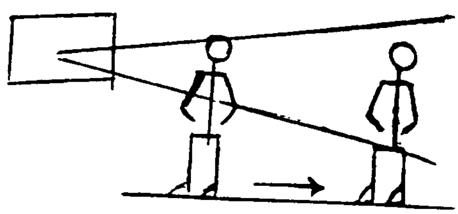
9. A small rectangular mirror is held vertically about one meter in front of the student. The mirror is positioned so that the top of the student's head appears at the top edge of the mirror. The student finds that the image in the mirror extends to about 20 cm below neck level. What can the student do to see more of himself in the mirror?



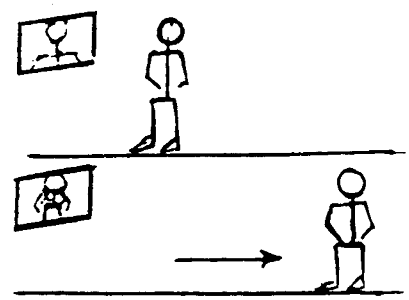
A. The student can see his whole body by moving backward so that the angle of view at the mirror becomes wider.
B. The student can see his whole body by moving away when more of his image will fit into the mirror.
C. By moving backward until the ratio of the height and distance of the student from the mirror is greater than 1:2, the student will be able to see his whole body.
D. There is nothing that can be done as long as the mirror is held and fixed in a vertical position and the size of mirror is not changed.

A diagram to support the answer is...

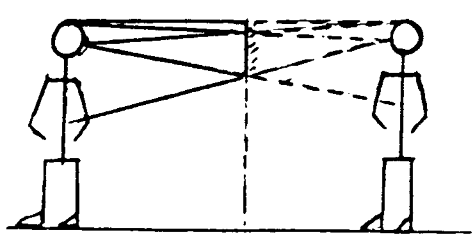
a.



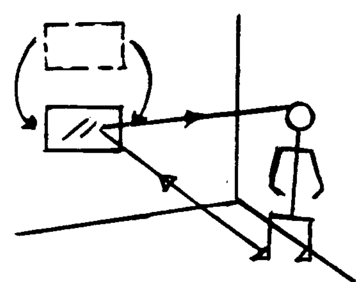
b.



c.



d.



10. Which sentence is correct?

A. Light and heat are the same thing.
B. Light contains warmth. We can prove this by hanging a wet cloth outside in the light. The cloth will become warm and dry.
C. Light doesn't contain warmth in itself. Heat is radiated from a source of light.
D. Light and heat are not the same thing, but are found in exact proportions.

Reason:

a. The more light, the more warmth.
b. Light contains warmth and transfers it to any object that it hits.
c. Both light and heat are energy, which can transform from one form to another.
d. Light is an electromagnetic wave, but heat is an infrared wave.

11. If we shine a beam of light into a room that has no dust, describe the light beam that you can observe in that room?

A. With no dust, we can see the light beam clearly.
B. Light doesn't need a medium for traveling to the eye, so the dust doesn't effect sight.
C. We cannot see the light beam. Light needs a medium to travel to the eye.
D. We cannot see the light because there must be a reflector to get light to the eye.

Reason:

a. Light can travel through transparence, translucence, and space as well.
b. Dust is a reflector. Light reflects dust to the eye.
c. Light is an energy. It has no colors of its own so it required a medium to pass through.
d. How clear one's vision is depends on the amount of dust in the air.

12. Why can black or white objects be seen?

A. Because there is a black light or a white light which enters the eyes.
B. Because the object's color is black or white and the color shines into the eyes.
C. Because if a light reflecting from the object doesn't enter the eye, we consider it to be black in color. On the other hand, if the reflection of a reflecting light enters the eyes, we consider it to be white in color.
D. Because if a refracting light from the object doesn't enter the eyes, we consider it to be black in color. On the other hand, if a refracting light enter the eyes, we consider it to be white in color.

Supportive details:

a. To see any color is dependent on whether or not that color of light enters the eyes.
b. Black objects obsorb all of the incident light and reflecting light cannot enter the eyes. But white color reflects all of the incident rays and enters the eyes.
c. Color is purely a property of an object, not of the light itself.
d. In the air, black color light refracts light at lower levels than white light.

13. How far can light travel?

A. It can travel until the energy is dissipated.
B. It can travel infinitely if it doesn't encounter an opaque object.
C. Light can travel infinitely.
D. The distance light can travel is limited by the extent of its visible effect.

Reason:

a. Light is a kind of energy. When it travels distances, energy is transferred to the medium until it is dissipated.
b. Light is seen because the optical nerve is alerted. Thus, the distance that light can travel is limited by the vision.
c. Light is an electromagnetic wave. Because light travel is not dependent on the medium, light can travel infinitely.
d. Both b and c.

14. Which statement is correct?

A. The object that has a color, can be seen only if its color is different from the background.
B. All colors together form ranges of light with intensities from black to white.
C. A black colored light has the lowest effect on the optical nerve.
D. Sun light is a white light.

Reason:

a. Components of white light will range from ultra-violet to infrared. It can be confirmed by using a prism. A prism will disperse the white light into its components.
b. A black colored light has the lowest intensity.
c. The optical nerve can't separate a given color if it is alerted by a similar color.
d. The intensity of light is in proportion to its wavelength.

15. Consider these given objects:

1. Sun, 2. Flashlight, 3. Lamp, 4. Candle.

Which one is a source of "light"?

A. #1 only B. #2, #3 and #4
C. #1, #2, #3, and #4 D. Not any of these choices

Reason:

a. All of them are sources of light.
b. Sources of light and light have the same meaning.
c. These objects cannot light themselves.
d. Both b and c.

16. "When the light source is switched on, a room is illuminated immediately." From this sentence, can we say the light has infinite speed?

A. Yes, we can. The velocity of light is an approximate measure.
B. Yes, we can. The light has a speed faster than our eyes can detect.
C. Yes, we can. Light in this situation occurs by transformation from electrical energy.
D. No, we can't say that. We can measure speed of light even if its speed is faster than our eyes can detect.

Reason:

a. Light velocity is about 186,000 miles/sec.
b. High speed and infinite speed have different meanings.
c. Light is a kind of energy that is transformed from other energies.
d. Both a and b.

17. When we go for a vacation at the beach, if we observe the sky we can see that it has a blue color similar to that of the sea. Why do they have the same colors?

    A. Lights reflects from the sea to the sky.
    B. It is the effect of the scattering of light.
    C. In the afternoon, blue colored light can refract better than other colors.
    D. It is the nature of the sky that it has a blue color.

    Reason:

    a. In the afternoon, blue color light reflects better than other colors, reflecting its color toward the sky.
    b. The sea has a lot of space area, the reflection of light on the sea surface and the sky are close. As we have seen, it looks like the same colors.
    c. The blue colored light can reflect up to the sky and refract it to the eye better than the other colors.
    d. The blue colored light can scatter and enter the eye better than the other colors.

18. Which optical instruments provide only erect images?

    A. a converging mirror   B. a concave mirror
    C. a plane mirror   D. Both a and c

    Reason:

    a. A property of a converging lens is that it disperses light. Light rays are supposed to focus only in front of the mirror.
    b. A converging mirror or a concave mirror can provide a real image when an object is located near a surface mirror.
    c. Depending on the position in which the object is located, all types of mirrors can provide real images.
    d. It is a property of a plane mirror that only erect images can form behind the mirror.

19. Which statement is correct?

    A. Shadows form easily on cloudy days, but are more difficult to observe than on clear days.
    B. Shadows form easily on cloudy days, but are difficult to observe on cloudy days.
    C. Shadow formation is not dependent on the condition of the sky.
    D. On a cloudy day, shadow formation is not possible.

    Reason:

    a. Clouds absorb the sunlight.
    b. Light rays passing clouds are a non-rectilinear propagation of light.
    c. On a cloudy day, light intensity is higher than for clear days, but because of the diffuse light it will be hard to form shadows.
    d. On a cloudy day, light intensity is lower than for clear days. Thus, no shadows will be formed.

20. The shadow size, bigger, smaller, or equal to an object depends on...

    A. Distance of an object from a source of light and distance of an object from a screen.
    B. The size of a source of light and an object.
    C. The illumination of a source of light.
    D. The size of a screen.

    Reason:

    a. The size of a shadow is large when the distance from an object to a screen is small. Simultaneously, if a screen is far from an object, the shadow will be large.
    b. If the size of a source of light is large than an object, a shadow will be smaller than the object.
    c. A larger surface for a big screen will provide a larger shadow on that screen.
    d. A diminished illumination produces a big shadow. An example is that a shadow during the sunset is longer than at noon.

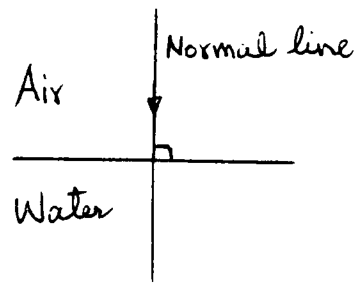
21. From the following statements, which one is correct?

    A. Humans and animals can't see anything if there is no light available.
    B. Humans can see everything in the dark.
    C. Only animals can see in the dark.
    D. Humans cannot see in the dark as clearly as animals.

Reason:

a. Animals have a special capability for seeing everything in the dark better than humans.
b. The human iris has vision limits.
c. Light is necessary for vision. No light means that nothing can be seen.
d. The iris can be adjusted by the condition of the light.

22. When light travels from one medium to another, a refraction phenomena occurs. If light travels toward a perpendicular line from air to water, which of the following is correct?



A. There is no refraction in this case because the incident ray is on the normal line.
B. There is no refraction because there is total internal reflection. The light goes backward until we can't see a refraction phenomena.
C. There is a refraction phenomena, but the light reflects backward so it is very hard to say that a refraction is not possible to observe.
D. There is a refraction phenomena because light travels through the two media.

Reason:

a. Light travels in a straight line.
b. Light doesn't change its direction.
c. Refraction will occur when the direction or the velocity is changed.
d. Two phenomena, a reflection and a refraction, will occur simultaneously, but inclination toward one phenomena is dependent upon the medium.

23. Why will the light passing through a clear red glass be red in color?

    A. Because light passing through a clear red glass is white light, but the red pigment in that glass activates red colored light entering the eye better than other colors.
    B. The red color observed is the color of the object, not the color of light.
    C. The red color that enters the eye is light reflected from red colored glass.
    D. Clear red glass absorbs other colored lights and lets most of the red colored light pass through.

    Reason:

    a. A clear red glass acts as a red filter.
    b. The light passing through colored glass will be changed by the pigment of the glass.
    c. For light colors blue, red and green, red light has an intensity higher than the others. Thus, it can be observed easily and clearly.
    d. A reflection and a refraction phenomena will occur simultaneously, but it will incline toward one of the phenomena, dependent on the medium.

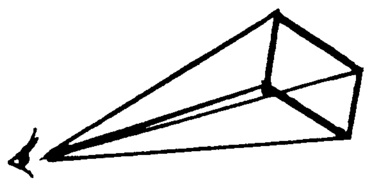
24. Which statement is correct?

    A. We can only see the part of lightning flashes that are reflected into the eye.
    B. A lightning flash is an example of non-rectilinear propagation.
    C. A flash is a kind of a light ray.
    D. A lightning flash that enters the eye travels in a straight line.

    Reason:

    a. A flash is the product of ion exchange in the air.
    b. The refracting angle of the light is necessary for vision. It must be an appropriate angle to enter the eye.
    c. A flash is not a light ray.
    d. There are two kinds of light propagation, rectilinear and non-rectilinear.

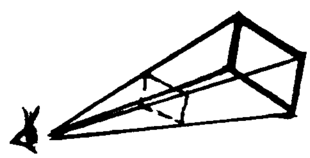
25. Half way between an observer and an object, what is the size of an existing image when compared to the object?



A. Half
B. Larger
C. Equal
D. The question is unclear.

Reason:

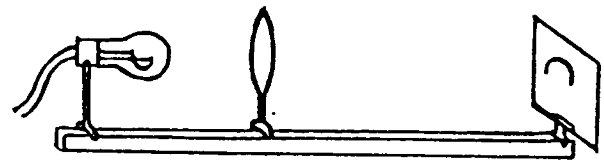
a. It follows from the law of perspective.
b. It follows from this diagram.



c. Both a and b.
d. The kind of optical instrument and distance from the object are not given in this question.

Appendix I

Two-Tiered Optics Misconception Test (Thai Version)



หลอดไฟ A ฉากรับภาพ C

เลนส์นูนบาง B

การทดลองชุดอุปกรณ์ ประกอบด้วยหลอดไฟ A ซึ่งเป็นหลอดไฟฟ้าใสชนิดมีไส้หลอด ไส้หลอดทำหน้าที่เป็นวัตถุของการทดลองนี้ เลนส์นูนบาง B และฉากรับภาพ C ทั้งหมดวางอยู่บนรางที่สามารถปรับเลื่อนตำแหน่งได้ ปรับเลนส์นูน B และฉาก C จนได้ภาพชัดบนฉาก C ดังรูป

จงตอบคำถามข้อ 1-4

1. ถ้าเอาเลนส์นูน B ออกไป โดยหลอดไฟ A และฉากรับภาพ C ยังอยู่ที่เดิม นักเรียนคิดว่าจะมีสิ่งใดเปลี่ยนแปลง

ก. ภาพบนฉากจะกลับเป็นภาพหัวตั้งขนาดเท่ากับวัตถุ
ข. ไม่เกิดภาพบนฉาก
ค. ภาพบนฉากไม่ชัดเท่ากับเมื่อมีเลนส์นูน
ง. ภาพบนฉากเป็นภาพหัวตั้ง แต่ภาพไม่ชัดเท่ากับเมื่อมีเลนส์นูน

เพราะเหตุว่า

a. เลนส์นูนมีคุณสมบัติรวมแสง เมื่อมีเลนส์นูนภาพที่ได้จึงมีความชัดเจน
b. เลนส์นูนทำให้เกิดภาพบนฉากเป็นภาพหัวกลับกับวัตถุ
c. ไม่มีเลนส์นูนรวมแสงให้รังสีแสงไปตัดกันจริง จึงไม่เกิดภาพ
d. ทั้งข้อ a และ ข้อ b

2. ถ้าเปลี่ยนหลอดไฟ A จากหลอดใสมาเป็นหลอดฝ้า และมีไส้หลอดเหมือนเดิม เมื่อเอาเลนส์นูน B ออก จะมีสิ่งใดเปลี่ยนแปลง

ก. ภาพบนฉากจะกลับเป็นภาพหัวตั้งขนาดเท่ากับวัตถุ
ข. ไม่เกิดภาพบนฉาก
ค. ภาพบนฉากไม่ชัดเท่ากับเมื่อมีเลนส์นูน
ง. ภาพบนฉากเป็นภาพหัวตั้ง แต่ภาพไม่ชัดเท่ากับเมื่อมีเลนส์นูน

เพราะเหตุว่า

a. เลนส์นูนมีคุณสมบัติรวมแสง เมื่อมีเลนส์นูนภาพที่ได้จึงมีความชัดเจน
b. เลนส์นูนทำให้เกิดภาพบนฉากเป็นภาพหัวกลับกับวัตถุ
c. ไม่มีเลนส์นูนรวมแสงให้รังสีแสงไปตัดกันจริง
d. เราไม่สามารถมองเห็นไส้หลอดผ่านหลอดฝ้าได้ ดังนั้นจะมีเลนส์หรือไม่มีก็จะไม่มีภาพเกิดขึ้นบนฉาก

3. ถ้าเลื่อนฉาก C เข้าหาเลนส์นูน B จะมีสิ่งใดเปลี่ยนแปลงบนฉาก

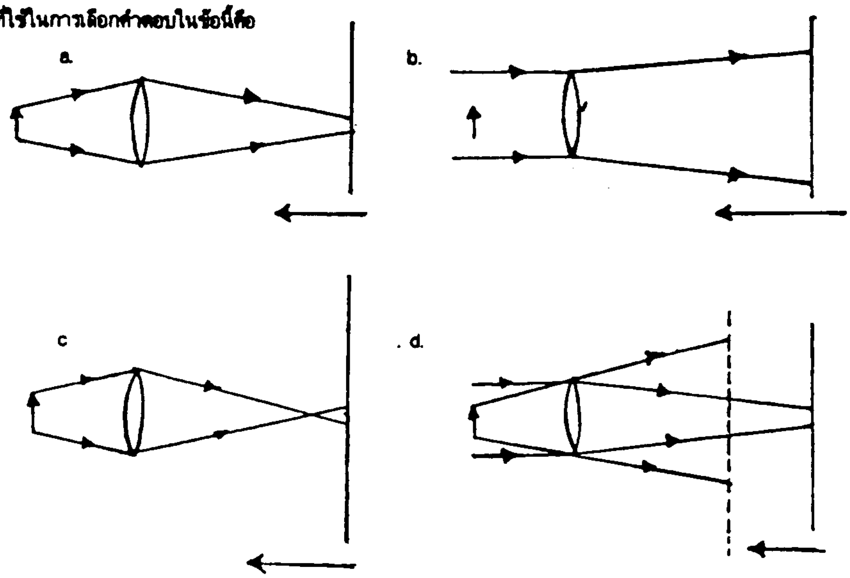
ก. ภาพจะพร่าเล็กลงแล้วค่อยๆหายไป

ข. ภาพจะพร่าและภาพจะใหญ่ขึ้น

ค. ภาพจะพร่าและภาพจะเล็กลง

ง. ภาพจะเล็กลงจนเป็นจุด และจะกลับใหญ่ขึ้นเรื่อยๆ

แผนภาพที่ใช้ในการเลือกคำตอบในข้อนี้คือ



4. ถ้าเอาฉาก C ออกไป ข้อใดต่อไปนี้ถูกต้อง

ก. ไม่มีภาพเกิดขึ้น

ข. ภาพจะไปปรากฏบนผนังห้องหรือบนวัตถุทึบแสงที่อยู่ในแนวแกนเลนส์แทน

ค. ถ้าเอาตาอยู่ที่ตำแหน่งของฉาก C จะมองเห็นภาพได้

ง. ถ้ายืนตามแนวแกนเลนส์ห่างจากตำแหน่งฉากเดิมพอสมควร จะมองเห็นภาพได้

เหตุผลที่ใช้ในการเลือกคำตอบคือ

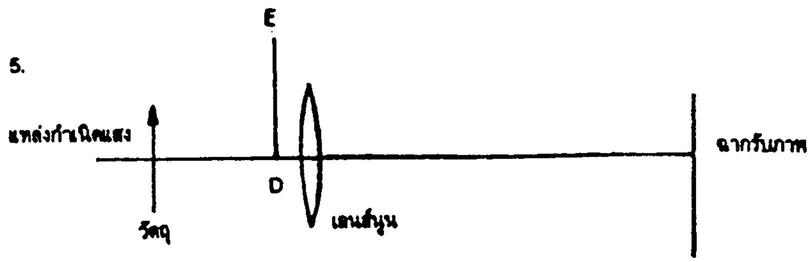
a. เพราะภาพยังเกิดที่เดิม ตาทำหน้าที่เป็นฉากรับภาพได้โดยมีเลนส์ตาช่วยอีกส่วนหนึ่ง

b. เพราะภาพเกิดอยู่ในเลนส์แทน

c. ภาพจะปรากฏให้เห็นได้เมื่อมีตัวกลางทึบแสงมารองรับเท่านั้น

d. เพราะมีภาพเกิดขึ้น แต่อากาศไม่สามารถเป็นฉากได้จึงต้องไปเกิดภาพบนวัตถุทึบแสง
ที่อยู่ใกล้ที่สุดแทน

5.



ถ้านำกระดาษแข็ง DE กั้นระหว่างวัตถุกับเลนส์ดังรูป ภาพที่เกิดบนฉากจะเป็นอย่างไร

ก. ภาพเกิดบนฉากปกติ และความสว่างของภาพยังเท่าเดิม

ข. ภาพเกิดบนฉากปกติ แต่ความสว่างของภาพลดลงไป

ค. ภาพบนฉากหายไปครึ่งหนึ่ง แต่ความสว่างของภาพเท่าเดิม

ง. ภาพบนฉากหายไปครึ่งหนึ่ง และความสว่างลดลงไปครึ่งหนึ่งด้วย

เหตุผลที่ใช้ในการเลือกคำตอบคือ

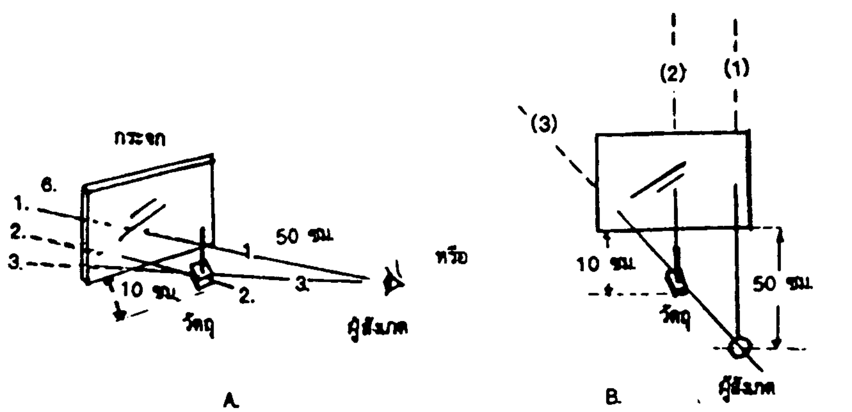
a. ฉากที่มากั้นไม่ได้กั้นการเกิดภาพ กั้นแต่ปริมาณแสงที่เดินทางเข้าสู่เลนส์ความสว่างจึงลดลง

b. ฉากที่กั้นไม่ได้กั้นการเกิดภาพและทางเดินแสง แสงจึงเดินทางเข้าสู่เลนส์ได้ตามปกติ แต่เนื่องจากการเลี้ยวเบนของแสงความสว่างของภาพจึงเท่าเดิม

c. เมื่อมีวัตถุทึบแสงมากั้น แสงจะเดินทางเข้าสู่เลนส์ได้เพียงครึ่งเดียว แต่เพราะปรากฏการณ์การเลี้ยวเบนของแสงความสว่างของภาพจึงเท่าเดิม

d. กระดาษแข็งที่มากั้นจะกั้นทั้งแสงและทางเดินแสง ภาพจึงปรากฏเพียงครึ่งเดียว และความสว่างของภาพลดลงไปด้วย

6.

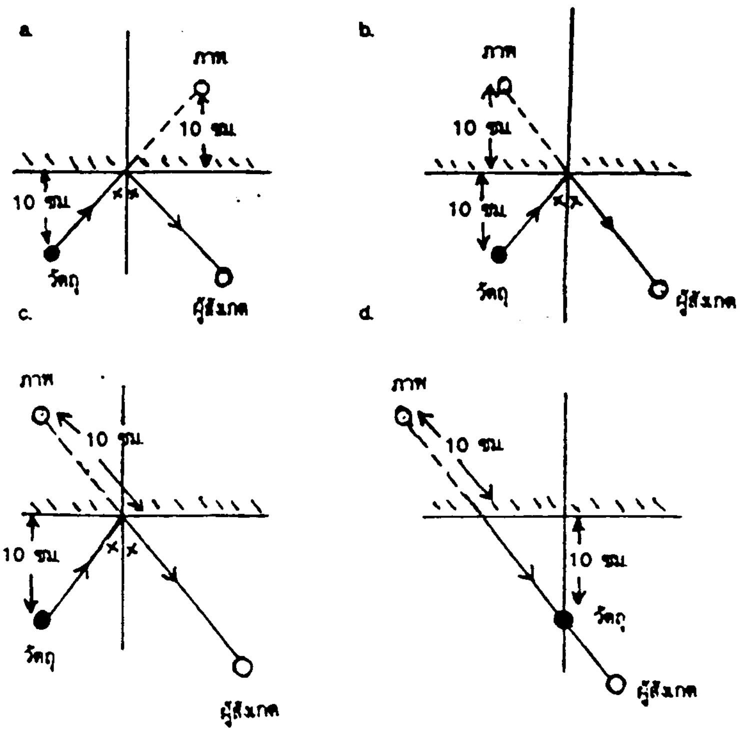


การทดลองประกอบด้วยกระจกเงาราบขนาด 20 X 30 ซม. วางวัตถุหน้ากระจกห่าง 10 ซม. ผู้สังเกตนั่งอยู่หน้ากระจกห่าง 50 ซม. และอยู่ด้านขวาของวัตถุ ผู้สังเกตจะมองเห็นภาพของวัตถุได้ที่ใดหลังกระจก

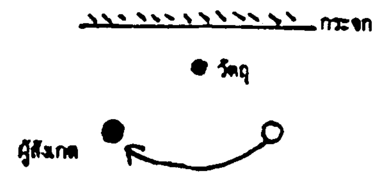
ก. ในแนวเดียวกับผู้สังเกต (1)ห่างไป 10 ซม. ข. แนวเดียวกับวัตถุ (2)ห่างไป 10 ซม.

ค. ตามแนวของวัตถุและผู้สังเกต (3)ห่าง 10 ซม. ง. ระยะ 10 ซม.ตามแนวเส้นสายตา (a line of sight)

เพราะแผนภาพที่เกิดเป็นไปตามข้อ


a.
ภาพ
10 ซม.
10 ซม.
วัตถุ
ผู้สังเกต
b.
ภาพ
10 ซม.
10 ซม.
วัตถุ
ผู้สังเกต
c.
ภาพ
10 ซม.
10 ซม.
วัตถุ
ผู้สังเกต
d.
ภาพ
10 ซม.
10 ซม.
วัตถุ
ผู้สังเกต

7. ถ้าผู้สังเกตเลื่อนมาอยู่ทางซ้ายของวัตถุ ในแนวระดับเดิมดังรูป ภาพจะเกิดขึ้นที่ใด



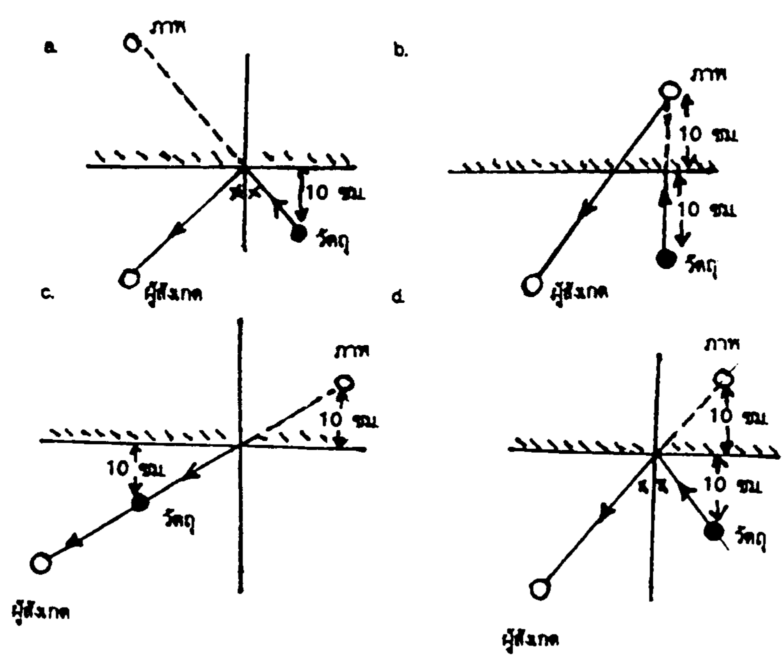
ก. ภาพจะเลื่อนมาเกิดทางซ้ายมือตามแนวเดียวกับผู้สังเกต

ข. ภาพเกิดหลังกระจก บนแนวเส้นสายตากับภาพห่างออกไป 10 ซม.

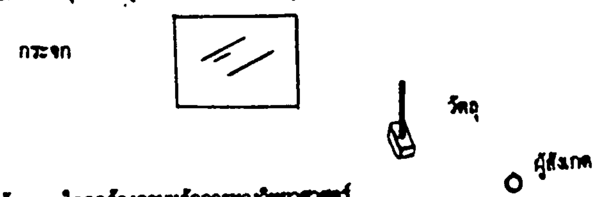
ค. ภาพจะเลื่อนไปเกิดทางขวามือ หลังกระจกในแนวเดียวกับวัตถุและผู้สังเกต

ง. ภาพไม่เปลี่ยนตำแหน่ง ยังเกิดที่เดิมเช่นเดียวกับในข้อ 6.

เพราะแผนภาพที่เกิดขึ้นเป็นไปดังรูป



8. ถ้าวัตถุไม่ได้อยู่ตรงหน้ากระจก และผู้สังเกตเลื่อนไปอยู่ทางขวามือดังรูป



ข้อความใดถูกต้องตามหลักการทางวิทยาศาสตร์

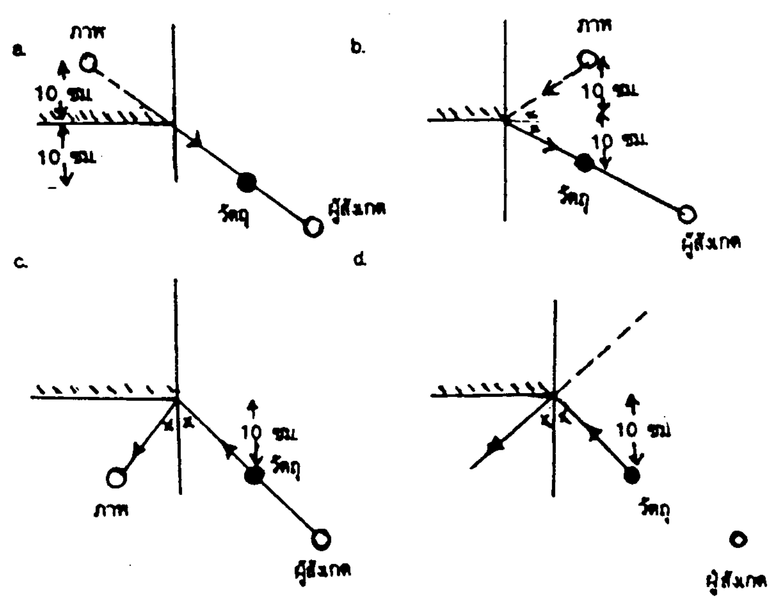
ก. ผู้สังเกตจะมองเห็นภาพของวัตถุเกิดบนแนวเดียวกับวัตถุและสายตา(a line-of-sight)

ข. ตามกฎการสะท้อนแสง ผู้สังเกตจะมองเห็นภาพเกิดอยู่หลังกระจก

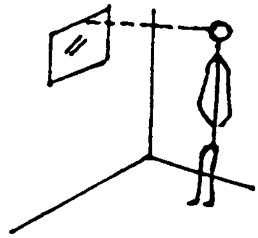
ค. ตามกฎการสะท้อนแสง เนื่องจากภาพเกิดหน้ากระจกแทนที่จะเกิดหลังกระจก ผู้สังเกตจึงมองไม่เห็นภาพ

ง. เนื่องจากแสงไม่สามารถสะท้อนกระจกเข้าตาผู้สังเกตได้ ผู้สังเกตจึงมองไม่เห็นภาพ

แผนภาพที่ใช้ประกอบคำตอบคือ



9.



กระจกสี่เหลี่ยมบานเล็กๆติดอยู่บนกำแพงในแนวดิ่งนักเรียนคนหนึ่งยืนห่างจากกระจกเป็นระยะ 1เมตร ศีรษะของนักเรียนผู้นี้อยู่ในแนวเดียวกับขอบบนของกระจก เมื่อเขามองภาพตนเองในกระจกพบว่า เขามองเห็นตัวเองได้มากที่สุดเพียงต่ำกว่าคอลงมาประมาณ 20 ซม.

โดยการใช้กระจกบานเดิมนี้ นักเรียนผู้นี้จะมองเห็นภาพตนเองได้เพิ่มมากขึ้นด้วยการ

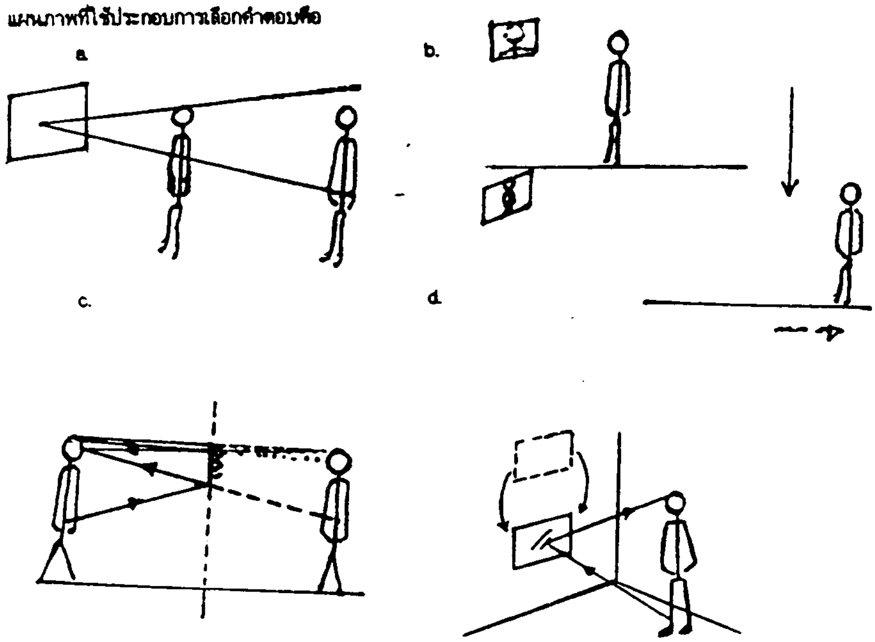
ก. ถอยหลังออกไปเพื่อให้มุมในกระจกกว้างขึ้นซึ่งจะเก็บภาพได้มากขึ้นด้วย

ข. ถอยห่างออกไป ยิ่งอยู่ห่างกระจก วัตถุจะเล็กลงภาพจะสามารถบรรจุลงในกระจกได้

ค. เลื่อนกระจกให้ติดต่ำกว่าศีรษะของผู้สังเกต

ง. ทำไม่ได้หากกระจกยังมีขนาดเท่าเดิม และถูกกำหนดให้อยู่ที่ตำแหน่งเดิม

แผนภาพที่ใช้ประกอบการเลือกคำตอบคือ



10. ข้อความใดต่อไปนี้ถูกต้องตามหลักการทางวิทยาศาสตร์

ก. แสงและความร้อนคือสิ่งเดียวกัน

ข. แสงมีความร้อนอยู่ในตัวเองพิสูจน์ได้ด้วยการตากผ้าไว้กลางแสงแดด ผ้าจะแห้งและอุ่นขึ้น

ค. แสงไม่มีความร้อนในตัวเอง แหล่งกำเนิดแสงต่างหากที่เป็นตัวแผ่รังสีความร้อนออกมา

ง. แสงและความร้อนเป็นสัดส่วนโดยตรงต่อกัน

เหตุผลที่ใช้ประกอบในการเลือกคำตอบคือ

a. เวลามีแสงมากเราจะรู้สึกร้อนมากกว่าเมื่อมีแสงน้อย

b. เมื่อแสงส่องไปที่ใดที่หนึ่งเป็นเวลานานๆจะถ่ายทอดพลังงานความร้อนให้สิ่งนั้นจนทำให้สิ่งนั้นร้อนขึ้น

c. ที่ใดมีแสงที่นั้นจะต้องมีความร้อนเกิดขึ้นคู่กันเสมอ

d. แสงเป็นคลื่นแม่เหล็กไฟฟ้าไม่สามารถให้คลื่นรังสีความร้อนออกมาได้อย่างวัตถุที่มีความร้อนในตัว

11. ฉายแสงเข้าไปในห้องมืดที่ไม่มีฝุ่นละอองเลย นักเรียนจะมองเห็นลำแสงที่ฉายเข้ามานั้น

ก. ชัดเจนมากกว่าปกติเนื่องจากไม่มีตัวกั้นแสง

ข. ชัดเจนและห้องจะสว่างกว่าปกติเนื่องจากไม่มีฝุ่น

ค. มองไม่เห็นลำแสงนั้นเนื่องจากไม่มีตัวกลางให้แสงเดินทางเข้าสู่ตา

ง. มองไม่เห็นลำแสงและห้องไม่สว่างเนื่องจากไม่มีฝุ่นละอองสะท้อนแสง

เหตุผลที่เลือกคำตอบเพราะว่า

a. แสงสามารถเดินทางผ่านตัวกลางโปร่งแสง โปร่งใส และสุญญากาศได้ดี

b. ฝุ่นละอองในอากาศจะช่วยเป็นตัวสะท้อนแสงเข้าสู่ตา

c. แสงเป็นพลังงานและไม่มีสีในตัวเอง จึงต้องการตัวกลางในการเคลื่อนที่ผ่าน

d. ความหนาทึบของฝุ่นละอองจะเป็นสัดส่วนกลับกับการมองเห็น

12. การที่มองเห็นวัตถุมีสีดำหรือขาวนั้น เป็นเพราะว่า

ก. มีแสงสีดำหรือแสงสีขาวเข้าสู่นัยน์ตา

ข. วัตถุนั้นมีสีดำ หรือสีขาว และสะท้อนสีของวัตถุเข้าสู่นัยน์ตา

ค. มีแสงตกกระทบวัตถุแล้วไม่มีรังสีหักเหไม่เข้าสู่นัยน์ตาจึงเห็นเป็นสีดำแต่ถ้ามีรังสีหักเหเข้าสู่นัยน์ตาจึงเห็นเป็นสีขาว

ง. มีแสงตกกระทบวัตถุแล้วไม่สะท้อนหรือสะท้อนเข้าสู่นัยน์ตาจึงเห็นเป็นสีดำหรือสีขาว

เหตุผลที่เลือกคำตอบคือ

a. การมองเห็นสีใดๆขึ้นกับว่ามีแสงสีนั้นเข้าสู่ตา

b. วัตถุสีดำดูดกลืนแสงทั้งหมดที่มาตกกระทบและไม่มีแสงสะท้อนเข้าสู่ตา ส่วนวัตถุสีขาวสะท้อนแสงทั้งหมดเข้าสู่ตา

c. สีต่างๆที่มองเห็นเป็นสีของวัตถุไม่ใช่สีของแสง

d. แสงสีดำมีการหักเหแสงได้น้อยมากในอากาศเมื่อเทียบกับแสงสีขาวที่มีการสะท้อนแสงได้ง่ายกว่า

13. แสงเดินทางไปได้ไกลเพียงใด

ก. ไกลจนหมดพลังงานแสง

ข. ไกลโดยไม่มีขีดจำกัดถ้าไม่ไปกระทบตัวกั้นแสง

ค. แสงเดินทางไปได้โดยไม่มีขอบเขตจำกัด

ง. ไกลเท่าที่ตามองเห็น

เหตุผลที่เลือกคำตอบคือ

a. แสงเป็นพลังงานรูปหนึ่ง เมื่อเคลื่อนที่ไประยะไกลๆพลังงานจะถูกถ่ายทอดออกไปเรื่อยๆ ให้กับตัวกลางที่ผ่าน

b. การมองเห็นแสงเป็นเพราะประสาทตาถูกกระตุ้น ระยะทางที่แสงเดินทางได้ จึงอยู่ในขอบเขตการมองเห็นเท่านั้น

c. แสงเป็นคลื่นแม่เหล็กไฟฟ้า การเคลื่อนที่ไม่มีการสูญเสียพลังงานและไม่ขึ้นกับตัวกลางที่ผ่านจึงไปได้ไม่มีขีดจำกัด

d. แสงไม่สามารถเดินทางผ่านตัวกั้นแสงได้ดังนั้นตัวกั้นแสงจะเป็นตัวกำหนดตำแหน่งสุดท้ายที่แสงเดินทางไปได้

14. คำกล่าวข้อใดถูกต้อง

ก. เรามองเห็นวัตถุได้เมื่อวัตถุมีสีแตกต่างจากสีพื้นที่วัตถุวางอยู่ (background)

ข. แสงสีจะเรียงกันอยู่ตามความเข้มของแสงโดยเริ่มจากสีดำสู่สีขาว

ค. ประสาทตาถูกกระตุ้นได้น้อยที่สุดด้วยแสงสีดำ

ง. แสงอาทิตย์เป็นแสงขาว

เหตุผลที่เลือกคำตอบคือ

a. แสงขาวประกอบด้วยแสงสีต่างๆจากแสงเหนือม่วงไปจนถึงแสงใต้แดง ทดสอบแยกแสงขาวได้ด้วยปริซึม

b. แสงสีดำมีความเข้มของแสงต่ำสุด

c. ประสาทตาจะแยกสีไม่ถูกถ้าถูกกระตุ้นด้วยแสงสีใกล้เคียงกัน

d. ความเข้มของแสงเป็นสัดส่วนโดยตรงกับความยาวคลื่น

15. พิจารณาสิ่งที่กำหนดให้นี้

1) ดวงอาทิตย์ 2) ไฟฉาย 3) ตะเกียง 4) เทียนไข

ข้อใดที่หมายถึง'แสง'

ก. ข้อ 1. เท่านั้น	ข. ข้อ 2,3, และ 4.
ค. ข้อ 1,2,3,4	ง. ไม่ใช่ทั้งข้อ 1,2,3,4.

เพราะเหตุว่า

a. สิ่งเหล่านี้เป็นแหล่งกำเนิดแสงไม่ใช่แสงสว่าง

b. แหล่งกำเนิดแสงและแสงสว่างมีความหมายเดียวกัน

c. สิ่งเหล่านี้ไม่สามารถจะสว่างได้ด้วยตัวเอง

d. ข้อ b. และ ข้อ c.

16. เมื่อเปิดสวิทซ์ไฟ จะเห็นแสงสว่างทันทีที่เปิดสวิทซ์ จากข้อความนี้จะสามารถกล่าวได้หรือไม่ว่า "แสงไม่มีขีดจำกัดความเร็ว"

ก. ได้เพราะความเร็วแสงที่วัดได้เป็นค่าประมาณเท่านั้น

ข. ได้เพราะแสงมีความเร็วสูงมากเกินกว่าที่ตาคนเราจะมองได้ทัน

ค. ได้เพราะแสงในที่นี้เกิดจากการเปลี่ยนรูปของพลังงานไฟฟ้า

ง. ไม่ได้เพราะเราสามารถหาความเร็วแสงได้แม้จะมีความเร็วสูงเกินกว่าที่ตาจะมองได้ทัน

คำอธิบายเสริมคำตอบ

a. เราสามารถหาอัตราเร็วแสงเท่ากับ 186,000 ไมล์/วินาที

b. ความเร็วสูงมากกับไม่มีขีดจำกัดความเร็วมีความหมายต่างกัน

c. แสงเป็นพลังงานรูปหนึ่งที่เกิดจากการเปลี่ยนรูปมาจากพลังงานรูปอื่น

d. ทั้งข้อ a. และ b.

17. เมื่อไปเที่ยวตามชายทะเล มองไปบนท้องฟ้าเห็นเป็นสีครามคล้ายน้ำทะเล เป็นเพราะ

ก. เกิดจากการสะท้อนของสีน้ำทะเลขึ้นไปบนท้องฟ้า

ข. เกิดจากปรากฏการณ์การกระเจิงของแสง

ค. เกิดจากการสะท้อนสีของท้องฟ้าลงบนท้องทะเล น้ำทะเลปกติไม่มีสีคราม

ง. สีที่เห็นเป็นสีธรรมชาติของท้องฟ้าซึ่งมีสีคราม

เหตุผลที่เลือกคำตอบคือ

a. ในตอนกลางวันแสงสีน้ำเงินสะท้อนแสงได้ดีที่สุด จึงสะท้อนขึ้นบนท้องฟ้าได้มากที่สุด

b. ทะเลเป็นที่โล่ง แสงสะท้อนจากพื้นน้ำและท้องฟ้าจะใกล้กันมาก จึงทำให้ดูมีสีคล้ายกัน

c. แสงสีน้ำเงินสะท้อนสู่ท้องฟ้าได้ดีกว่าสีอื่น และในเวลาเดียวกันก็หักเหเข้าสู่ตาได้ดีกว่า

d. แสงสีอื่นๆสะท้อนออกสู่บรรยากาศได้ดีกว่าแสงสีน้ำเงิน จึงเหลือแต่แสงสีน้ำเงินกระเจิงเข้าสู่ตา

18. ถ้าใช้อุปกรณ์แสงชนิดใดต่อไปนี้เพียงชิ้นเดียวแล้วให้ภาพเสมือนแต่เพียงอย่างเดียว

ก. กระจกนูน ข. กระจกเว้า ค. กระจกราบ ง. ทั้ง ก. และ ค.

เพราะเหตุว่า

a. กระจกนูน,กระจกราบทำหน้าที่กระจายแสง รังสีแสงเสมือนตัดกันหน้ากระจกแต่เพียงอย่างเดียว

b. กระจกนูน,กระจกเว้าให้ภาพจริงได้ถ้าวางวัตถุชิดเลนส์

c. คุณสมบัติของกระจกทุกชนิดที่ทำให้เกิดภาพจริงได้ ขึ้นกับตำแหน่งที่วางวัตถุ

d. เป็นคุณสมบัติของกระจกราบและกระจกนูนที่เกิดภาพเสมือนหัวตั้งหลังกระจก

19. สถานที่แห่งหนึ่งเป็นลานกว้างล้อมรอบด้วยภูเขาตรงกลางลานปลูกต้นไม้ใหญ่ไว้ต้นหนึ่ง ทุกๆวันเมื่อพระอาทิตย์ขึ้น จะมองเห็นเงาของต้นไม้ได้ชัดเจน อยู่มาวันหนึ่งอากาศมืดครึ้ม จงพิจารณาคำกล่าวต่อไปนี้ว่าข้อใดถูกต้อง

ก. วันที่ท้องฟ้ามืดครึ้มจะเกิดเงาได้ยากกว่าและเห็นเงาได้ยากกว่าวันที่ท้องฟ้าโปร่ง

ข. วันที่ท้องฟ้ามืดครึ้มจะเกิดเงาได้ง่ายแต่เห็นเงาได้ยากกว่าวันท้องฟ้าโปร่ง

ค. สภาพของท้องฟ้าไม่ใช่ตัวกำหนดการเกิดเงา

ง. วันที่ท้องฟ้ามืดครึ้มจะมีเมฆมากและจะไม่มีเงาเกิดขึ้นในวันนั้น

เหตุผลเพราะว่า

a. เมฆจะบังแสงอาทิตย์ไว้

b. รังสีแสงที่ผ่านชั้นเมฆลงมาไม่ได้เดินทางเป็นเส้นตรง(non-rectilinear)

c. ในวันที่มีเมฆมาก ความเข้มของแสงจะมากกว่าวันท้องฟ้าโปร่ง แต่เพราะแสงเดินทางไม่เป็นระเบียบ(diffuse light)จึงเห็นเงาได้ยาก

d. ในวันที่เมฆมากความเข้มแสงจะลดลงกว่าวันที่ท้องฟ้าโปร่ง การเกิดเงาทำได้ยากกว่า

20. เงาอาจมีขนาดใหญ่กว่า เล็กกว่า หรือเท่ากับวัตถุได้ ขึ้นกับ

ก. ระยะของวัตถุกับแหล่งกำเนิดแสงและระยะของวัตถุกับฉาก

ข. ขนาดของแหล่งกำเนิดแสงและขนาดของวัตถุ

ค. ความสว่างของแหล่งกำเนิดแสง

ง. ขนาดของฉากรับภาพ

เหตุผลที่เลือกคำตอบคือ

a. ระยะของวัตถุกับแหล่งกำเนิดแสงน้อย ขนาดของเงาจะโตกว่าวัตถุ ฉากที่อยู่ไกลจากวัตถุจะทำให้เกิดเงาที่มีขนาดใหญ่ด้วย

b. ถ้าขนาดแหล่งกำเนิดแสงใหญ่กว่าวัตถุ เงาจะมีขนาดเท่ากับวัตถุ

c. ฉากที่ใช้รับภาพมีขนาดใหญ่จะมีอาณาเขตของการเกิดเงาได้กว้างกว่าฉากขนาดเล็ก

d. แหล่งกำเนิดแสงที่มีความสว่างน้อยจะทำให้เกิดเงาที่มีขนาดใหญ่ ตัวอย่างเช่นเงาตอนพระอาทิตย์ใกล้ตกดินจะโตกว่าตอนเที่ยงวัน

21. ในที่ๆไม่มีแสงสว่างเลย เมื่อเราพิจารณาระหว่างคนและสัตว์เราจะพบว่า

ก. คนและสัตว์ไม่สามารถมองเห็นได้ในที่ที่ไม่มีแสงสว่าง

ข. คนสามารถเห็นได้ในที่ที่ไม่มีแสงสว่าง

ค. สัตว์เท่านั้นที่มองเห็นได้ในที่ที่ไม่มีแสงสว่าง

ง. คนสามารถมองเห็นได้ในที่มืดเช่นเดียวกับสัตว์ แต่ไม่ชัดเจนเท่า

ทั้งนี้เพราะเหตุว่า

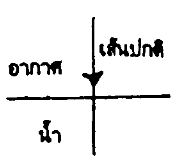
a. สัตว์มีความสามารถพิเศษที่มองเห็นในที่ไม่มีแสงดีกว่าคน

b. ม่านตาของคนมีขีดจำกัดในการมองเห็น

c. แสงสว่างช่วยให้คนและสัตว์มองเห็นสิ่งต่างๆได้

d. ม่านตาของคนและสัตว์สามารถปรับปรับให้ยืดหรือขยายได้ ตามสภาพของแสงสว่าง

22. เมื่อแสงเดินทางจากตัวกลางหนึ่งไปสู่อีกตัวกลางหนึ่ง จะมีการหักเหจากตัวกลางที่หนึ่งสู่ตัวกลางที่สอง ถ้าแสงเดินทางในแนวตั้งฉากกับผิวรอยต่อของน้ำและอากาศ ข้อใดถูกต้อง



ก. ไม่มีการหักเหเกิดขึ้นในกรณีนี้ เพราะแสงตกลงตามแนวของเส้นแนวฉาก

ข. ไม่มีการหักเหเกิดขึ้นเพราะแสงสะท้อนกลับทางเดิมหมดจึงมองไม่เห็นการหักเห

ค. มีการหักเหกลับทางเดิมจึงเสมือนไม่มีการหักเห

ง. มีการหักเหเกิดขึ้นเพราะเดินทางผ่านตัวกลางสองชนิด

คำอธิบายเพิ่มเติม

a. แสงยังเดินทางเป็นแนวเส้นตรง

b. แสงไม่เปลี่ยนทิศการเดินทาง

c. การหักเหจะเกิดขึ้นเมื่อเดินทางผ่านตัวกลางที่มีความหนาแน่นไม่เท่ากัน

d. แสงที่ตกบนผิวราบจะมีการหักเหไปเป็นมุมฉาก รังสีหักเหจะขนานไปกับผิวน้ำ

23. แสงซึ่งเดินทางผ่านแก้วน้ำใสสีแดงออกมา จะเห็นเป็นสีแดงเพราะ

ก. แสงที่ผ่านออกมาเป็นแสงขาว แต่สารสีแดงในถ้วยแก้วกระตุ้นให้แสงสีแดงเข้าสู่ตาได้มากกว่าสีอื่น

ข. สีแดงที่เห็นเป็นสีของวัตถุ ไม่ใช่แสงสี

ค. แสงที่เห็นเป็นแสงสะท้อนกับแก้วน้ำใสสีแดงเข้าสู่ตา

ง. แก้วน้ำใสสีแดงจะดูดกลืนสีอื่นไว้ และยอมให้สีแดงผ่านออกมาเป็นส่วนใหญ่

เหตุผลที่เลือกคำตอบคือ

a. แก้วน้ำใสสีแดงทำหน้าที่เป็นแผ่นกรองแสงสีแดง

b. แสงที่ผ่านถ้วยแก้วที่มีสี จะถูกอาบด้วยสีของสารสีในถ้วยแก้ว

c. ในบรรดาแสงสี แสงสีน้ำเงิน แดง เขียว แสงสีแดงจะมีความเข้มมากกว่าสีอื่นๆ จึงมองเห็นได้ชัดเจนกว่า

d. จะเกิดการสะท้อนและการหักเหพร้อมกันเมื่อแสงตกบนตัวกลางโปร่งแสง แต่จะเกิดปรากฏการณ์ใดชัดขึ้นกับสารสีในตัวกลางโปร่งแสงนั้น

24. ก่อนฝนตกจะมีฟ้าแลบอยู่แปลบปลาบ จากปรากฏการณ์ฟ้าแลบนักเรียนคิดว่าคำกล่าวใดควรจะถูกต้อง

ก. สายฟ้าแลบ (lightning flash) เป็นตัวอย่างของแสงที่หักเหในชั้นบรรยากาศ

ข. ฟ้าแลบเป็นตัวอย่างของแสงที่ไม่ได้เดินทางเป็นเส้นตรง

ค. สายฟ้าแลบ (lightning flash)เป็นรังสีแสงประเภทหนึ่ง

ง. แสงที่เห็นจากฟ้าแลบเดินทางเข้าสู่ตานั้นเดินทางเป็นเส้นตรง

เพราะเหตุว่า

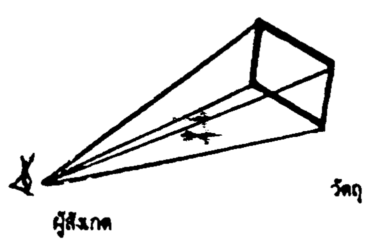
a. สายฟ้าเกิดจากการแลกเปลี่ยนประจุไฟฟ้าในบรรยากาศ

b. ความหนาแน่นของประจุไฟฟ้าในก้อนเมฆและที่ชั้นบรรยากาศไม่เท่ากันจึงเกิดการหักเหเกิดขึ้น

c. ฟ้าที่แลบเข้าตาเรานั้นแสงเดินทางเป็นเส้นตรง และสายฟ้าไม่ใช่รังสีแสง

d. แสงมีการเดินทางเป็นสองแบบเป็นเส้นตรง(Rectilinear) และไม่เป็นเส้นตรง(Non-Rectilinear)

25.



ผู้สังเกตขณะนั่งพิจารณาวัตถุรูปสี่เหลี่ยมตั้งรูปเกิดมีความคิดแว่บขึ้นมาว่าที่ตำแหน่งกึ่งกลางระหว่างตัวเขาและวัตถุ ดังรูป สิ่งที่มองเห็นควรจะเป็นอย่างไรเมื่อเทียบกับขนาดของวัตถุ (วัตถุยังอยู่ที่เดิม)

ก. ครึ่งหนึ่งของขนาดวัตถุ

ข. ใหญ่กว่าวัตถุ

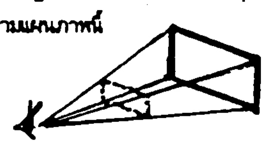
ค. เท่ากับวัตถุ

ง. บอกไม่ได้

เพราะเหตุว่า

a. เป็นไปตามกฎของสัดส่วนภาพ (law of perspective)

b. เป็นไปตามแผนภาพนี้



c. เมื่อวัตถุอยู่ใกล้เข้ามาภาพจะมีขนาดใหญ่ขึ้น

d. ไม่มีวัตถุย่อมไม่เกิดภาพและโจทย์ไม่ได้ระบุชนิดของอุปกรณ์แสงที่ใช้รวมทั้งระยะวัตถุให้ทราบด้วย