The purpose of this study was to develop an instrument to provide valid and reliable measures of misconceptions in the area of photosynthesis and respiration among fourth, fifth, and sixth grade students in Thailand. A 17-item, two-tier multiple-choice test was developed and validated using construct-related evidence to determine the appropriateness of inferences from a set of test scores. The test was administered to 4,346 students in the fourth, fifth, and sixth grades in schools throughout Thailand. The study attempted to identify misconceptions held by Thai elementary students in the area of photosynthesis and respiration, and to examine the effects of grade level and gender on students’ understandings of these concepts.

A two-way analysis of variance, with grade level and gender as independent variables, was used to analyze test scores. Findings revealed that: (a) The two-tier multiple-choice test was valid and reliable; (b) mean scores among grade levels were significantly different ($p = 0.001$); (c) mean scores between male and female genders
were not significantly different ($p = 0.180$); and (d) there was a significant interaction
effect between grade level and gender ($p = 0.005$).

From these findings, the following was concluded: (a) The two-tier multiple-
choice test provided valid and reliable measures of student misconceptions of selected
sciece concepts at the elementary school level in Thailand; (b) most Thai students in
grades 4, 5, and 6 held a large number of misconceptions of the selected concepts;
(c) a majority of the students answered the content questions correctly, but did not
understand the justification for the correct responses; (d) the higher the grade level,
the greater the understanding of the concepts; and (e) female and male Thai students
in grades 4, 5, and 6 did not differ significantly in their understanding of photosyn-
thesis and respiration.
Development and Use of an Instrument to Measure Student Misconceptions of Selected Science Concepts at the Elementary School Level in Thailand

by

Somsri Tangmongkollert

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Development and Use of an Instrument to Measure Student Misconceptions of Selected Science Concepts at the Elementary School Level in Thailand

CHAPTER 1
INTRODUCTION

Misconceptions affect the way students understand science concepts (Eaton, Anderson, & Smith, 1984). In recent decades, increased emphasis has been placed on research into content and context-dependent learning in science and the ways in which students' knowledge and misconceptions of science concepts can be revealed. This research has been important. Findings have contributed to improved understanding of science learning difficulties as well as concern for the necessity of changes in the teaching and learning processes in order to improve meaningful learning in science education (Betkouski, 1987).

Misconception is one of the various terms used by science education researchers to describe wrong knowledge (Brumby, 1979; Cho, 1988; Doran, 1972; Fisher, 1985; Griffiths & Preston, 1992; Ralya, & Ralya, 1938; Treagust, 1986). Others include misunderstanding (Brumby, 1979), alternative framework (Betkouski, 1987), and alternative conception (Abimbola, 1988). Wrong knowledge has also been referred to as intelligent wrongness, because it often shows imagination and perceptive thinking on the part of the learner (Betkouski, 1987).
Educators who reflect the cognitive, developmental or constructivist perspectives believe that the most important things which students bring to class are their own concepts (Ausubel, 1963; Driver & Oldham, 1986; Inhelder & Piaget, 1958). Children have a natural drive to find answers to their own questions (Betkouski, 1987). They employ their own concepts to interpret what they see, hear or read, from which they may find meanings that are different from or in conflict with what is considered to be correct. They then incorporate that correct or incorrect interpretation into their memory systems (Abimbola, 1988; Betkouski, 1987).

Misconceptions, therefore, are constructed in the learning process. Because they have been constructed on the basis of experience, they appear to be systematic, intelligently conceived, and quite reasonable (Clement, 1982). In addition to misconceptions, coherent conceptual structures are formed that are pervasive, stable, and resistant to change (Griffiths & Preston, 1992).

Misconceptions can be formed at any age. Evidence suggests that they begin to be formed before and during early school years (Ault, 1984; Minstrell, 1984). A number of sources serve to enhance the formation of misconceptions. Children may develop misconceptions from information presented in the media, particularly from cartoons. For example, the “Roadrunner” cartoons, in which Wiley Coyote usually overruns the cliff edge in his pursuit of Roadrunner, reinforce the belief that once an object leaves the cliff, nothing can hold it up, it must fall straight down. This belief persists among many children and adults (McCloskey, 1984).

Teachers affect students' understanding of science concepts. Teachers who do not understand the concepts that they must teach or who teach students only enough
to pass tests, facilitate the formation of student misconceptions of science concepts. Inconsistencies in conceptual teaching by teachers from different backgrounds contribute to student misconceptions. Those teachers who are unprepared to teach science and whom have inadequate time and facilities to do the job, but view the situation as tolerable, can lead students to misconceptions (Lawrenz, 1986; Marek, 1986). Teacher's guides which are either inaccurate, fail to answer questions clearly, do not stress the importance of concepts, or do not provide suggestions how to respond to students who do not accept given answers can also contribute to student misconceptions (Eaton et al, 1986). Students usually believe what they read in textbooks. If concepts are presented incorrectly or require a higher reasoning levels than has yet been attained, students will develop misconceptions (Barrass, 1984; Cho, 1988).

As early as 1930, the problem of student misconceptions was examined by surveying elementary students and cataloging their misconceptions (e.g., Frank, 1930). In studies conducted during the 1960s through the 1980s, scientific phenomena were demonstrated to students and students were then interviewed. The interviews elicited extensive information on the thought processes students employed, and which led to both correct and incorrect ideas about science (Anderson, 1965; Inbody, 1963; Osborne & Gilbert, 1980).

Though the individual student interview has been a fruitful method for the identification of student misconceptions of science concepts, the method is of only questionable use to teachers, researchers, and curriculum developers since considerable time and substantial training are required and the method can be conducted only for small samples. Subsequently, efforts have been directed at the development of
paper and pencil multiple-choice tests for the diagnosis of student misconceptions of
science concepts (Doran, 1972; Eaton et al., 1984; Tamir, 1971; Treagust, 1986,
1988; Za’Rour, 1975). Multiple-choice tests are potentially valuable to science
teachers and to curriculum developers since they make information on student mis-
conceptions readily available (Haslam & Treagust, 1987). Thus, multiple-choice tests
have been used to determine misconceptions in various areas, and have been proven
useful for the investigation of misconceptions among large numbers of subjects
(Doran, 1972; Haslam & Treagust, 1987; Tamir, 1971; Treagust, 1986, Za’Rour,
1975). They are time-saving, easy to administer and to interpret, and do not require
that students have writing skills (Halloun & Hestenes, 1985; Tamir, 1971, 1989;

Treagust (1986, 1988) proposed a two-tier diagnostic multiple-choice item test,
developed from a design comparable to the format of logical thinking tests, with
which to measure misconceptions. The first part (i.e., tier) of each test item consisted
of a multiple-choice content question. The second part contained sets of possible jus-
tifications for the response chosen in the first part. Included among the multiple-
choice reason responses were correct answers, misconceptions, and simply incorrect
answers. It was asserted that this method could be usefully adopted by teachers to
help them identify student misconceptions.

Effective measurement of science misconceptions held by students is of
obvious importance to both teachers and science curriculum developers. This type of
information is needed and can be used to develop science curricula as well as to plan
and teach science lessons. Hence, it is important that an instrument be developed
that is easy to administer and to score, and which will provide both valid and reliable measures of the misconception of science concepts.

Statement of the Research Problem

The principal purpose of the present study was to develop a valid and reliable test for the measurement of the misconceptions of photosynthesis and respiration reflected by elementary school students in Thailand. Following development of the instrument, the research questions investigated were as follows:

1) What are the understandings of selected concepts in the area of photosynthesis and respiration among fourth, fifth, and sixth-grade students in Thailand?

2) Do misconceptions of selected concepts among Thai elementary school students vary according to gender or grade level, or is there an interaction between these variables?

Need for the Study

In Thailand, both formal and non-formal education are of life-long concern. The educational system is centralized under the direction of the Ministry of Education and extends throughout 12 educational regions, each of which includes from four to eight provinces. Curricula are developed by the Ministry of Education and teachers are expected to conform to the requirements of this national design. From a plan implemented in 1978, the National Scheme of Education, six years are required for elementary education (grades 1 to 6), three years for lower secondary (grades 7, 8,
Elementary education in Thailand is compulsory. Children enter elementary school at age seven years and remain until they complete elementary grade 6 or reach 15 years of age (Ministry of Education, 1990).

The goals of elementary education in Thailand are to develop and maintain literacy, cognitive ability, numeral manipulation, and communication skills, and to instill adequate knowledge and abilities for application in future occupational roles. A further goal is personal development and the promotion of responsible citizenry, which is considered to be desirable for the development of life in a democratic society (Ministry of Education, 1990). The curriculum for elementary education is based upon an integrated approach to instruction in the social studies and in science, with emphasis on work experience and character development. The content of the curriculum is divided into five subject-areas, as follows:

1) **Skill**: The skill subject area covers Thai language and mathematics, the key subjects which enable learners to gain more knowledge.

2) **Life experience**: This subject area emphasizes the process of solving social problems and covers science, health, and history subject areas. Selected content concerns such problems and issues as health, population, society, religion, culture, economics, technology, environment, and communication.

3) **Character development**: This subject-area deals with the experiences necessary for the development of good character. Content includes
moral education, music and rhythmic movement, and physical education.

4) Work: This subject-area emphasizes basic, practical work experiences, including household work, handicrafts, woodworking, agriculture, and optional topics relevant to local situations and needs.

5) Special: This subject-area emphasizes career-related experience and basic English language. Teachers select either one of these areas to teach only to fifth or sixth grade students.

The teaching/learning period must not be less than 200 days per year, nor less than 1,000 hours for grade 4 and not less than 1,200 hours for grades 5 and 6.

Approximately 23% of the students who graduate from the elementary educational level continue formal schooling at the secondary educational level; 77% leave school and start to earn their livelihoods (Ministry of Education, 1990).

At the time the present study was conducted, no documented studies of science-related misconceptions at the elementary school level in Thailand had been undertaken. Thus, misconceptions of science concepts among Thai elementary students is an area which requires investigation. Since the study of misconceptions of elementary science concepts is at a preliminary stage in Thailand, the present study was intended to lay the groundwork for future studies. Though the present study was focused on the concepts of photosynthesis and respiration, it was based upon the intent to provide a model for the development of a two-tier instrument for the measurement of misconceptions, as well as to contribute to the knowledge of misconceptions among Thai elementary students in the area of photosynthesis and respiration.
and to knowledge of how those misconceptions vary according to selected variables. It was also intended that the present study would encourage Thai teachers and science curriculum developers to gather additional and useful information on student misconceptions.

Limitations of the Study

1) The study was limited to fourth, fifth, and sixth-grade students in Thailand.

2) The study was limited to selected concepts in the areas of photosynthesis and respiration.

Definition of Terms

For the purposes of the present study, the following terms are defined as follows:

Misconception: any conceptual idea whose meaning deviates from the one commonly accepted by scientific consensus (Cho, & Kahle, 1984).

Concept: knowledge which results from the manipulation of sensory impressions.

Elementary students: students who attend grades 4, 5, and 6 in Thailand.

Two-tier multiple-choice test: multiple-choice test containing a set of items, each one composed of two parts. The first part of the item is a multiple-choice content question with a set of forced-choice responses. The second tier consists of a set of justifications for the chosen response to
the question in the first part. Space is provided for writing an alternative reason response.

Theoretical Framework for the Study

The theoretical framework for the study was drawn from four areas: (a) constructivist theory of knowledge, which is based on an explanation for the acquisition of knowledge; (b) psychometric and measurement literature related to test construction; (c) research in the area of misconceptions of science concepts among school children; and (d) research relating misconceptions to gender and grade level. Each of these areas is briefly reviewed in this section.

Constructivist Theory of Knowledge

Theories presented by Ausubel (1963) and Piaget (Inhelder & Piaget, 1958) share a constructivist view; based upon the postulation that new knowledge is acquired from an existing knowledge base (Cho, 1988; Pine & West, 1986). According to von Glasersfied (cited in Bodner, 1986), the constructivist theory explains that learners construct understanding. They do not simply mirror and reflect what they are told or what they read. Learners look for meaning and will try to find regularity and order in the events of the world even in the absence of full or complete information.

This can be summarized in a single statement: Knowledge is constructed in the mind of the learner (Bodner, 1986).

Constructivist theory views knowledge acquisition as the result of the life-long construction of both formal and informal knowledge. Informal knowledge is gained
from interaction with the environment, whereas formal knowledge is gained through
the intervention of the school (Bodner, 1986; Pine & West, 1986). Children construct
knowledge in order to manage their experiences. An impressive body of informal
knowledge, which is the tool for making sense of the environment, tempered and
manipulated through interactions with parents, friends, and other influences, is con-
structed. This knowledge base is built on everyday-life experience, influencing con-
sideration of any or all explanations by children. Thus, it impacts whatever children
will learn subsequently (Bettencourt, 1989; Bodner, 1986; Butts & Brown, 1989;

If what children consider to be reasonable explanations are incorrect, and are
provided with this knowledge (either formally or informally) via any media or school
system, the incorrect knowledge will be maintained. However, if they are provided
with correct knowledge, that is, knowledge approved by consensus opinion among,
for example, respected scientists, and they are engaged in constructing meaning, the
children may or may not change their existing knowledge base (Bettencourt, 1989;
Cho, 1988; Inhelder & Piaget, 1958). This is because the acquisition of knowledge is
influenced to a considerable extent by existing knowledge or naive knowledge
(Bettencourt, 1986; Pine & West, 1989). Therefore, constructivists are not surprised
that some conceptions held by students are not those intended by their teachers. Con-
structivist theory helps to provide explanations why children bring misconceptions to
the classroom, and why some children prove to be more resistant than others to
instruction. Thus, the task of changing misconceptions is not easy since they have,
from the constructivists' perspective, been incorporated into student cognitive structures.

Numerous science educators have attempted to otherwise modify student misconceptions. Gilbert and Watts (1983) posited that if it can be accepted that concepts change with experience, then it follows that student misconceptions are subject to change with experience. Hand and Treagust (1991) and Minstrell (1984) have suggested strategies based on the active involvement of students in the construction of their own conceptual understanding. This is an approach which can be used in science curriculum development and teaching to encourage changes from misconceptions to scientifically acceptable conceptual understanding.

Psychometric and Measurement Literature Related to Test Construction

Testing can be used to help teachers, curriculum developers, and researchers enhance instructional effectiveness and improve student learning only when tests provide scores which are reliable and valid. For the greater part, reliability and validity are determined by the procedures used to develop the test. Hence, it is important to identify and use appropriate procedures in test construction. At the same time, the content domain of the theoretical construct, misconception has not been defined to the degree of general acceptance, thus misconceptions must be measured indirectly until such time a definite criterion measure is available. The appropriate type of evidence to support validity is construct-related evidence (American Psychological Association [APA], 1985; Gronlund & Linn, 1990; Herman, 1984; Hopkins, Stanley, & Hopkins, 1990; Mueller, 1986). Construct-related evidence determines the extent to which test
performance can be interpreted in terms of psychological constructs (Gronlund & Linn, 1990).

In general, test construction steps are as follows: (a) Create test specifications which indicate the numbers of items for each content area; (b) develop test items following the specifications; (c) review the test items; and (d) administer the test to the subjects and the data to a series of analyses (Gronlund, & Linn, 1990; Herman, 1986; Hopkins et al., 1990). However, inferences from scores obtained from testing will be effective only when the tests provide scores that are both valid and reliable, in large measure determined by the procedures used to develop the test.

Construct-related evidence for validity cannot be found within a single procedure, and the accumulated findings of several procedures must be used to constitute an empirical base for construct-related evidence. However, Cronbach and Meehl (1955) stated that it is impossible to describe a specific set of procedures that can be used to establish construct validation, observing that these procedures are identified by the orientation of the research. Some alternative procedures are suggested in psychometric and measurement literature. For example, Cronbach and Meehl (1955) suggested the following procedures: known-group difference, correlation matrices and factor analysis, studies of internal structure, studies of change over occasions, and studies of process. Mueller (1986) recommended correlation with measures of similar constructs, correlation with unrelated and dissimilar constructs, and the opinions of judges. It was added that objectivity is a concern when judges are used and that the most favorable use of judges is in an editorial capacity. Defining the domain of tasks to be measured and analyzing the mental processes required by the test items are also
suggested as sources for the accumulation of construct-related evidences (Gronlund & Linn, 1990).

However, the procedures followed in the development of tests, including format, method of administration, scoring, language level, and item analysis, may affect test measurement and interpretation of the scores, and are thus important concerns in gathering construct-related evidence (APA, 1974, 1985). In summary, the use of construct-related evidence gathering procedures suggested by the literature of psychometrics and measurement are necessary whenever an entirely adequate criterion measure or universe of content has not gained general acceptance. Such evidence is used: (a) to enhance the quality of the test instrument and (b) to establish the appropriateness, meaningfulness, and usefulness of inferences made from the scores obtained by administration of the instrument to a given group.

Research in the Area of Misconceptions in Science

Misconceptions of science concepts have been studied by researchers in both the biological and the physical sciences. For the biological sciences, misconceptions of the following concepts have been investigated: genetics (Fisher, 1985); animal and animal classification (Trowbridge & Mintzes, 1985); circulatory system (Arnaudin & Mintzes, 1983); photosynthesis and respiration (Cho, 1988; Chowpreecha, 1990; Eaton et al., 1984; Haslam & Treagust, 1987; Institute for the Promotion of Science Teaching and Technology [IPST], 1987; Wandersee, 1983); cell and diffusion
(Westbrook, 1987). Misconceptions of the following physical science concepts have been examined: magnetism (Benbow, 1987); sink and float (Stepans, Beiswenger & Dyche, 1986); Newton’s laws (Brown, 1988); covalent bonding and structure (Kiokaew, 1989).

Science-related misconceptions among elementary, secondary, and college students, as well as teachers at these levels, have been investigated (Cho, 1988; Griffiths & Preston, 1992; Stepans, Dyche, & Beiswenger, 1988, Treagust, 1986; Wandersee, 1983). Misconceptions of science concepts have also been studied by science education researchers in a number of nations, including, Australia, England, Korea, Israel, Lebanon, Nigeria, Thailand, and the United States (Adeniyi, 1985; Cho, 1988; Doran, 1972; Griffiths & Preston, 1992; IPST, 1987). Since no documented study of science misconceptions at the elementary school level in Thailand has been conducted, it is desirable to address misconceptions among Thai elementary science students.

Research Relating Misconceptions to Gender and Grade Level

Gender is an important variable of consideration in cognitive research in science education, and researchers have reflected persistent concerned with the relation of achievement to gender differences (Becker, 1989). Evidence has indicated that females do not achieve as well as they might in science. According to findings established by Erickson and Erickson, Jones, and Kelly (cited in Tobin & Garnett, 1987), males achieved at higher levels in science than did females. The Second IEA Science Study found that sex differences in science achievement not only existed at
all grade levels, but also in different nations (Humrich, 1988). From these findings, it can be inferred that females evidence a greater number of misconceptions in science than do males. However, only a limited number of studies of gender differences among younger subjects have been conducted (Steinkamp & Maehr, 1983). Treagust (1986) found no statistically significant differences for gender with respect to misconceptions of concepts of photosynthesis and respiration. At the same time, researchers have found that grade levels affect achievement, evidenced by mean test scores that increased progressively with grade level (Doran, 1972; Fisher, 1986; Wandersee, 1985).

It has been logically posited that levels of achievement in science and levels of misconceptions of science concepts are inversely related. The hypothesis that achievement is also related to gender and to grade level suggests that conceptual misconception may also be related to these variables.

**Summary of the Theoretical Framework for this Study**

This study was based on the following theoretical framework:

1) **Constructivist theory** asserts that knowledge is constructed in the mind of the learners, and that new knowledge is acquired based upon existing knowledge (Ausubel, 1963; Bodner, 1986; Inhelder & Piaget, 1958; Pine & West, 1986).

2) **Misconceptions** occur when students construct knowledge, in order to manage the experiences, while interacting with their environments. If what students consider to be reasonable explanations are incorrect, they
will nonetheless continue to hold these misconceptions (Bettencourt, 1989; Bodner, 1986; Butts & Brown, 1989; Garnett & Stavy, 1992; Pine & West, 1989).

3) Misconceptions are highly robust, but nevertheless are subject to change (Hand & Treagust, 1991; Minstrell, 1984).

4) Construct-related evidence, as suggested by the literature of psychometrics and measurement, can be used to support validity; that is, validity as indicated by the appropriateness, meaningfulness, and usefulness of inferences from test scores obtained by administering a given instrument to a given group.

5) Misconceptions of science concepts among children exist at every grade level and in various content areas, as well as in countries around the world (Adeniyi, 1985; Arnaudin & Mintzes, 1985; Benbow, 1987; Brown, 1988; Cho, 1988; Chowpreecha, 1990; Doran, 1972; Eaton et al., 1984; Griffiths & Preston, 1992; IPST, 1987; Kiokaew, 1989; Stepans et al., 1986; Treagust, 1986, 1988; Wandersee, 1983;).

6) Gender differences in science achievement exist at all grade levels and in many nations (Erickson & Erickson, 1984; Humrich, 1988; Jones, 1991; Steinkamp & Maehr, 1983; Tobin & Garnett, 1987).

7) Achievement in science increases progressively with grade level (Doran, 1972; Fisher, 1985; Wandersee, 1985). Hence, misconceptions of science concepts should decrease with grade level.
Organization of the Study

The remainder of this study is presented in four chapters. Chapter 2 is a review of related literature. Chapter 3 summarizes the methodologies used for this study. Chapter 4 provides an analysis of the data as well as the results of data interpretation. Finally, conclusions, discussions, and recommendations are provided in Chapter 5.
CHAPTER 2
REVIEW OF LITERATURE

This chapter reviews the literature relevant to this study, presented in five sections organized as follows: (a) The first section is devoted to test construction in relation to research on misconceptions; (b) the second section examines research involving elementary students and misconceptions of science concepts; (c) the third section describes research concerning student misconceptions in relation to the variables of grade level and gender; (d) the fourth section considers student misconceptions at higher grade levels and misconceptions among teachers; and (e) the fifth section is concerned with the literature of constructivist theory and the ways in which misconceptions can be changed.

Test Construction

Misconception is an abstract concept for which there is no operational definition and for which no criteria for defining the quality to be measured have been generally accepted. Therefore, construct-related evidence is required for the construction of an instrument to measure misconceptions. The use of procedures which determine the appropriateness of inferences from a set of test scores resulting from consideration of construct-related evidence is suggested in the literature of psychometrics and measurement (APA, 1985; Gronlund & Linn, 1990; Herman, 1984;
Hopkins et al., 1990; Mueller, 1986). Constructs for particular tests should be embedded in a conceptual framework, even though that framework may be imperfect (APA, 1985). From the literature, the following procedure for the construct of a test to measure student misconceptions is suggested:

1) Create test specifications. Building test specifications includes preparing instructional objectives, outlining the content, and preparing a two-way chart. The list of instructional objectives describes what students are expected to demonstrate, and the list of instructional content clarifies the content that will be covered. A two-way chart is used to relate instructional objectives to instructional content. The chart indicates the total number of test items and the number of test items allotted to each objective and to each content area.

2) Develop test items following the specifications. To develop items, attention must be given to extraneous factors that could confound student responses. These factors include sentence structure, vocabulary, cultural background, prior experiences, age, and gender.

3) Review test items. Test items should be subject to thorough review to assure that items match the objectives and content. An expert panel, used to judge the correctness of content, language, and level of difficulty or complexity for each item, may be enlisted for this process (APA, 1985; Herman, 1984; Mueller, 1986).

4) Administer the test to a group of subjects and subject data to a series of analyses. This step is necessary to ensure high quality items, to
verify test structure, to determine an appropriate number of items, to
determine reliability, and to gather evidence for validity. Revision of
test items is included in this step. Appropriate items will be retained
and those that are judged inappropriate will be withdrawn (Herman,

Reliability and Validity

To construct a useful test, reliability and validity are two important qualities
that the test developer must consider (Mueller, 1986). Reliability refers to the consist-
tency of evaluation results. In other words, it is the degree to which test scores are
free from errors of measurement. If the instrument is reliable and its method of
measurement is both consistent and accurate, then each respondent's score can be
believed (Hopkins et al., 1990; Mueller, 1986).

There are four procedures for determining the reliability of a psychological
measure: test-retest, alternative forms, split-half, and internal consistency (Mueller,
1986). In the test-retest procedure, the instrument is administered twice to the same
group. The second tests are administered approximately two weeks following the
administration of the first test. If the high scorers on the first test score high on the
retest, while average scorers score average and low scorers score low, then the instru-
ment may be judged to be substantially reliable.

The alternative forms procedure requires the use of alternative test forms that
are equivalent. Alternative forms are administered to the same group of subjects, and
the second form may be administered immediately following the first form or after a
certain time interval. Scores from the two forms are correlated to obtain reliability coefficients for test items.

The split-half procedure requires the administration of only a single test to a group of subjects. Test items are divided into two half-length tests. Each test taker receives two scores, one for each half of the test, following which findings from the two sets of scores are correlated. Correlation coefficients are calculated using the Spearman-Brown formula for doubled length (Hopkins et al., 1990; Mueller, 1986).

The internal consistency procedure requires that only a single test be administered. The procedure is different from other reliability procedures in that correlation statistics are not used directly since there are not two sets of scores that can be intercorrelated (Mueller, 1986). An internal consistency coefficient, or an index of interitem consistency, is developed to indicate similarities in measurement across items. Items should reflect moderate intercorrelation.

The formulas used to calculate the internal consistency coefficients include the Kuder-Richardson formula 20 (K-R 20) and Cronbach’s alpha (Mueller, 1986). The K-R 20 is used for tests with dichotomously scored items, whereas the Cronbach’s alpha, as developed from the K-R 20, is used when test items are scored along a continuum. Therefore, regardless of which of the tests is used to calculate the internal consistency of a test with dichotomously scored items, the results can be expected to be identical (Kajornsin, 1987).

In turn, validity is the most important quality to be considered when constructing testing instruments. Validity refers to the appropriateness, meaningfulness, and usefulness of specific inferences from test scores (APA, 1985). Test validation is the
process of accumulating evidence to support such inferences. There are three approaches to test validation: content-related evidence, criterion-related evidence, and construct-related evidence. In each case, all evidence should contribute to the meaning of the test scores (APA, 1985; Gronlund & Linn, 1990).

Content-related evidence is used to demonstrate the degree to which a sample of items, tasks, or questions on a test are representative of a given defined content domain. This method is often reliant upon expert judgement for the assessment of relationships between parts of the test and the universe (APA, 1985).

Criterion-related evidence is used to demonstrate how well test scores predict or estimate performance based upon a given criterion measure. The criterion behavior is of concern to the tester, who may have no concern whatsoever with the type of behavior exhibited in the test. There are two designs for obtaining criterion-related evidence. One is predictive and the other is concurrent. The predictive study obtains information about the test that can be used to estimate the criterion scores that will be obtained in the future. A concurrent study obtains prediction and criterion information simultaneously (APA, 1985; Cronbach & Meehl, 1955; Gronlund & Linn, 1990).

Construct-related evidence is important to all types of test construction, and cannot be identified solely with specific investigative procedures (Cronbach & Meehl, 1955). The process of compiling construct-related evidence is initiated at test development and is continued until the pattern of empirical relationships between test scores and other variables can be used to clearly indicate the meaning of the test (APA, 1985). Validating construct inferences requires careful attention to those
aspects of measurement that may affect test meaning and interpretation. Procedures for the accumulation of this type of evidence are given detailed consideration in the following section.

Procedures for Gathering Construct-Related Evidence

As noted above, for the construct of an instrument to measure misconceptions, construct-related evidence is required since the term misconception is an abstract concept that lacks an operational definition. The evidence may be determined from the development of a set of procedures, with a rationale for each procedure based upon logical steps (APA, 1985; Gronlund & Linn, 1990; Hopkins et al., 1990; Mueller, 1986). These steps should include the following: defining the concept of misconception; developing an item pool; trial testing the instrument; reviewing items by an expert panel; performing item analysis; measuring internal consistency; determining known-group differences; determining correlations between two measures of similar constructs; and testing for readability.

The item pool can be developed from a literature review, interviews with experts or subjects, or analysis of the curriculum. Access to an expert panel is often suggested for the process of test construction (Mueller, 1986). The panel considers whether the items are closely related to the concepts they are intended to measure. The panel may also edit, verify, and evaluate the items for correctness of content and appropriateness of content and language (APA, 1985; Edwards, 1957). It has been suggested that any item that does not meet the criterion of at least 80% agreement
among panel members should be improved or withdrawn; however, no criteria have been established concerning the number of experts which constitute a panel.

Trial testing of the instrument is conducted to assure the high quality of test items, to verify the test structure, to determine the number of items that will be required, and to determine the appropriate time lengths for subjects to respond to the instrument. This process is usually conducted through a series of pilot studies. The subjects participating in the pilot studies must be representative of the target population. Feedback regarding revision of the instrument is necessary (Herman, 1984). This procedure, which assures the quality of the test, includes procedures for item analysis, measures of internal consistency and known-group differences, and the correlation of two measures based upon similar constructs.

Item analysis is required to confirm that test items function empirically in the desired manner (Hopkins et al., 1990). It is used to determine the difficulty and discrimination capacity of each item. The difficulty index indicates the percentage of the group tested that answered each question correctly. The discrimination index indicates how well each item distinguishes between more knowledgeable and less knowledgeable students. These two indices are obtained by administering the test to a subject group. After scoring, the upper and lower 27% technique is used to determine the proportion of subjects in the high and low groups who answered particular items correctly. The difficulty index is obtained by adding the proportion constituted by the high group to that for the low group and then dividing by two. The discrimination index is obtained by subtracting the low group proportion from that of the high group. An item that has a positive discrimination index will discriminate in a manner
similar to that for the total score (Mueller, 1986). A reasonable range for difficulty and for discrimination are, respectively, 0.2 to 0.8 and 0.2 to 1.0 (Hopkins et al., 1990; Kajornsin, 1987).

The known-group difference procedure identifies two groups of subjects, those who understand the concept and those who have misconceptions concerning the concept. This procedure may begin with interviews of selected subjects to determine who does and who do not understand the concept, followed by administration of the instrument to both groups. The t-statistic may be employed to compare the mean scores of these two groups. If the mean scores for the “understands concept” group are significantly higher than the mean scores for the misconception group, then use of the instrument is supported by the construct-related evidence (Hopkins et al., 1990; Mueller, 1986).

The procedure for correlation between two measures of similar constructs involves correlation of the scores of the two measures. For example, the developed instrument is administered to a group of subjects, who are then ranked by test scores, from highest to lowest. Subjects are also ranked by scores from another instrument, such as a science achievement test, with constructs similar to those of the developed instrument. The rank difference coefficient is employed to compute the correlation between the scores for the two measures. A moderate to high correlation is required to support the construct-related evidence for validity (Cronbach & Meehl, 1955; Gronlund & Linn, 1990; Hopkins et al., 1990; Mueller, 1986).

With respect to test items, vocabulary and sentence structure must be appropriate to the test-taker population. If vocabulary and sentence structure are too
difficult, test results may reflect this difficulty rather than what is being measured (i.e., misconceptions) (Gronlund & Linn, 1990). The procedure for checking reading levels may be conducted by asking experts to consider and judge the language for each item. Reading levels may also be checked by asking a group of subjects studying at the same level as the target population to read the items. If there are any words or sentence structures that are not understood, they must be revised. This procedure assures that subjects will be able to read and understand each test item.

Directions for taking the test should be presented to test takers in sufficient detail to allow response to the items in the manner intended by the test developer(s). A sample practice and/or sample question should be included to assist in clarifying the procedure for responding to test items and for recording test responses (APA, 1985; Hopkins et al., 1990).

Construct-related evidence accumulated in the validation process are used to determine the appropriateness, meaningfulness, and usefulness of inferences from scores obtained by administration of the instrument to a given group.

Elementary Students and Misconceptions in Science

The study of misconceptions of science concepts among elementary students is an established interest among science educators. In the 1930s and 1940s, misconceptions were considered to be science-based superstitions (Benbow, 1987). Over the years, there has been little change in this perspective. A study by Inbody (1963) on understanding of selected natural phenomena marked a certain shift. The sample was comprised of 50 kindergarten students in three school districts within a large
residential suburb of Kansas City, Kansas and Kansas City, Missouri. There were few families of either the upper or lower socioeconomic classes in this area. Student subjects were questioned individually, using interview techniques of demonstrated utility, posed questions as derived from an analysis of textbooks. Of the 12 topics or experiences, eight involved demonstrations of natural phenomena with commonplace materials, two used pictures, and two were purely verbal. During interviews from 25 to 30 minutes in length, subjects were asked by the interviewer to explain selected phenomena. The misconceptions cited included: air did not have weight; rain wasn't derived from clouds; and "light" and "heavy" were absolutes. The young subjects were capable of understanding the relationship of cause and effect. The results also demonstrated that adult logic was often meaningless to children.

A study by Anderson (1965) concerned the ability of young children to formulate mental models for the explanation of observations of natural phenomena. Subjects in the study included 180 randomly selected elementary students from grades 3 to 6 at 34 elementary schools located in various classes of socioeconomic neighborhoods. The technique employed was the interview-demonstration of selected natural phenomena. Each subject was asked questions during the demonstration. The results indicated that the subjects provided consistent explanations which were in direct proportion to their ages and IQ levels. Among misconceptions were the following: liquid was made up of atoms and "something else"; water was partially composed of living materials, or non-living materials in water behaved in a manner similar to living materials; and magnetic attraction between particles became stronger when they were cold.
Doran (1972) administered a 77-item test, via motion picture film to 253 subjects in grades 2 through 6, to determine misconceptions in various selected science areas. The subjects were students in a school located in a middle-class neighborhood of Wisconsin City. The test items, some of the response choices for which represented possible misconception, dealt with the particle theory of matter. Grade level, age, gender, and IQ data were analyzed to determine whether they related to the misconceptions. The F-ratio was significant at the 0.01 level, providing support for the hypothesis that there would be a grade effect: mean test scores increased progressively with grade level. The effect of gender on performance was not reported. Overall, it was found that the subjects believed that matter was continuous, there was no spacing between particles of matter, and that natural phenomena could be explained as changes in the size of particles.

A study that used a variety of analytical instruments was conducted by Eaton et al. (1984), using observation, a 43-item short answer and multiple-choice test, and textbook analysis. The study design was to have one group pretest and posttest. The purpose of the study was to examine the relationship between fifth-grade student misconceptions about light and photosynthesis and textbook and classroom instruction. Subjects were selected from classes given by 14 fifth-grade teachers, five of whom provided light instruction and nine of whom taught photosynthesis, and 102 subjects were tested. Only misconceptions about light were reported, centered upon misconceptions about how objects are seen and what happens when light encounters objects. The subjects believed that light from the sun entered their eyes and then encountered objects, allowing visualization and the absorption of light by the objects.
Grade Level, Gender, and Misconceptions in Science

Studies that consider grade level as a variable are useful for understanding concepts held by students across grade levels. Such studies provide the opportunity to examine those changes in student understanding of scientific phenomena which result from maturation and additional instruction. Among independent variables considered, studies of misconceptions tended to focus more on grade level or age than upon gender.

Knifong (1973) conducted a study based upon use of demonstration and interview techniques to collect data about student understanding of 15 different physical phenomena. However, the researcher discussed only one example, pendulum behavior. The subjects, between the ages 12 to 14 years, were shown a swinging pendulum and then asked to drawing the phenomena, indicating the direction of gravity with arrows. Common misconceptions were revealed. Many of the subjects drew arrows which showed that the force of gravity pulled sideways rather than downward. They also demonstrated that a very heavy pendulum would stop in the center of the swing.

Za’Rour (1975) carried out a study of misconceptions in Lebanon, based upon 1,444 students from 11 high schools and the American University of Beirut. The instrument used was a 40-item multiple-choice test with four alternatives per item (it is noted that the reliability and validity of the test were not reported). The
data indicated that 30% or more of the students held a number of potential misconceptions about physical science, misconceptions which decreased as grade and socio-economic levels increased. At the grade 11 level, male subjects had fewer misconceptions than female subjects, and female subjects were weaker with respect to mechanics and density questions. Common misconceptions reflected among the subjects included the following: it is impossible to change an element into another element; the density of the dry air is less than that of moist air; and air is mostly composed of oxygen.

Tamir, Gal-Choppin, and Nussinovitz (1981) conducted research to determine the concepts that students in grades 3 through 9 had of life and non-life, and the relationship of thought processes and maturity. Subjects were 424 students selected from 17 schools throughout Israel. The researchers combined a written test with a follow-up interview technique. Common misconceptions among these subjects included: movement and growth are the most commonly used indicators of life; the lives of man and animals differ from those of plants, embryos, or inanimates; and seeds and eggs are not alive. The older students employed characteristics in addition to that of movement (e.g., nutrition, reproduction, respiration, growth) as basic indicators of life status.

Osborne and Cosgrove (1983) used demonstration and interview techniques to determine student concepts of familiar phenomena associated with water, namely the evaporation, condensation, boiling, and melting of ice. The materials used in the demonstrations were familiar kitchen implements. Working with 43 subjects, from ages 8-17 years, all of whom were studying science at each grade level, each subject
was interviewed for 30 minutes. The purpose of the study was to determine how students' explanations of the same demonstrated phenomena changed with age. It was found that the older and younger students held similar views, despite the increased exposure of older students to science teaching. Common misconceptions elicited in the interviews were that bubbles were composed of heat, condensation was sweat, from water on a plate, some evaporated into the plate and some was converted into air, and the condensation on glass was due to melting ice coming through the glass.

In another study, student concepts of animals and animal classifications were examined at the elementary school, junior high school, and college levels, using interview and problem-solving techniques (Trowbridge & Mintzes, 1985). There were 62 subjects involved in this study, each of whom were interview and after which, each was given a set of 20 animals to classify. Most of the subjects classified the animals according to number of legs, bodycovering (fur or feather), and habitat (woods or outside). The college students tended to ascribe to animals both scientifically acceptable attributes and attributes which are common to both plants and animals. However, most of the subjects used movement to distinguish animals from plants, and the criteria of well-defined head and limbs for vertebrates and soft or lengthy bodies, or the existence of shell or exoskeleton, for invertebrates. Amphibians and reptiles were difficult for most of the subjects to classify.

The study designed by Wandersee (1985) focused on photosynthesis concepts, searching for relationships between students' conceptual problems and the transformation of the photosynthesis concept through time, as noted by a historian of the sciences. The sample consisted of 1,405 fifth, eighth, and eleventh-grade students and
college sophomores. The subjects were from both rural and urban middle-class backgrounds. The Photosynthesis Concept Test, a paper-and-pencil test consisting of 12 tasks which present an experiment, a natural phenomenon, or a situation, was used to detect student misconceptions about photosynthesis. To simulate what occurred in clinical interviews, the subjects were asked to make forced choices or free responses and to complete drawings. The instrument was validated through content-related evidence, with reliability established at 0.72. The study findings indicated that with increased grade levels, there was an increase in the percentages of subjects who favored accepted answers about the basic function of soil in plant growth and photosynthesis, the basic role of photosynthesis in the carbon cycle, and the basic roles of the leaf and light energy in photosynthesis. Student concepts of photosynthesis continued to change as they moved through the educational system, but over time little improvement was noted for some concepts.

A study on student concepts of the circulatory system was conducted by Arnaudin and Mintzes (1985). Their methodology included a test construction phase and a validation phase. In the construction phase, consisting of three 290-minute sessions prior to the investigation, 25 fourth grade students and 25 college students were trained to map. They were then given a list of eight concept labels and asked to synthesize a map of the human circulatory system. Each subject was also interviewed for 20-25 minutes. For the validation phase, a 15-item test, consisting of 11 multiple choice and four open-ended questions, was developed as follows: Concept maps and interview tapes were evaluated for scientifically acceptable responses and alternative concepts. These concepts were grouped to produce a set of alternative
belief categories used to develop questions and response choices for the test instrument. The instrument was then evaluated by a panel of biologists and science educators and determined to have an internal consistency reliability of 0.62.

The final instrument was administrated to 495 subjects, representing fifth and tenth grade students and college students who were both non-biology and biology majors (Arnaudin & Mintzes, 1985). It was found that the relative frequencies of alternative conceptions common to elementary students remained stable at the secondary and college levels. The students understood that blood had a cellular component, but did not understand the concept of plasma. The elementary students thought that blood was simply a red liquid. Most of the secondary and college students thought that blood was a red liquid or red cells which lacked an intercellular liquid. For the function of blood, the majority of the elementary school subjects answered that it was a vitalistic response. This response dropped across grade levels. The common response for the remaining subjects was that blood only carried oxygen or only transported nutrients. Correct responses on two or more items changed across grade levels. There was a low percentage of accurate responses and diversity in viewpoints at different grade levels about the structure of the heart, but the overwhelming majority of the subjects at every grade level indicated that the function of the heart was to pump blood. Most of the subjects did not include lungs in the circulatory system, and there were no significant differences in response patterns across grade levels regarding the questions on the circulatory and respiration relationship.

Stepans et al. (1986) conducted research to determine student understanding of concepts related to how objects sink and float in water, interviewing 184 students at
the primary, intermediate, junior high, and college levels. The college students were enrolled in a science content course for elementary education majors at the University of Wyoming. The researchers employed the clinical interview developed by Piaget and, during the interviews, used items similar to those employed by Carpenter. Results indicated that the different subject groups used significantly different language to describe concepts. The elementary students gave responses based on common sense and were unencumbered by science terminology. The older students tended to be so concerned with trying to fit the correct scientific terms into their explanations that they lost sight of the phenomena at hand.

Westbrook (1987) conducted a study of student understanding of the concepts of cells, diffusion, homeostasis, and gene function. Three groups of students, including 100 seventh-grade students, 100 tenth-grade students, and 100 college students majoring in zoology, participated in the study. Each was asked to respond to a test packet consisting of a biographical questionnaire, two Piagetian developmental tasks, and concept evaluation statements. Understanding was evaluated by application of the following scale: complete understanding, sound understanding, partial understanding, partial understanding with specific misconception, specific misconception, and no understanding. College students showed greater understanding of selected concepts; however, there were no significant differences in the frequency of misconceptions among groups. Misconceptions regarding the concepts existed regardless of development level.

The methodology used in by Westbrook (1987) study was employed subsequently by Westbrook and Marek (1992) in a study of student understanding of
homeostasis. Results of the analyses indicated that understanding of the concept increased across grade levels. Only 3% of the seventh-grade students and 30% of the college students had "partial understanding" of the homeostasis process; 46% and 64%, respectively, exhibited misconceptions regarding the concept and the process. None of the tenth graders exhibited "complete understanding," whereas 12% reflected "partial understanding," and 54% demonstrated misconceptions.

A two-tier multiple-choice diagnostic test was developed by Treagust (1986, 1988) as a tool for examining student misconceptions about photosynthesis and respiration. The first tier consisted of multiple-choice questions and the second tier consisted of a multiple-choice set of reasons for answers given in the first tier. Attention was given to the responses selected by more than 10% of the subjects. The instrument was validated by science educators and scientists, and reliability was determined to be 0.72. The subjects were 438 students selected from years 8-12 in high schools in Perth, Western Australia, each of whom were taught science subjects every year. The research data illustrated how student misconceptions about photosynthesis and respiration in plants were retained throughout secondary school years, despite instruction in these concepts each year. This finding highlighted the consistency of student thinking processes across grade levels. Statistically significant differences were found between grade levels, the relationship between grade levels, and the persistence of misconceptions across grade levels (Haslam & Treagust, 1987). However, there were no significant differences between gender and misconceptions, and no interaction effects between gender and year level.
Cho (1988) tested Korean fifth and eighth-grade students in the inner city of Seoul on concepts related to photosynthesis, for which three instruments were developed: the Photosynthesis Concepts Test (PCT), the Piagetian Logical Reasoning Test, and a questionnaire. A panel selected from the Ohio State University Department of Educational Studies, Science Education Section, with the addition of a professor of botany, judged the content-related evidence of validity and logical reasoning for the PCT instrument. The internal consistency of the PCT was 0.58 for fifth-grade and 0.75 for eighth-grade students. The data showed that students in both grades had misconceptions about making food, the definition of food, the use of light by plants, the function of plant roots and leaves, photosynthetic products, and elemental requirements for photosynthesis. The eighth-grade students scored higher on achievement than did the fifth-grade students. For the eighth-grade students, gender was positively and significantly correlated with achievement. Overall, the data favored male students. However, there was no significant difference between gender and achievement for the fifth-grade students.

Misconceptions in Science Among Secondary and College Level Students and Teachers

Secondary and College Level Students

The persistence of misconceptions over time is evident in the findings of studies involving secondary school and college students. These studies also show that the patterns are similar for different countries around the world.
A study conducted by Clement (1982), using undergraduate students who had taken a mechanics course, found that physics students tended to have a stable alternative view of the relationship between force and acceleration. However, the conceptual primitive was misunderstood at the qualitative level, in addition to any difficulties that might have occurred with mathematical formulation. The data collection measures were written tests and videotaped problem-solving interview.

Research conducted by Brumby (1984) explored the conceptual frameworks and reasoning patterns used for unfamiliar biological problems, using individually structured interviews and two written problems. The sample consisted of 150 first-year medical students from one university. The written problems called for open-response explanations, and were given in the second week of class and at the end-of-year examination to all 150 subjects, whereas only 32 subjects were given the individual interviews. The data clearly indicated that the majority of the subjects believed that evolutionary change occurred as a result of need. They had misconceptions about adaptation (which they confused with immunity), immunity, antibiotics, and antibodies. About two-thirds of the subjects clearly related natural selection to the frequency of genetic diseases. It was apparent that the students reproduced the content of the evolution lecture in their exam answers, but without applying their understanding of selective pressures to a medical context.

A study was conducted by Adeniyi (1985) in Nigeria to determine common misconceptions among secondary school students regarding selected ecology concepts. Participants in the study included 232 students from five classes at one school. Each of the students was randomly assigned one of three different essay tests, and 26
of the students were subsequently interviewed. The data indicated a variety of misconceptions in the area studied, and the concepts of ecosystem, habitat, community, and population were difficult for the students to define or describe. For other concepts, students gave conflicting or multiple definitions, or erroneous answers. It was evident that the students were not willing to give up their alternative conceptions and accept information provided by the teacher. The misconceptions were restated in the interviews, from which two sources of misconceptions were observed: one was the existing conceptions of students and the other was instructional misconception.

Fisher (1985) interviewed college students about misconceptions in protein synthesis. The subjects were students taking classes in introductory biology and genetics. The collecting data measures were a written examination, a multiple-choice and essay test, and interviews. The data indicated that the students lacked knowledge of the actual origins of amino acids in cells; they often stated that amino acids were the product of translation. Although the students could recite the individual steps in the process, they did not make the necessary connections to indicate they understood the concept. The subjects confused the familiar and unfamiliar levels of generality and also had difficulty separating the dual roles of enzymes, as both players in and products of protein synthesis.

In a study of the effects of tutoring, with and without written materials, on understanding Newton’s third law, Brown (1988) used an interview technique and a multiple-choice diagnostic test to evaluate student misconceptions. The subjects were 104 high school students taking a physics course. Findings indicated that the students entered the physics classes with misconceptions in the area of Newton’s third law and
that based upon use of traditional instructional techniques, these misconceptions proved difficult to overcome. The data supported the hypothesis that the persistence of misconceptions may result from students' generally naive view that force is a property of single objects, rather than a relation between objects.

Three studies of student misconceptions in Thailand have been reported. The Institute for the Promotion of Science Teaching and Technology (1987) in Thailand conducted a study on misconceptions and misunderstandings of photosynthesis. Subjects were 1,297 twelfth-grade science students selected at random from schools in Bangkok and throughout Thailand. The instrument was composed of two situation descriptions followed by questions. The first situation was composed of three questions about the relationship between gases used in plant and animal respiration. Each question included a set of multiple-choice responses from which subjects selected the best answer, followed by an explanation of the reasons for the selected choice. The second situation composed of seven open-ended questions about reactions in photosynthesis. The data were analyzed to determine mean percentages. Some misconceptions revealed by the study indicated that the subjects believed that plants respired only at night or when there was no light; that respiration was the process of taking in and giving off gases; that plants photosynthesizes during both day and night; that light reactions occurred during the day and dark reactions occurred at night; that starch was the product of photosynthesis; and that oxygen was used in photosynthesis.

A comparative study of Thai college students to identify common misconceptions about covalent bonding and structure, and effect of college classification and
gender on misconceptions, was conducted by Kiokaew (1989). A two-tier multiple-choice test was employed to examine 111 freshmen in the College of Science and 66 freshmen in the College of Education. The data indicated that a higher percentage of students selected correct content choice responses (tier 1) than correct content and reason responses (tiers 1 and 2). The students in the College of Education reflected more misconceptions regarding covalent bonding and structure than did those in the College of Science. A two-way analysis of variance determined there was a significant difference for the main effect of college classification \( (p = 0.0001) \) and the interaction effect between gender and college classification \( (p = 0.0101) \), but that there was no significant difference for the main effect of gender \( (p = 0.2133) \).

Chowpreecha (1990) conducted research on misconceptions in the physical and biological sciences among upper-secondary school students in Bangkok, Thailand. The subjects were 800 twelfth-grade arts program students. The instrument was composed of a questionnaire and a test containing 50 misconceptions. The data were analyzed to determine frequency and percentage means. Test scores indicated misconceptions for 23 of the 50 science topics. With respect to photosynthesis and respiration, the subjects responded that photosynthesis occurred during the day and that respiration occurred at night.

**Teachers**

Misconceptions of science concepts do not occur only among students, but have also been found among teachers and female college students who planned teaching careers (Lawrenz, 1986; Ralya & Ralya, 1938). Mibiol (1983) conducted a study
that focused the attention of teachers and curriculum developers upon misconceptions among teachers. An interview technique was employed to ask 100 Nigerian school certificate students 53 questions regarding photosynthesis, respiration, and related physical science concepts. Data interpretation indicated that prevalent misconceptions included the following: oxygen always passes into the leaves and carbon dioxide always passes out; chlorophyll manufactures food during photosynthesis; only animals use oxygen for respiration; a respiratory organ conducts the process of respiration; and plants respire only during daylight hours.

A study involving prospective elementary teachers was conducted by Stepans et al. (1988), who divided 52 subjects into two groups. Each group was taught about sinking and floating of objects using a different model: one model was based upon exposition and the other a learning cycle. Each group received 250 minutes of instruction. Prior to and following instruction, subjects were interviewed. It was found that the subjects entered college with little comprehension of science concepts of sinking and floating. The data from post-interviews demonstrated considerable gains in understanding the concepts among both groups. The mean gain for the learning cycle group was slightly higher than that for the expository group.

Lawrenz (1986) investigated in-service elementary school teachers' understanding of selected elementary physical science concepts, examining 333 teachers in Arizona. A questionnaire and the Physical Science Test (PST), consisting of 31 multiple-choice items on various topics in physics and chemistry, were administered. Results from the PST indicated that the elementary school teachers did not have adequate backgrounds in physical science. Only 11 of the 31 items were answered cor-
rectly by 50% or fewer of the teachers, and the mean test score was 19. Two-thirds of the teachers scored 21 or below. More than 50% of the teachers responded correctly to items about atomic structure, off-center balancing, lenses, batteries, density, stars, heat exchange, and chemical reactions. The teachers reflected misconceptions about the nature of substances and the conservation of mass, as well as motion, electromagnetic phenomena, electricity, and light.

Constructivist Theory and Changing Misconceptions

As noted in Chapter 1, the constructivist perspective is based upon the theory that children construct knowledge to manage their experiences and to make sense of their environment, and that this knowledge is tempered and manipulated through interactions with parents, friends, teachers, and other influences. At the same time, children's misconceptions exercise significant influence upon what they will learn (Ausubel, 1963; Bodner, 1986; Driver & Oldham, 1986; Inhelder & Piaget, 1958). Thus, student misconceptions of science concepts may be constructed from experiences in their daily lives or from instruction (Bodner, 1986).

Minstrell (1984) and Hand and Treagust (1991) attempted to apply constructivist theory to help students understand concepts or change misconceptions. Minstrell employed a conceptual conflict strategy to teach Newton's laws. The strategy was to: (a) have students present their initial conceptions; (b) provide a number of activities (e.g., laboratory activities, demonstrations, and other experiences) directly related to their initial conceptions, each involving concrete experiences as much as possible, and to gradually build toward the abstract; and (c) provide opportunities for students to
reuse the arguments that led to new ideas. By the second year of the study, the researchers obtained some success in changing the initial conceptions expressed by the students.

Hand and Treagust (1991) developed a curriculum based upon a strategy similar to that used by Minstrell (1984) to teach the topics of acids and bases to tenth-grade students in a school in North Queensland, Australia. The teaching strategy was based on information obtained through interviews to determine the students' knowledge and misconceptions of acids and bases. A 15-lesson teaching plan, involving the use of seven worksheets designed to encourage conceptual conflict among students who held misconceptions, was developed. The researchers divided the subjects into control and experimental groups, and a test containing both content and process questions was used to evaluate the subjects in both groups. The reliability of the content section was 0.43 and that for the process section was 0.88. Results for the process section showed that students in the experimental group, compared to the control group, had greater ability to understand some of the concepts taught and also to apply what they learned in problem-solving situation. This finding indicated that the constructivist approach enhanced meaningful science learning. Results of the content test were not reported.

Summary of the Review of Literature

Psychometric and measurement literature suggests the use of construct-related evidence gathering procedures for the development of instruments to measure theoretical constructs whose universe of content has not been adequately defined. Such
procedures are used to determine the appropriateness, meaningfulness, and usefulness of inferences from scores obtained by administering the instrument to given groups of subjects.

A number of methods and a variety of instruments have been employed to determine misconceptions of science concepts among students at all grade levels as well as teachers. Review revealed that student misconceptions of science concepts occurred at every grade level, and that teachers also had been found to misconceive certain science concepts. Research has been focused on both the physical and the biological sciences, though more studies have been focused upon the latter. Grade level and age were factors found to affect student misconceptions of science concepts. In general, as grade/age increased, misconceptions decreased. However, some misconceptions tend to persist across age and grade levels. Gender was another factor that tended to affect student misconceptions of science concepts. In many studies, male subjects were found to have fewer misconceptions than female subjects; however, not all researchers have focused on the gender variable.

Though misconceptions are robust and difficult to change, there have been a number of attempts by researchers to change student misconceptions. Constructivist theory has been successfully applied to affect positive change in students' conceptual thinking.
CHAPTER 3
METHODOLOGY

This chapter describes the research procedures used in this study to develop a valid and reliable instrument for the measurement and investigation of misconceptions of science concepts among elementary school students in Thailand. This chapter is organized in four sections, as follows: (a) development of the instrument; (b) description of the subjects; (c) procedure used to administer the instrument; and (d) method for analyzing the data collected from administration of the instrument.

Development of the Instrument

Procedural Summary

Development of the two-tier multiple-choice test for the present study was based on procedures suggested by psychometric and measurement literature for the determination of the appropriateness of inferences from a set of scores obtained from administration of an instrument using construct-related evidence (APA, 1985; Gronlund & Linn, 1990; Herman, 1984; Hopkins et al., 1990; Mueller, 1986). The procedures followed are summarized below:

1) Establish a definition of misconceptions.

2) Analyze photosynthesis and respiration content covered in fourth, fifth, and sixth-grade classrooms in Thailand (Appendix A).
3) Identify specific photosynthesis and respiration content for each potential test item and create a table of item specifications.

4) Generate an item pool based upon information derived from a literature review and interviews with elementary school teachers, science educators, and one scientist, and from analyses of science curricula currently used in Thailand.

5) Select the test items from the pool and develop an open-ended paper-and-pencil test containing 21 items.

6) Conduct a pilot study, using both interviews and the open-ended paper-and-pencil test developed in step 5. Each test item required explanation. Items were divided into two tests, one consisting of 10 items and the other consisting of 11 items. The open-ended paper-and-pencil tests were then given to 162 students in the fourth, fifth, and sixth grades from two schools in Bangkok, Thailand, and 12 students, four from each grade level, were interviewed using the same question items as in the open-ended paper-and-pencil test.

7) From reference to student responses to each item question in the pilot study, develop two-tier test based on original 21 test items.

8) Select a panel consisting of 11 experts to evaluate and comment on each of the 21 items (Appendix B). The criteria for evaluation included whether the answers to question items in the content portion were correct; whether each item related to a propositional statement; whether items were appropriate for measuring the selected concepts;
and whether the level of difficulty of each item was appropriate. The panel was also asked to point out grammatical errors, difficult language, and need for clarification. Of the original 21 items, 19 were retained following acceptance by 80% of the expert panel.

9) Revise the 19 items based upon expert panel feedback.

10) Employ two experts, an elementary school teacher/science educator and a research and evaluation team member from the IPST, Thailand, to evaluate the 19 items for appropriateness of language. Based upon feedback, each item was revised for use in the second pilot study.

11) Conduct second pilot study. The purpose of the second pilot study was to determine the reliability, difficulty, and discrimination ability of the 19-item two-tier multiple-choice test. Subjects for the pilot study were 460 fourth, fifth, and sixth-grade students from four schools in Bangkok, Thailand, and from provincial schools adjacent to Bangkok.

12) Score tests and use the score data to test the quality of the test items. The procedures used to score each item of the two-tier multiple-choice test were: (a) A score of one point was given when both tiers were answered correctly; (b) a score of zero was given when both tiers or either tier were answered incorrectly. The correct scores of each item were used for item analysis. The scores of the top and bottom 27% were employed to determine the difficulty and discrimination indices for each item (the indices are reported in Chapter 4). From the analysis, two items were eliminated because they did not discriminate
between high and low scoring students. The final instrument consisted of 17 items (Appendices C & D). Total test scores were used to compute reliability and internal consistency for the instrument, using Cronbach's alpha (Mueller, 1986). The results of the reliability test procedure are reported in Chapter 4.

13) Conduct a third pilot study, the purpose of which was to determine whether the final instrument could identify and distinguish between subjects who understood selected concepts and those who had misconceptions, as well as to correlate scores subjects obtained with their scores on a science achievement test. The instrument was administered to 40 students in Thailand.

14) Conduct a fourth pilot study, the purpose of which was to assess the readability of the final instrument. The instrument was administered to 20 fourth-grade students selected at random. The students were asked to identify items, vocabulary, and language that they were not able to understand. From student feedback, the readability level of each item was deemed acceptable. One expert, an elementary school teacher and science educator, also considered each item and found them to be at an acceptable readability level.

15) Develop the demographic information-gathering part of the test and a set of directions for taking the test. The demographic information included gender, age, grade level, and parents' education. The directions provided information concerning the number of items, type of test,
features of each item and how to respond (an example was included),
and time allowed for completing the test.

Description of the Instrument

The final instrument consisted of two parts, the first of which asked subjects
to provide demographic information. Part 2 consisted of 17 two-tier multiple-choice
items measuring elementary student misconceptions in the areas of photosynthesis
and respiration (Tamir, 1989; Treagust, 1986). Both tiers contained sets of multiple-
choice responses constructed from the responses obtained from students who were
administered the first pilot study. The first tier (Part a) was a content set, and the
second tier (Part 2) was a reason set. The second tier also included space for write-in
responses. See Appendix C for the Thai version of the instrument and Appendix D
for the English translation.

Subjects

The instrument was administered to 4,346 fourth, fifth, and sixth-grade stu-
dents in Thailand. These subjects were selected at random from schools in Bangkok
and from 12 educational regions of Thailand. The following steps were taken in the
random selection of the subjects: Select at random (a) three schools in Bangkok; (b)
one province from each regional area; (c) three schools, one in an urban area and two
from suburban or rural areas; and (d) classes of fourth, fifth, and sixth grades, one
class for each grade in each school. There were a total of 40 schools and 40 classes
for each grade. The distribution of the subject population is shown in Table 1.
Table 1. Subject Population by Gender and Grade Level.

<table>
<thead>
<tr>
<th>Grade Level</th>
<th>Female</th>
<th>Male</th>
<th>Not Given</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>747</td>
<td>778</td>
<td>1</td>
<td>1,526</td>
</tr>
<tr>
<td>5</td>
<td>724</td>
<td>694</td>
<td></td>
<td>1,418</td>
</tr>
<tr>
<td>6</td>
<td>774</td>
<td>628</td>
<td></td>
<td>1,402</td>
</tr>
</tbody>
</table>

According to the Cohen (1988) sample size table, the minimum sample size, where $Y$ is equal to 0.15, power level $(1 - \beta)$ is equal to 0.90, and the significance level ($\alpha$) is set at 0.05, is 234 subjects per cell. As shown in Table 1, the sample size in this study exceeded the minimum sample size requirement.

In Thailand, the typical age range for fourth, fifth, and sixth-grade students is 10-12 years. The ages of the subjects in this study, however, ranged from 9 to 16 years.

**Administration of the Instrument**

In the field test, 40 schools were used to represent each educational region of Thailand and the city of Bangkok. For each school, the final instrument was administered during a regular classroom period by the researcher, or by representatives of the researcher, and two trained teachers from that school.

The procedure for administering the test was as follows: The subjects had 10 minutes to answer the demographic questions (Part 1). They were given five minutes of oral instruction and a demonstration on how to respond to each item, and then had 50 minutes to work on the test items (Part 2). This time length was selected because
the range of time that students needed to complete the test during pilot studies was between 30 and 50 minutes.

Method of Statistical Analysis

Procedure

Statistical analysis procedure was applied only to the field test data. The independent variables were grade level and gender. The dependent variable was student scores on the two-tier multiple-choice test developed for the study.

A two-way analysis of variance (ANOVA) procedure was used to assess the impact of grade level and gender. The first factor was grade level, which was divided into fourth, fifth, and sixth grades. The second factor was gender. Table 2 represents the two-way, fixed layout used for this investigation.

Table 2. Design Layout for the Analysis of Variance.

<table>
<thead>
<tr>
<th>Grade level</th>
<th>4th grade</th>
<th>5th grade</th>
<th>6th grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>F</td>
<td>M</td>
<td>F</td>
</tr>
</tbody>
</table>

For this design, the mathematical model was:

\[ Y_{ijk} = M + L_j + G_k + LG_{jk} + E_{ijk} , \]

where

\[ M \]

is a fixed constant representing the prior background portion of the data,
$L_j$ is the condition effect attributable to the variable grade level,
$G_k$ is the condition effect attributable to the variable gender,
$LG_{jk}$ is the effect associated with the statistical interaction between
the levels of the variables grade level and gender, and
$E_{ijk}$ is the residual effect.

**Hypotheses**

The following null hypotheses were tested using the ANOVA procedure:

$H_{01}$: There will be no significant effect for grade level.

$H_{02}$: There will be no significant effect for gender.

$H_{03}$: There will be no significant interaction between grade level and gender.

The layout for the ANOVA procedure is shown in Table 3.

**Table 3. Design Layout Analysis of Variance for Testing Null Hypotheses.**

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade level</td>
<td>2</td>
<td>$SSL_j$</td>
<td>$MSL_j$</td>
<td>$F_1$</td>
</tr>
<tr>
<td>Gender</td>
<td>1</td>
<td>$SSG_k$</td>
<td>$MSG_k$</td>
<td>$F_2$</td>
</tr>
<tr>
<td>Grade level × Gender</td>
<td>2</td>
<td>$SSL_jG_k$</td>
<td>$MSL_jG_k$</td>
<td>$F_3$</td>
</tr>
<tr>
<td>Error</td>
<td></td>
<td>$SSE_{ijk}$</td>
<td>$MSE_{ijk}$</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
An F-test was conducted to ascertain differences at the 0.05 level of significance. The Newman-Keuls method was employed to determine individual mean differences for grade levels when significant differences were obtained from F-test calculations.

Summary of the Methodology

An instrument was developed to measure and to allow analysis of Thai elementary student misconceptions of photosynthesis and respiration concepts. The procedure for developing the instrument included defining misconception, generating an item pool, expert panel review of the instrument, determination of reliability, performance of item analysis, assessment of known-group differences, correlation of measures of similar constructs, and testing for readability.

The instrument was administrated to 4,346 fourth, fifth, and sixth-grade students during regular classroom periods. The subjects were selected at random to represent all elementary students in Thailand. Demographic data, including grade level and gender, were collected from each subject. A two-way ANOVA procedure was employed to test the null hypotheses.
CHAPTER 4
RESULTS OF THE STUDY

This chapter is organized in three sections. The first section presents the instrument and the construct-related evidence data used to develop the instrument. The second section reports the results of analysis of correct responses by grade level and gender. The third section reports the frequencies of student responses for each test item.

Instrument

A 17-item two-tier test for measuring Thai student misconceptions in the area of photosynthesis and respiration at the elementary level was developed for this study. The first tier contained content questions, each with a set of multiple-choice responses. The second tier contained a set of multiple-choice justifications for the responses given in the first tier.

The validity of the instrument was ascertained using construct-related evidence. The accumulated construct-related evidence, to include reliability, item analysis, known-group difference procedure, and the correlation with measures of the similar construct procedure, are presented in the following sections.
Reliability

Cronbach’s alpha coefficient was used to determine the reliability of the instrument. The reliability of the 17-item instrument was found to be 0.70.

Item Analysis

A preliminary instrument consisting of 19 items was administered in a pilot test to 460 Thai students in grades 4, 5, and 6 at four schools. The scores were used to determine difficulty and ability to discriminate for each item. The top and bottom 27% of the scores were employed in the item analysis, and two of the 19 items were eliminated. For the 17 items retained, Table 4 shows an item difficulty index range of 0.20-0.73 and an item discrimination index range of 0.20-0.67.

Table 4. Difficulty and Discrimination of Each of the Items.

<table>
<thead>
<tr>
<th>Items</th>
<th>Difficulty</th>
<th>Discrimination</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.73</td>
<td>0.47</td>
</tr>
<tr>
<td>2</td>
<td>0.67</td>
<td>0.55</td>
</tr>
<tr>
<td>3</td>
<td>0.59</td>
<td>0.43</td>
</tr>
<tr>
<td>4</td>
<td>0.70</td>
<td>0.40</td>
</tr>
<tr>
<td>5</td>
<td>0.71</td>
<td>0.36</td>
</tr>
<tr>
<td>6</td>
<td>0.30</td>
<td>0.21</td>
</tr>
<tr>
<td>7</td>
<td>0.50</td>
<td>0.67</td>
</tr>
<tr>
<td>8</td>
<td>0.20</td>
<td>0.24</td>
</tr>
<tr>
<td>9</td>
<td>0.47</td>
<td>0.56</td>
</tr>
<tr>
<td>10</td>
<td>0.45</td>
<td>0.40</td>
</tr>
<tr>
<td>11</td>
<td>0.42</td>
<td>0.43</td>
</tr>
<tr>
<td>12</td>
<td>0.55</td>
<td>0.57</td>
</tr>
<tr>
<td>13</td>
<td>0.54</td>
<td>0.62</td>
</tr>
<tr>
<td>14</td>
<td>0.28</td>
<td>0.20</td>
</tr>
<tr>
<td>15</td>
<td>0.49</td>
<td>0.62</td>
</tr>
<tr>
<td>16</td>
<td>0.52</td>
<td>0.62</td>
</tr>
<tr>
<td>17</td>
<td>0.63</td>
<td>0.59</td>
</tr>
</tbody>
</table>
Known-Group Difference Procedure

The final 17-item instrument was analyzed using a known-group difference procedure to determine whether this instrument could differentiate between students who had and those who did not have misconceptions of selected concepts in science, that is, photosynthesis and respiration. Forty students, 20 for each group, were randomly selected for this procedure. Using the t-test, a statistically significant difference ($p < 0.05$) was found between those students who had and those who did not have misconceptions of selected concepts in the area of photosynthesis and respiration. Table 5 presents the results of analysis of responses.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean score</th>
<th>t</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Known</td>
<td>20</td>
<td>12.55</td>
<td>11.13</td>
<td>0.001*</td>
</tr>
<tr>
<td>Unknown</td>
<td>20</td>
<td>5.30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < 0.05

Correlation of Measure of Similar Constructs Procedure

Test scores for 40 students on the final instrument were correlated with science achievement test results for the same students. The Spearman correlation coefficient was found to be 0.77.
Analysis of Correct Responses by Grade Level and by Gender

This section reports the results in four parts: (a) mean scores and standard deviations by gender, (b) mean scores and standard deviations by grade level, (c) mean scores and standard deviations by grade level and gender, and (d) results of testing the null hypotheses.

**Mean Scores and Standard Deviations by Grade Level**

Mean scores and standard deviations, derived from the number of correct responses to the content and reason choices for each grade level, are presented in Table 6. The standard deviations revealed that the range of scores for the fifth-grade students were greater than those for either the fourth or sixth-grade students.

<table>
<thead>
<tr>
<th>Grade level</th>
<th>N</th>
<th>Mean score</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1,526</td>
<td>5.32</td>
<td>2.64</td>
</tr>
<tr>
<td>5</td>
<td>1,418</td>
<td>6.49</td>
<td>2.92</td>
</tr>
<tr>
<td>6</td>
<td>1,402</td>
<td>7.66</td>
<td>2.88</td>
</tr>
</tbody>
</table>

**Mean Scores and Standard Deviations by Gender**

The mean scores and standard deviations for correct responses by female and male Thai students in grades 4, 5, and 6 are presented in Table 7. The standard deviations revealed that the range of scores of the male students was greater than that of the female students.
Table 7. Mean Scores and Standard Deviations by Gender.

<table>
<thead>
<tr>
<th>Gender</th>
<th>N</th>
<th>Mean score</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>2,246</td>
<td>6.45</td>
<td>2.89</td>
</tr>
<tr>
<td>Male</td>
<td>2,100</td>
<td>6.46</td>
<td>3.05</td>
</tr>
</tbody>
</table>

Mean Scores and Standard Deviations by Grade Level and Gender

The mean scores and standard deviations for female and male Thai students in grades 4, 5, and 6 are presented in Table 8. The mean scores were higher for the male students than for the female students in grades 5 and 6. The standard deviations revealed that the range of scores for the male students in fifth grade was greatest and that for the female students in fourth grade was smallest.

Table 8. Mean Scores and Standard Deviations by Grade Level and Gender.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Grade level</th>
<th>N</th>
<th>Mean score</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>4</td>
<td>747</td>
<td>5.42</td>
<td>2.64</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>724</td>
<td>6.44</td>
<td>2.84</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>774</td>
<td>7.44</td>
<td>2.83</td>
</tr>
<tr>
<td>Male</td>
<td>4</td>
<td>778</td>
<td>5.22</td>
<td>2.65</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>694</td>
<td>6.54</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>628</td>
<td>7.92</td>
<td>2.92</td>
</tr>
</tbody>
</table>
Testing the Hypotheses

A two-way ANOVA was employed to test the following null hypotheses at the significance level of 0.05:

\( H_{01} \): There will be no significant effect for grade level.

\( H_{02} \): There will be no significant effect for gender.

\( H_{03} \): There will be no significant interaction for grade level and gender.

The results of the two-way ANOVA are presented in Table 9.

The analysis of variance by grade level yielded an F-ratio of 253.62 and a p-value of 0.001, which was smaller than the established significance level of 0.05, indicating that there was significant effect for grade level. Thus, the first null hypothesis was rejected. Application of the Newman-Keuls follow-up method indicated that all grade levels were significantly different at the 0.05 level.

Table 9. Analysis of the Mean Scores and Interaction Between Gender and Grade Level.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>1</td>
<td>14.190</td>
<td>14.190</td>
<td>0.002</td>
<td>0.180</td>
</tr>
<tr>
<td>Grade</td>
<td>2</td>
<td>4000.698</td>
<td>2000.349</td>
<td>253.615</td>
<td>0.001*</td>
</tr>
<tr>
<td>Gender X Grade</td>
<td>2</td>
<td>82.875</td>
<td>41.437</td>
<td>5.254</td>
<td>0.005*</td>
</tr>
</tbody>
</table>

Total 4,343 38,299.157 8.819

* \( p < 0.05 \)

Table 9 reveals that the analysis of variance by gender yielded an F-ratio of 0.002 and a p-value of 0.180, which was larger than the established significance level.
of 0.05. This indicated that no significant effect was found for gender. Thus, the second null hypothesis was retained.

Table 9 also shows that the analysis of variance for the interaction between grade level and gender yielded an F-ratio of 5.254 with a p-value of 0.005, which was smaller than the established significance level of 0.05. This indicated there was a significant interaction between grade level and gender. Thus, the third null hypothesis was rejected. The effect of the gender on student understanding of photosynthesis and respiration concepts was dependent upon grade level. The interaction between grade level and gender, graphically displayed in Figure 1, clearly indicates that the mean scores of correct responses for male students were lower than those for female students in grade 4, but were higher than those for female students in grades 5 and 6.

![Figure 1. Interaction Between Grade Level and Gender.](image)
Response Percentages by Item

Frequencies of responses for each item were converted to percentages, for each grade level. Interpretation of responses to each item was primarily focused on those responses selected by more than 10% of the students (Gilbert, 1977).

Item 1

The percentages of subject responses to Item 1 are shown in Table 10.

Table 10. Percentages of Subject Responses to Item 1.

<table>
<thead>
<tr>
<th>Grade level</th>
<th>Number of respondents</th>
<th>Content response</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1,526</td>
<td>1</td>
<td>54.5</td>
<td>2.2</td>
<td>2.5</td>
<td>5.4</td>
<td>1.6</td>
<td>66.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>1.1</td>
<td>1.4</td>
<td>2.6</td>
<td>2.2</td>
<td>0.1</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>2.6</td>
<td>6.9</td>
<td>1.8</td>
<td>14.7</td>
<td>0.4</td>
<td>26.4</td>
</tr>
<tr>
<td>5</td>
<td>1,418</td>
<td>1</td>
<td>65.1</td>
<td>1.1</td>
<td>1.7</td>
<td>5.0</td>
<td>2.0</td>
<td>74.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.8</td>
<td>2.2</td>
<td>1.8</td>
<td>1.8</td>
<td>0.1</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>2.6</td>
<td>4.3</td>
<td>1.4</td>
<td>9.4</td>
<td>0.6</td>
<td>18.3</td>
</tr>
<tr>
<td>6</td>
<td>1,400</td>
<td>1</td>
<td>75.7</td>
<td>2.0</td>
<td>0.7</td>
<td>3.6</td>
<td>0.9</td>
<td>82.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.5</td>
<td>0.4</td>
<td>1.1</td>
<td>1.2</td>
<td>-</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>1.3</td>
<td>2.2</td>
<td>0.7</td>
<td>9.3</td>
<td>0.4</td>
<td>13.9</td>
</tr>
</tbody>
</table>

Note: Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade level may not add to 100% because of rounding.

Table 10 shows that when asked the question, “which of the following living things can photosynthesize or make their own food,” 66%, 75%, and 83% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response; whereas 55%, 65%, and 76%, respectively, selected the correct content and reason responses. Among the fourth-grade students, 15% selected the incorrect content and reason responses that “sunflower, human, bird, and rat” can make their own
food because “human, bird, and rat use light to make vitamin D, and sunflower uses light in photosynthesis.”

**Item 2**

Percentages of subject responses to Item 2 are shown in Table 11.

<table>
<thead>
<tr>
<th>Grade level</th>
<th>Number of respondents</th>
<th>Content response</th>
<th>Reason response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>1,526</td>
<td>1</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>1.9</td>
</tr>
<tr>
<td>5</td>
<td>1418</td>
<td>1</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>6</td>
<td>1402</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Note:** Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade level may not add to 100% because of rounding.

Table 11 shows that when asked the question, “could a toad which had green skin and a parrot which has green feathers photosynthesize,” 61%, 73%, and 78%, of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response; whereas 45%, 58%, and 68%, respectively, selected the correct content and reason responses. Among fourth-grade students, 12% selected the incorrect content and reason responses that “both toad and parrot photosynthesize” because “both toad and parrot have a green color which comes from chlorophyll”; and 11% selected the incorrect content and reason responses that “only the toad could photosynthesize”
because "the toad has chlorophyll and photosynthesizes when it gets both water and light." Among fourth and fifth-grade students, 11% and 10%, respectively, selected the correct content response that "both could not photosynthesize," but selected the incorrect reason response that "even though having chlorophyll, the toad has thick skin and the parrot has thick feathers, so light cannot get through."

**Item 3**

Percentages of subject responses to Item 3 are shown in Table 12.

Table 12. Percentages of Subject Responses to Item 3.

<table>
<thead>
<tr>
<th>Grade level</th>
<th>Number of respondents</th>
<th>Content response</th>
<th>Reason response</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1,514</td>
<td>1</td>
<td>22.8 22.1 3.5 1.7 3.4</td>
<td>53.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>2.3 3.1 34.1 3.9 2.5</td>
<td>46.5</td>
</tr>
<tr>
<td>5</td>
<td>1,399</td>
<td>1</td>
<td>25.2 18.8 3.7 1.5 4.6</td>
<td>53.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>1.5 2.1 38.1 2.4 2.1</td>
<td>46.2</td>
</tr>
<tr>
<td>6</td>
<td>1,392</td>
<td>1</td>
<td>17.7 19.8 2.2 1.1 5.1</td>
<td>46.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.4 1.2 42.2 2.7 7.4</td>
<td>53.9</td>
</tr>
</tbody>
</table>

**Note:** Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade may not add to 100% because of rounding.

Table 12 shows that when asked the question, "can we find green plants in the deep area where light cannot get through," 47%, 46%, and 54% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response; whereas 34%, 38%, and 42%, respectively, selected the correct content and reason responses. However, 23%, 25%, and 18%, respectively, selected the incorrect content and reason responses that "we can find green plants everywhere in the world." and 22%, 19%, and 20%, respectively, selected the incorrect content and reason responses
that "we find living things in the deep sea; this means that green plants are also there."

**Item 4**

Percentages of subject responses to Item 4 are shown in Table 13.

<table>
<thead>
<tr>
<th>Grade level</th>
<th>Number of respondents</th>
<th>Content response</th>
<th>Reason response</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1,520</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>12.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>72.4</td>
</tr>
<tr>
<td>5</td>
<td>1,410</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>10.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>4.3</td>
</tr>
<tr>
<td>6</td>
<td>1,399</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>8.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>79.9</td>
</tr>
</tbody>
</table>

**Note:** Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade may not add to 100% because of rounding.

The situation presented in Item 4 was: "Nisa left a pot of Pug Boong in a dark box and she found that all the plants died not long after that. So she put plants in the dark again but added fertilizer and water." Table 13 shows that when asked the question, "will plants die if she leaves them in the dark box for a long time," 72%, 75%, and 80%, of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response; whereas 36%, 40%, and 45%, respectively, selected the correct content and reason responses. Over one-fourth of students (28%, 27%, and 28%, respectively) selected the incorrect reason response that "there is no carbon dioxide in the dark box so it cannot photosynthesize." Among the fourth and fifth-grade students, 12% and 10%, respectively, selected the incorrect content and
reason responses that “fertilizer and water are plants’ food and are sufficient for living.”

**Item 5**

Percentages of subject responses to Item 5 are shown in Table 14.

<table>
<thead>
<tr>
<th>Grade level</th>
<th>Number of respondents</th>
<th>Content response</th>
<th>Reason response</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1,509</td>
<td>1</td>
<td>1.9 2.3 11.4 1.4 0.6</td>
<td>17.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>5.0 56.8 4.1 13.8 2.7</td>
<td>82.4</td>
</tr>
<tr>
<td>5</td>
<td>1,406</td>
<td>1</td>
<td>1.1 2.0 11.0 1.0 1.0</td>
<td>17.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>3.7 63.7 4.0 9.5 3.0</td>
<td>82.9</td>
</tr>
<tr>
<td>6</td>
<td>1,392</td>
<td>1</td>
<td>0.4 1.4 13.5 0.7 0.6</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>2.7 63.8 3.8 9.7 3.4</td>
<td>83.4</td>
</tr>
</tbody>
</table>

**Note:** Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade may not add to 100% because of rounding.

Table 14 shows that when asked the question, “do you think the leaves of the plant in question 4 are still green,” 82%, 83%, and 84% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response; whereas 57%, 64%, and 64%, respectively, selected the correct content and reason responses. The incorrect content and reason responses that the leaves are still green because “chlorophyll makes plants green whether there is light or not” was selected by 11%, 11%, and 14%, respectively. Of the fourth-grade students who selected the correct content response (82%), 14% selected the incorrect reason response that “air (gas) makes plants green, and there is no air in the dark box so the green color changes.”
Item 6

Percentages of subject responses to Item 6 are shown in Table 15.

Table 15. Percentages of Subject Responses to Item 6.

<table>
<thead>
<tr>
<th>Grade level</th>
<th>Number of respondents</th>
<th>Content response</th>
<th>Reason response</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>1,526</td>
<td>1</td>
<td>1.2</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>19.8</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.4</td>
<td>8.5</td>
</tr>
<tr>
<td>5</td>
<td>1,418</td>
<td>1</td>
<td>1.7</td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>12.8</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.8</td>
<td>7.3</td>
</tr>
<tr>
<td>6</td>
<td>1,402</td>
<td>1</td>
<td>0.6</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>11.1</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.6</td>
<td>8.3</td>
</tr>
</tbody>
</table>

Note: Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade may not add to 100% because of rounding.

Item 6 introduced a picture of a leaf showing green and white color, with lines pointing to certain areas of the leaf, and asked the question, “in which area(s) could photosynthesis occur.” Table 15 shows that the correct content response was selected by 39%, 34%, and 38% of the fourth, fifth, and sixth-grade students, respectively; whereas the correct content and reason responses were selected by 27%, 25%, and 28%, respectively. The incorrect reason response that “only the green color in area 2 is from chlorophyll” was selected by 22%, 30%, and 29%, respectively. Also, 20%, 13%, and 11%, respectively, selected the incorrect content and reason responses that photosynthesis occurs in “areas 1 and 2” because they “are areas on a leaf.”
**Item 7**

Percentages of subject responses to Item 7 are shown in Table 16.

**Table 16. Percentages of Subject Responses to Item 7.**

<table>
<thead>
<tr>
<th>Grade level</th>
<th>Number of respondents</th>
<th>Content response</th>
<th>Reason response</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1,526</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>15.6</td>
<td>1.0</td>
<td>0.8</td>
<td>9.0</td>
</tr>
<tr>
<td>2</td>
<td>1.4</td>
<td>3.0</td>
<td>30.3</td>
<td>2.6</td>
</tr>
<tr>
<td>3</td>
<td>1.2</td>
<td>28.0</td>
<td>2.9</td>
<td>2.0</td>
</tr>
<tr>
<td>5</td>
<td>1,418</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>40.1</td>
<td>1.4</td>
<td>1.6</td>
<td>15.6</td>
</tr>
<tr>
<td>2</td>
<td>1.1</td>
<td>2.5</td>
<td>19.2</td>
<td>1.7</td>
</tr>
<tr>
<td>3</td>
<td>0.8</td>
<td>11.1</td>
<td>1.6</td>
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<td>18.5</td>
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<td>0.4</td>
<td>12.6</td>
<td>1.1</td>
<td>0.8</td>
</tr>
</tbody>
</table>

*Note:* Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade may not add to 100% because of rounding.

Table 16 shows that when asked the question, “after photosynthesis occurs, which substance can we test for,” 27%, 59%, and 61% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response; whereas, 16%, 41%, and 44%, respectively, selected the correct content and reason responses. However, 28%, 11%, and 13%, respectively, selected the incorrect content and reason responses that “the leaf needs carbon dioxide in photosynthesis, so we can test for this gas,” and 30%, 19%, and 19%, respectively, selected the incorrect content and reason responses that “chlorophyll is the product of photosynthesis.” Among the fifth and sixth-grade students, 16% and 14%, respectively, selected the correct content response, but also the incorrect reason response that “starch is the product of photosynthesis, which we can see in the white area.”
Percentages of subject responses to Item 8 are shown in Table 17.

Table 17. Percentages of Subject Responses to Item 8.

<table>
<thead>
<tr>
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<th>Reason response</th>
<th>Total</th>
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</thead>
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<td>4.9</td>
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<td></td>
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<td>2.4</td>
<td>1.6</td>
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<tr>
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<td>8.1</td>
</tr>
<tr>
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</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>2.8</td>
<td>1.9</td>
</tr>
<tr>
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</tr>
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<tr>
<td></td>
<td></td>
<td>3</td>
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<td>1.9</td>
</tr>
</tbody>
</table>

Note: Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade may not add to 100% because of rounding.

Table 17 shows that when asked the question, “in which areas (of the leaf in question 6) does respiration occur,” only 18%, 18%, and 25% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response; whereas 10%, 8%, and 13%, respectively, selected the correct content and reason responses. However, 42%, 39%, and 39%, respectively, selected the incorrect response that respiration could occur in “areas 1 and 2” because “they are the areas of the leaf,” and 16%, 16%, and 10%, respectively, selected the incorrect response that respiration could occur in “areas 2 and 3” because “there is chlorophyll helping in respiration.”
Table 18. Percentages of Subject Responses to Item 9.

<table>
<thead>
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<th>Content response</th>
<th>Reason response</th>
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</thead>
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<td></td>
</tr>
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<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1.9  2.6 29.2 1.0 1.5</td>
<td>36.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5.1  4.3 1.8  2.2 0.8</td>
<td>14.2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1,418</td>
<td>1.1  19.2 2.0  17.1 0.7</td>
<td>40.1</td>
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</tr>
<tr>
<td></td>
<td>2</td>
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<td>52.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
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</tr>
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<td>3.9</td>
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</tr>
</tbody>
</table>

Note: Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade may not add to 100% because of rounding.

Table 18 shows that when asked the question, “which of the following is not a factor for photosynthesis,” 36%, 53%, and 60% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response; whereas 29%, 45%, and 53% selected the correct content and reason responses. However, 26%, 19%, and 18% selected the incorrect content and reason responses that “water” is not an essential factor because “the essential factors must be gases so they can get into the leaf, but water is a liquid not a gas,” and another 18%, 17%, and 15%, respectively, selected “water” for the reason that “water supports only the stem and branches, not the leaf.”
Percentages of subject responses to Item 10 are shown in Table 19.

Table 19. Percentages of Subject Responses to Item 10.

<table>
<thead>
<tr>
<th>Grade level</th>
<th>Number of respondents</th>
<th>Content response</th>
<th>Reason response</th>
<th>Total</th>
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</tr>
<tr>
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<td></td>
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</tr>
<tr>
<td></td>
<td></td>
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<td>3.9</td>
</tr>
<tr>
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<td>1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>24.7</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>2.1</td>
<td>1.3</td>
</tr>
<tr>
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<td>1,402</td>
<td>1</td>
<td>1.1</td>
<td>2.4</td>
</tr>
<tr>
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<td></td>
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<td>22.3</td>
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<td></td>
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<td>1.1</td>
</tr>
</tbody>
</table>

Note: Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade may not add to 100% because of rounding.

Table 19 shows that when asked the question, “when do plants respire,” 50%, 46%, and 56% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response, but only 16%, 14%, and 16% selected the correct content and reason responses. Further, 25%, 27%, and 26%, respectively, selected the correct content response, but the incorrect reason response that “plants take in carbon dioxide during day time, and take in oxygen at night time.” Another 23%, 25%, and 22%, respectively, selected the incorrect content and reason responses that plants respire “both day and night” because “plants use chlorophyll in photosynthesis and respiration at the same time.”
Percentages of subject responses to Item 11 are shown in Table 20.

Table 20. Percentages of Subject Responses to Item 11.

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<th>4</th>
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<td>0.3</td>
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<td></td>
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<td>18.0</td>
<td>2.2</td>
<td>1.4</td>
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<tr>
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<td></td>
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<td>0.3</td>
<td>0.4</td>
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<td>11.9</td>
<td>42.1</td>
<td>3.1</td>
<td>58.2</td>
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</tbody>
</table>

Note: Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade may not add to 100% because of rounding.

Table 20 shows that when asked the question, “during the day time, which of the following respire,” 52%, 48%, and 58% of the fourth, fifth and sixth-grade students, respectively, selected the correct content response; whereas only 40%, 37%, and 42%, respectively, selected the correct content and reason responses. Further, 17%, 21%, and 15%, respectively, selected the incorrect content and reason responses that “grass and rose tree” respire during the day because “grass and rose tree need energy while photosynthesizing, so they respire,” and 18%, 18%, and 16%, respectively, selected the incorrect content and reason responses that “human, monkey, and toad” respire during the day because “human, monkey, and toad by taking in oxygen, and grass and rose tree respire by taking in carbon dioxide.”
Percentages of subject responses to Item 12 are shown in Table 21.

Table 21. Percentages of Subject Responses to Item 12.

<table>
<thead>
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<th>Content response</th>
<th>Reason response</th>
<th>Total</th>
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<td></td>
<td>3</td>
<td>1.4</td>
<td>2.5</td>
</tr>
<tr>
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<td>1,418</td>
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<td>15.2</td>
<td>1.6</td>
</tr>
<tr>
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<td></td>
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<td>1.3</td>
<td>13.5</td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
<tr>
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<td>13.9</td>
<td>0.8</td>
</tr>
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<td></td>
<td></td>
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<td>0.7</td>
<td>10.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.9</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Note: Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade may not add to 100% because of rounding.

Table 21 shows that when asked the question, "at night, when there is no light, which of the following respire," 52%, 56%, and 64% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response; whereas 42%, 53%, and 62%, respectively, selected the correct content and reason responses.

Further, 15%, 15%, and 14%, respectively, selected the incorrect content and reason responses that "grass and rose tree" respire at night because "at night, plants do not photosynthesize, so they respire to get energy," and 14%, 14%, and 10%, respectively, selected the content and reason responses that "human, monkey, and toad" respire at night because "human, monkey, and toad need energy all the time so they also respire at night"; 10% of the fourth-grade students selected the incorrect reason response that "human, monkey, and toad have lungs and hearts."
Item 13

Percentages of subject responses to Item 13 are shown in Table 22.

Table 22. Percentages of Subject Responses to Item 13.

<table>
<thead>
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<th>Reason response</th>
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</thead>
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<tr>
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</tr>
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<td>8.5</td>
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<td></td>
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<td>0.8</td>
<td>3.2</td>
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<td></td>
<td></td>
<td>3</td>
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<td>2.0</td>
</tr>
</tbody>
</table>

Note: Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade may not add to 100% because of rounding.

Item 13 introduced the situation in which a pot of Pug Boong was placed in a dark box one night, taken out to water in the morning, and then divided into two groups. One group was placed in a plastic bag containing carbon dioxide; the other was placed in a plastic bag containing a substance that absorbed carbon dioxide. Table 22 shows that when asked the question, “in which bag does photosynthesis occur,” 51%, 62%, and 67% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response; whereas only 36%, 49%, and 57%, respectively, selected the correct content and reason responses. Further, 13%, 11%, and 11%, respectively, gave the incorrect content and reason responses that photosynthesis occurs in “both bags 1 and 2” because “plants in both bags have chlorophyll and get light, which is enough for photosynthesis.
Percentages of subject responses to Item 14 are shown in Table 23.

Table 23. Percentages of Subject Responses to Item 14.

<table>
<thead>
<tr>
<th>Grade level</th>
<th>Number of respondents</th>
<th>Content response</th>
<th>Reason response</th>
<th>Total</th>
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</tr>
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<td>5.1</td>
</tr>
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<td>1.5</td>
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<td>2.0</td>
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</tr>
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<td>0.6</td>
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<td>0.9</td>
</tr>
</tbody>
</table>

Note: Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade may not add to 100% because of rounding.

Table 23 shows that when asked the question, “during the day time, do plants outside in the sun give off carbon dioxide or oxygen, or neither,” 31%, 27%, and 36% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response, but only 10%, 11%, and 22% selected the correct content and reason responses. Further, 37%, 32%, and 30%, respectively, selected the incorrect content and reason responses that plants “give off only oxygen” because “plants only have photosynthesis, so only oxygen is given off.”

Item 15

Item 15 introduced a situation in which a boy puts some fish “in a jar covered tightly with a lid without adding any food nor changing the water.” Percentages of
subject responses to Item 15 are shown in Table 24, from which it is shown that
when asked the question, “do you think the quantity of oxygen or carbon dioxide
change,” 40%, 48%, and 62% of the fourth, fifth, and sixth-grade students, respec-
tively, selected the correct content response, but only 26%, 34%, and 48% selected
the correct content and reason responses. Further, 20%, 14%, and 12%, respectively,
selected the incorrect content and reason responses that “there will not be any
change” because “there is no air getting in or out of the jar.”

Table 24. Percentages of Subject Responses to Item 15.

<table>
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<th>Content response</th>
<th>Reason response</th>
<th>Total</th>
</tr>
</thead>
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<td>5.9</td>
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<td>11.6</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Note: Percentages for correct content and reason responses are emphasized. Sum of
total percentages for each grade may not add to 100% because of rounding.

Item 16

Item 16 was a continuation of the situation described in Item 15: The fish
die, and “Preecha thinks he should improve the experiment by adding something to
help the fish stay alive for a long time.” Percentages of subject responses to Item 16
are shown in Table 25.
Table 25. Percentages of Subject Responses to Item 16.

<table>
<thead>
<tr>
<th>Grade level</th>
<th>Number of respondents</th>
<th>Content response</th>
<th>Reason response</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>1,526</td>
<td>1</td>
<td>6.5</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>3.5</td>
<td>25.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>4.0</td>
<td>3.4</td>
</tr>
<tr>
<td>5</td>
<td>1,418</td>
<td>1</td>
<td>4.1</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>2.8</td>
<td>20.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>3.5</td>
<td>3.4</td>
</tr>
<tr>
<td>6</td>
<td>1,402</td>
<td>1</td>
<td>1.8</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>1.4</td>
<td>17.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>1.9</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Note: Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade may not add to 100% because of rounding.

From Table 25, when asked the question, “which of the following should he add—food, oxygen or green water plants such as Hydrilla,” 46%, 56%, and 69% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response, but only 21%, 33%, and 48%, respectively, selected the correct content and reason responses. Further, 26%, 20%, and 18%, respectively, selected the content and reason responses that Preecha should add oxygen because “oxygen for respiration is enough for a fish to stay alive for a long time.”

Item 17

Percentages of subject responses to Item 17 are shown in Table 26, from which it is indicated that when asked, “where should Preecha put his jar,” 62%, 70%, and 79% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response, but only 35%, 49%, and 66%, respectively, selected the correct content and reason responses that he should put it “by the window where there is
light" because "green plants need light for photosynthesis and give off oxygen for the fish to respire." Among the fourth-grade students, 12% selected the correct content response but the reason response that "light will kill germs in the food that he adds" or that "light will take air through the jar." Among fourth and fifth-grade students, 10% and 11%, respectively, selected the correct reason response, but the incorrect content response that "the boy should put his jar either in the window or in the middle of a room which has its door and window closed all the time".

Table 26. Percentages of Subject Responses to Item 17.

<table>
<thead>
<tr>
<th>Grade level</th>
<th>Number of respondents</th>
<th>Content response</th>
<th>Reason response</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1,525</td>
<td>1</td>
<td>12.2 11.8 34.9</td>
<td>62.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>1.0  1.8 3.1</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>4.4  6.2 10.4</td>
<td>29.6</td>
</tr>
<tr>
<td>5</td>
<td>1,418</td>
<td>1</td>
<td>8.4  9.2 49.3</td>
<td>70.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.8  1.0 3.0</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>2.0  3.8 10.5</td>
<td>22.1</td>
</tr>
<tr>
<td>6</td>
<td>1,400</td>
<td>1</td>
<td>5.1  5.1 66.3</td>
<td>79.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.7  0.9 2.1</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>1.5  0.9 8.7</td>
<td>16.0</td>
</tr>
</tbody>
</table>

Note: Percentages for correct content and reason responses are emphasized. Sum of total percentages for each grade may not add to 100% because of rounding.

Findings Not Directly Related to the Hypotheses

School Location

All 4,346 respondents furnished data on school location. The t-test was employed to test the effect of school location on the students' understanding of the selected concepts. Results indicated that there was a significant effect (p = 0.001) for
The mean test scores of students studying in urban area schools were higher than those of students studying in suburban/rural area schools (Table 27).

Table 27. Mean Scores by School Location.

<table>
<thead>
<tr>
<th>Location</th>
<th>Number of respondents</th>
<th>Mean scores</th>
<th>t</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>1,862</td>
<td>6.96</td>
<td>9.70</td>
<td>0.001*</td>
</tr>
<tr>
<td>Suburban/rural</td>
<td>2,484</td>
<td>6.08</td>
<td></td>
<td>*p &lt; 0.05</td>
</tr>
</tbody>
</table>

Parent Educational Levels

Data on the educational level of mothers and fathers were provided by 4,333 subjects (i.e., 13 subjects did not submit this data). Percentages of subject responses on the educational levels of mothers and fathers are presented in Table 28.

Table 28. Educational Levels of Parents.

<table>
<thead>
<tr>
<th>Educational level</th>
<th>Father</th>
<th></th>
<th></th>
<th>Mother</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of respondents</td>
<td>Percent</td>
<td></td>
<td>Number of respondents</td>
<td>Percent</td>
<td></td>
</tr>
<tr>
<td>Elementary</td>
<td>2,130</td>
<td>49.16</td>
<td></td>
<td>2,480</td>
<td>57.06</td>
<td></td>
</tr>
<tr>
<td>Lower secondary</td>
<td>340</td>
<td>7.85</td>
<td></td>
<td>304</td>
<td>7.02</td>
<td></td>
</tr>
<tr>
<td>Upper secondary</td>
<td>623</td>
<td>14.34</td>
<td></td>
<td>435</td>
<td>10.04</td>
<td></td>
</tr>
<tr>
<td>Vocational</td>
<td>284</td>
<td>6.55</td>
<td></td>
<td>225</td>
<td>5.19</td>
<td></td>
</tr>
<tr>
<td>College</td>
<td>873</td>
<td>20.09</td>
<td></td>
<td>772</td>
<td>17.82</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>83</td>
<td>1.91</td>
<td></td>
<td>117</td>
<td>2.70</td>
<td></td>
</tr>
</tbody>
</table>

Table 28 shows that about one-half of the fathers had completed an elementary education (49%), and that the remaining proportion had attended schools at higher levels than elementary school (49%). The table also indicates that the majority of
mothers had completed an elementary education (57%). Compared to fathers, fewer mothers (40%) had attended schools at higher levels than elementary school.

The ANOVA procedure was employed to test whether there was a significant difference effect for parents' educational levels. The results of the ANOVA procedure and mean scores are shown in Tables 29 and 30.

Table 29. Mean Scores by Educational Level of Fathers.

<table>
<thead>
<tr>
<th>Father's educational level</th>
<th>Mean scores</th>
<th>F-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elementary</td>
<td>5.96</td>
<td>31.95</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Lower secondary</td>
<td>6.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper secondary</td>
<td>6.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vocational</td>
<td>6.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>College</td>
<td>7.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>6.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < 0.05

Table 30. Mean Scores by Educational Level of Mothers.

<table>
<thead>
<tr>
<th>Mother's educational level</th>
<th>Mean scores</th>
<th>F-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elementary</td>
<td>6.11</td>
<td>29.19</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Lower secondary</td>
<td>6.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper secondary</td>
<td>6.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vocational</td>
<td>6.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>College</td>
<td>7.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>5.92</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < 0.05

Table 29 shows that there was a significant effect (p = 0.0001) for the educational levels of fathers. The Newman-Keuls follow-up procedure indicated that at a significance level of 0.05 there was a significant effect between both college level
and elementary educational level and every other educational level, except for "no" education. Mean test scores were highest for students who reported that their fathers' education was at the college level, and lowest for those reporting that their fathers' education was at the elementary educational level.

The results of the ANOVA procedure presented in Table 30 shows that there was a significant effect \( p = 0.0001 \) for the educational levels of mothers. The Newman-Keuls follow-up procedure indicated that there were significant effects between college level and every educational level, between elementary and lower secondary educational levels, and between elementary and upper secondary educational levels. Mean test scores were highest for students who reported that their mothers' education was at the college level and lowest for those reporting "none" for mothers' educational level.

Summary of Findings

Instrument

The final instrument, reflecting a Cronbach's alpha of 0.70, consisted of 17 items to measure student misconceptions. The instrument had an item difficulty index range of 0.20-0.73, an item discrimination index range of 0.20-0.67, and was able to discriminate among students who had and those who did not have misconceptions of photosynthesis and/or respiration. Students scores on the instrument correlated with scores on a science achievement test at the 0.77 level.
Findings Related to the Hypotheses

1) There was a significant effect for grade level; all grade levels had statistically significant differences at the significance level of 0.05.

2) There was no significant effect for gender at the significance level of 0.05.

3) There was a significant interaction between grade level and gender at the significance level of 0.05.

Misconceptions of Selected Science Concepts

A minimum of 10% of the subjects held misconceptions of photosynthesis and/or respiration, including the following:

1) Both plants and animals can produce their own food by using light;

2) Animals with green color photosynthesize since the green color is from chlorophyll;

3) Light is not a factor in making the green color of the plants;

4) Fertilizer and water are food for plants;

5) Only the green areas on the leaf have chlorophyll;

6) Photosynthesis can occur only in the leaf, regardless of whether green in color;

7) Chlorophyll is the product of photosynthesis;

8) Respiration occurs only on the leaf;

9) A gas, not a liquid, has to be a factor in the process of photosynthesis;
10) Respiration in plants occurs both day and night by taking in carbon dioxide during day time and oxygen at night;

11) Respiration in plants occurs at night because they do not photosynthesize;

12) Animals have respiration both day and night because they need energy and they do not have photosynthesis; and

13) Having only light and chlorophyll is sufficient for plants to conduct photosynthesis.

**Findings Not Related to the Hypotheses**

It was found that school location and parents' educational levels were related to understanding of the selected concepts. Students who were studying in schools located in urban areas scored higher than those who were studying in schools located in suburban/rural areas. Students whose parents had completed college education scored significantly higher than those whose parents had completed lower educational levels.
CHAPTER 5

CONCLUSIONS, DISCUSSIONS, AND RECOMMENDATIONS

This chapter is organized in five sections. The first provides an overview of the study, including a summary of the findings. The second section discusses the development of the instrument, the results of statistical analyses for testing the hypotheses, and the results from analysis of the descriptive statistics. The third section presents the conclusions of this study, whereas the fourth section presents recommendations for improving science education at the elementary grade level in Thailand and the fifth section presents recommendations for further study.

Overview of the Study

The principal purpose of the present study was to develop a valid and reliable test for the measurement of misconceptions of photosynthesis and respiration among elementary school students in Thailand. Gender and grade level were examined to determine whether they influenced student misconceptions. Specifically, this study sought answers to the following questions:

1) What are the understandings of selected concepts in the area of photosynthesis and respiration among fourth, fifth, and sixth-grade students in Thailand?
2) Do misconceptions of selected concepts among Thai elementary school students vary according to gender or grade level, or is there an interaction between these variables?

Construct-related evidence gathering procedures used to develop the instrument included defining misconception, developing an item pool, obtaining expert panel review of the question items, determining reliability of the instrument, performing item analysis, determining known-group difference, correlating the instrument with measures of similar construct, and testing for readability. The 17-item two-tier multiple-choice test developed for this study was determined to be reliable at 0.70, had an item difficulty index range from 0.20 to 0.73, and an item discrimination index range from 0.20 to 0.67. The instrument was able to discriminate between students who understood the concepts and those who had misconceptions of selected concepts. Correlation between scores from the developed instrument and those from a science achievement test was 0.77.

The subjects included for field testing were 4,346 fourth, fifth, and sixth-grade students selected at random from schools in Bangkok and 12 educational regions in Thailand during the 1992 academic year. The criterion instrument was administered to the students during regular classroom periods. Data on gender and grade level were collected from each subject, and the following null hypotheses were tested:

- \( H_{01} \): There will be no significant effect for grade level.
- \( H_{02} \): There will be no significant effect for gender.
- \( H_{03} \): There will be no significant interaction between grade level and gender.
A two-way ANOVA procedure was employed to assess effects for grade level and gender. A statistically significant effect was found for grade level (p = 0.001) and there was an interaction effect between gender and grade level (p = 0.005). Application of the Newman-Keuls method indicated a statistically significant difference between scores for all grades, but there was no significant difference for gender (p = 0.180). Mean scores were higher for male subjects than for female subjects in grades 5 and 6, but were lower for males in grade 4.

Not all students at every grade level understood the concepts of photosynthesis and respiration, that is, the majority of students had misconceptions concerning the selected concepts. The following is a list of misconceptions among the subjects:

1) Both plants and animals can produce their own food by using light;
2) Animals with green color photosynthesize since the green color is from chlorophyll;
3) Light is not a factor in making the green color of the plants;
4) Fertilizer and water are food for plants;
5) Only the green areas on the leaf have chlorophyll;
6) Photosynthesis can occur only in the leaf, regardless of whether green in color;
7) Chlorophyll is the product of photosynthesis;
8) Respiration occurs only on the leaf;
9) A gas, not a liquid, has to be a factor in the process of photosynthesis;
10) Respiration in plants occurs both day and night by taking in carbon dioxide during day time and oxygen at night;
11) Respiration in plants occurs at night because they do not photosynthesize;

12) Animals have respiration both day and night because they need energy and they do not have photosynthesis; and

13) Having only light and chlorophyll is sufficient for plants to conduct photosynthesis.

Conclusions

The accumulated evidence from administration of the two-tier multiple-choice test developed for this study indicated that inferences from test scores were appropriate. Therefore, the developed instrument was judged to be valid and reliable for measuring student misconceptions of photosynthesis and respiration among fourth, fifth, and sixth-grade students in Thailand.

Based on analysis of the data collected, the following was also concluded:

1) Most Thai students in grades 4, 5, and 6 held a large number of misconceptions of the selected concepts.

2) A majority of the students answered the content questions correctly, but did not understand all of the justifications for correct responses.

3) The higher the grade level, the greater the understanding of the concepts.

4) Female and male Thai students in grades 4, 5, and 6 did not significantly differ in their understanding of photosynthesis and respiration.
Discussions

Instrument

Misconception is a theoretical concept. Therefore, for the present study, instrument development was focused upon an accumulation of construct-related evidence, rather than upon content-related evidence, to support interpretation of the test scores. The evidence accumulated from the present study was as follows:

An internal consistency procedure indicated that the reliability factor for the instrument was 0.70. Correlation between scores from the developed instrument and from a science achievement test for the same subjects was 0.77. The known-group difference procedure demonstrated that the instrument could discriminate among students who had and those who did not have misconceptions of photosynthesis and respiration.

The accumulation of some of the evidence ruled out extraneous factors. For example, testing for readability showed that fourth-grade Thai students could understand the language used in each instrument item. There were no words that the students did not understand. Pilot testing demonstrated that the time allowed for students to complete the test, 50 minutes, was sufficient.

This evidence was sufficient to support the claim that the instrument was valid and reliable for the measurement of misconceptions among elementary students in Thailand, and that test scores could be interpreted as measures of misconceptions. However, the developed instrument had a moderate reliability of 0.70, and the difficulty index of some items was rather low.
Reliability of the instrument could be improved by increasing the number of test items. One problem associated with long tests, however, is the time that students have to work on long tests. Fatigue, which may affect testing performance, can occur when elementary students have to work on tests for longer periods of time.

A typical goal in choosing the items is to choose items with an average difficulty index range between 50 and 65 (Lindvall, 1967). But some items had a low difficulty index, indicating that these items were too difficult. These items could be revised, and the effects of the changes on the individual item and instrument could be investigated.

Evidence from alternative procedures could be added to the testing procedure. For example, the “thinking aloud” procedure, which checks students' mental processes, could be added. However, the resultant accumulation of evidences may then be endless.

**Testing the Hypotheses**

In this study, use of a two-way ANOVA indicated a statistically significant difference for grade level, and for the interaction effect between grade level and gender, but not for gender in itself. The usual expectation in misconception studies is to find evidence of a decrease in misconceptions of science concepts with an increase in years of education. Although the mean scores for male subjects in the fifth and sixth-grades were higher than those for females, implying that the male subjects experienced fewer misconceptions than female subjects, the mean difference was not significant.
The findings of this study were not in agreement with those of Haslam and Treagust (1987), who reported that there was no significant interaction effect between grade level and gender. The findings of the present study were also not supportive of other investigations of gender differences (Doran, 1972; Shepardson & Pizzini, 1992; Za’Rour, 1975).

Za’Rour (1975) studied science misconceptions among ninth-grade, eleventh-grade, and university students in Lebanon. He reported that the percentage of females that held misconceptions was significantly higher than the percentage of males who held misconceptions at the eleventh-grade level, but the phenomenon was less significant at the ninth-grade and university levels. A study by Doran (1972), involving misconceptions of selected science concepts among students in grades 2-6, indicated that the correlation of misconception test scores was nearly zero (0.003); that is, there was a gender-bias. Similar results were reported by Erickson and Erickson (1984) in a study of fourth, eighth, and twelfth-grade students, in which boys achieved at a higher level than did girls.

The reason the findings of this study were not in agreement with those of Doran (1972), Shepardson and Pizzini (1992), and Za’Rour (1975) may be explained by the fact that the selected concepts used for the present study were basic biological science concepts. According to Vockell and Lobonc (1981), both boys and girls perceive the biological sciences to be a less masculine field. This may explain why the mean scores of the male students in this study were not significantly higher than those of the female students. Neither were the findings of the present study in agreement with those reported by Kiokaew (1989), Haslam and Treagust (1987), Bailey
(1962, cited in Za'Rour, 1975), and Roger (1961), each of whom found that the mean scores of males and females were not significantly different.

With respect to grade level, the findings of this study were in agreement with those of Westbrook and Marek (1992), Cho (1989), Haslam and Treagust (1987), and Za'Rour (1975): The mean scores of students increased as grade level increased. The implication is that understanding increases across grade level or, in other words, students at higher grade levels had fewer misconceptions than those at lower grade levels. This can be explained by the fact that the students at higher grade levels have had more experiences than those at lower grade levels. In this study, the students at each grade level had studied photosynthesis and respiration; however, the content and experiences presented for the fifth-grade students were more advanced than those presented to the fourth-grade students, and less advanced than those for sixth-grade students. In grade 6, students had opportunities to learn about the ecosystem in class discussions, which may have helped them better understand the two selected concepts—photosynthesis and respiration. However, the mean scores for each grade level were less than one-half of the total score of 17 points. This may imply that the students at each grade level did not fully understand the two selected concepts.

Results from Descriptive Statistical Analysis

A higher percentage of the fourth, fifth, and sixth-grade students tested selected the correct content responses (Part a) than selected the correct content and reason responses (Parts a and b) for the 17 items (see Tables 10-26). A possible explanation for this difference is that students had memorized the correct answers
without acquiring an adequate understanding of the concepts involved (Niedzielski & Walmsley, 1982). In the following paragraphs, items are discussed according to phenomena related to photosynthesis, respiration, and the gas exchange between plants and animals.

1. Photosynthesis:

Items 1 and 2 were intended to examine whether the students understood that green plants photosynthesize, but that animals do not. On item 1, 66%, 75%, and 83% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response; and 55%, 65%, and 76%, respectively, selected the correct content and reason responses. On item 2, 45%, 58% and 68%, respectively, selected the correct content and reason responses. These data suggest that a majority of the elementary students understood the fact that green plants have chlorophyll and that chlorophyll is used in the process of photosynthesis.

However, it is worth noting that about 10% of students at each grade level selected the response that the sunflower, human, bird, and rat can photosynthesize or make food (Item 1). The students understood that “light” is involved in “making food,” but did not really understand the word “photosynthesis” and included vitamin D as “food.” The latter misconception could be the result of students being taught that exposure to sunlight produces vitamin D within humans or some animals.

It is also worth noting that most of the students understood that the green in leaves is due to chlorophyll. Some students attributed the green color in toads and parrots to chlorophyll (Item 2). About 34%, 24%, and 19% of the fourth, fifth and sixth-grade students, respectively, applied this fact and facts concerning the essential
factors of photosynthesis (light, chlorophyll, water, and carbon dioxide) logically when asked to give the reason why the toad and parrot could or could not photosynthesize. Perhaps the color determination of animals is not studied in class, or if it is, green coloration is not mentioned with respect to chlorophyll.

Items 3 and 5 were intended to examine whether the students understood that light is necessary for plants to develop chlorophyll which helps green plants green. For Item 5, 82%, 83%, and 83% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response, but only 57%, 64%, and 64%, respectively, selected the correct content and reason responses. These data indicate that slightly more than one-half of the students at every grade level understood this fact. For Item 3, more than 30%, but less than 50%, of students at each grade level selected the correct content and reason responses.

Based on percentages of responses to Items 3 and 5, it seems that less than 50% of the students really understood that light is necessary to develop chlorophyll. The situation presented in Item 5 is little different from an experiment presented in class. The students could have applied what they learned to this new situation. But for Item 3, which required understanding of the same facts, more than 50% could not provide the correct answer. This suggests that more than one-half of students at each grade level really did not understand this fact.

Evidence of a lack of understanding regarding light and chlorophyll was derived from student interviews. Two of the students stated that in a movie they saw green plants everywhere, even in the desert; therefore, they reasoned, the deep sea should have green plants, even though the light does not get through. This
misconception was evidenced by the selection of the reason response, for Item 5, that "chlorophyll is in the plants and plants are green whether there is light or not."

Other possible reasons for this misconception are: (a) Students may have watched movies that showed green colored living things within the deep seas; and (b) while teaching this concept, the teacher may not have provided enough examples. In either case, the students brought what they experienced into the answers. Responses to Items 3 and 5 also showed that with increasing grade level, misconceptions decreased.

Items 6, 9, and 13 were intend to examine whether students understood that carbon dioxide, water, chlorophyll, and light were essential factors in photosynthesis. Responses to Item 1 indicated that most of the students comprehended that chlorophyll is used in the photosynthesis process; whereas, responses to Item 6 showed that they comprehended this fact. A misconception surfaced that chlorophyll in the petiole was not involved in photosynthesis. The reason the response was selected was that the function of the leaves is to make food, but the function of the petiole is the transportation of food and water. The chlorophyll in the petiole, therefore, is not involved in photosynthesis.

Another misconception among students was that photosynthesis occurs in areas of leaves which lack chlorophyll. This misconception may be explained by the fact that students learned that one function of the leaf is photosynthesis (making food) and that of the (stem, branch) petiole is transportation. Some students experimented with this and combined the concepts, applying them to new situations.
On Item 9, the percentage of the students who selected only the correct content response and the percentage of the students who selected the correct content and reason responses increased with grade level. The percentage of misconceptions (i.e., incorrect responses) decreased with grade level. In other words, the percentage of correct responses was slightly higher than 50% for sixth-grade students, while less than 50% for fourth and fifth-grade students. The implication is that more than 50% of the students believed that oxygen was an essential factor in photosynthesis.

The percentage of correct responses on Item 9 indicated that a majority of students understood that light is an essential factor for photosynthesis. One of the misconceptions among students was that water was not an essential factor in photosynthesis because it is not a gas and therefore could not enter the leaf. This reason response was selected by 26%, 19%, and 18% of the fourth, fifth, and sixth-grade students, respectively, and 18%, 17%, and 15%, respectively, responded that water was used in stems and branches, but not in leaves. What was the source of this misconception? Perhaps in class discussions on water transportation in plants, the transportation and use of water in leaves was not mentioned. Perhaps the lecture or textbook readings were not sufficient to alter prior misconceptions. Among the students interviewed, some explained that an essential factor for photosynthesis was direct entry into the leaves, and this must indicate gases since gases are composed of only very small particles. It was believed that water particles were too large to get into leaf structures.

On Item 13, 36%, 49%, and 57% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content response. This indicated that about 50% of
the students in grades 5 and 6, but only about 30% of the students in grade 4, comprehended that carbon dioxide was one of the essential factors of photosynthesis. About 10% of the students from each grade responded that carbon dioxide was not necessary because chlorophyll and light are sufficient. The students' experiments with extraction of chlorophyll and testing for starch may have led them to this conclusion. The derivable meaning of the Thai word for photosynthesis could have lead some students to think that light is an essential factor. Another possibility is that carbon dioxide may not have been mentioned very often in class discussions.

The data for Items 9 and 13 supported earlier research conducted by Haslam and Treagust (1987), who found that 25%, 13%, 18%, 10%, and 2% of Australian students in years 8, 9, 10, 11, and 12, respectively, selected the response that plants make their food from oxygen (i.e., not from carbon dioxide). The data also supported research by Wandersee (1985), who found that most students realized that light is a vital part of photosynthesis.

Item 4 was intended to examine whether students understood that green plants make their own food from the essential factors used in photosynthetic growth. Only 36%, 40%, and 45% of the fourth, fifth, and sixth-grade students, respectively, selected the correct content and reason responses for this item. The incorrect content and reason responses that fertilizer and water were essential to photosynthesis were selected by 12% and 10% of the fourth and fifth-grade students, respectively. These data indicated that some of the students had misconceptions about what is essential to plant survival and growth. The students may have thought that food for plants is anything that plants can take in for survival, or they may have witnessed the growth
of plants following application of fertilizer and water. An earlier study (Roth & Anderson, 1987) found that most of the subjects believed that food was anything that plants need to live and be healthy, and that roots absorb minerals and water as food.

2. Respiration:

The concept of respiration was examined through Items 8, 10, 11, 12, 14, and 15. Item 8 was developed to measure student comprehension of respiration occurring in every cell. However, because the word “cell” was not mentioned in the curriculum, the concept was presented by using a picture of a leaf, with lines pointing to many areas of the leaf. For this item, correct content responses were selected by 18%, 18%, and 25% of the fourth, fifth, and sixth-grade students, respectively; but only 10%, 8%, and 13%, respectively, selected the correct content and reason responses. This finding indicates that the majority of the students did not understand that respiration occurs in every area (cell) because the plant needs energy to survive.

The content response to Item 8 that most students at all grade levels selected to explain where respiration occurred was “area 1 and 2,” which are the areas of the leaf. The reason response selected was that the function of the leaf is respiration, demonstrating that the students did not understand why plants have to respire or the nature of the respiration process. In Thai, the word for “respiration” is the same for “breathe”; students may have been confused by this and have failed to understand that “respiration” has a scientific meaning. This was also indicated by selected responses to Item 10, that plants respired both day and night because during the day plants take in carbon dioxide, whereas oxygen is taken in at night.
These findings were in agreement with findings from earlier studies. Haslam and Treagust (1987) found that 24%, 42%, 34%, 24%, and 12% of students in years 8, 9, 10, 11, and 12, respectively, had the misconception that plants respired only at night time. Two studies reported that students believed that respiration was the same as breathing (Roth & Anderson, 1987).

Items 10, 11, and 12 were developed to measure comprehension of when respiration occurred in plants (and other living things). The findings for these three items supported each other. For Item 12, the percentages of fourth, fifth, and sixth-grade students selecting only the correct content response were 52%, 56%, and 64%, respectively. Similarly, the percentages of students, respectively, selecting the correct content and reason responses for this items were 42%, 53%, and 62%. This indicates that only about 50% of the students in each grade comprehended that at night living things, including plants, need energy for survival. With respect to respiration during the day, the percentages of students selecting only the correct content response and those selecting the correct content and reason responses were lower than those for Item 12. Students tended to believe that during the day plants did not respire, but photosynthesized.

On Item 10, 23%, 25%, and 22% of the fourth, fifth, and sixth-grade students, respectively, selected the incorrect response that plants respired at night. On Item 11, less than 50% of the students at each grade level selected the correct content and reason responses. The data for Item 14 was in agreement with the data for Items 10, 11, and 12; 37%, 32%, and 30%, respectively, of the fourth, fifth, and sixth-grade students selected the response that during the day plants produce only oxygen because
plants have only photosynthesis. This finding supports earlier research conducted by Haslam (cited in Treagust, 1986).

The implication of the findings in this study is that the term “respiration” is not mentioned in current teaching about photosynthesis. This would help to explain why students had the misconception that plants respired only at night time. Some students indicated that we should sit under the trees during the day since trees photosynthesize and produce oxygen, but at night we should not sit under the trees, or have plants in the bedroom, because we would have to compete for oxygen with trees or plants for respiration.

3. Exchange of gases between plants and animals:

Misconceptions about the exchange of gases between plants and animals were examined through Items 15, 16, and 17. Item 15 introduced the situation leading to solution of the problem. For Item 16, 85%, 91%, and 96% of the fourth, fifth, and sixth-grade students, respectively, understood that fish need oxygen for respiration. However, only 21%, 33%, and 48%, respectively, selected the correct content and reason responses for this item. Students who selected the response that the boy should add oxygen in the big jar may not have thought that the oxygen could again be depleted. They may not have understood the relationship between photosynthesis and respiration in terms of gas exchange and how adding a plant would provide an unlimited supply of oxygen.

Item 17 provided students with an opportunity to apply their knowledge of light and photosynthesis. Although most of the students for each grade responded that the boy should put the big jar by the window so the plants could get light, only
35%, 49%, and 66% of the fourth, fifth, and sixth-grade students, respectively, could give correct content and reason responses. It seems that in spite of understanding the necessity of light for the process of photosynthesis, when different situations were presented, only about 50% of the fifth and sixth-grade students and only 35% of the fourth-grade students could apply what they understood. The percentage of students who could apply the concept concerning the exchange of gases increased with grade level. This could be because students learned and discussed gas exchanges in animals and plants in fifth grade and the ecosystem in sixth grade.

Overall, the mean scores of the students at every grade level were less than 50% of the total scores. This may imply that the majority of students did not understand the two selected concepts, photosynthesis and respiration. Misconceptions about these concepts among secondary school and college students have been observed by others (Westbrook & Marek, 1992; Eisen & Stavy, 1988). Student experiences in and out of school affect their understanding of concepts. Perhaps these misconceptions existed because the concepts were abstract, and students were unable to grasp the abstract. Another possibility is that the students may not have had the experience necessary to understand the concepts.

Recommendations for the Improvement of Science Education at the Elementary Level in Thailand

1. Valid and reliable instruments, including two-tier multiple-choice tests, should be introduced in preservice and inservice teacher educational programs. The two-tier multiple-choice test has potential for use in evaluating student knowledge
and for provision of information on student misconceptions of selected concepts. Regular evaluation methods fail to examine the reasons for student selection of right or wrong answers to content questions. These types of tests could provide a starting point from which teachers, science educators, and science curriculum developers could assess student understanding of science concepts. It is asserted that this type of instrument would be useful for curriculum development.

2. Teachers could use the instrument developed for the present study to diagnose fourth, fifth, and sixth-grade student knowledge prior to teaching photosynthesis and respiration. In addition, teachers could use this instrument as well for the evaluation process.

3. In the teaching and learning process, teachers should not just teach the content, but should spend time in discussion and in helping students develop science process skills through laboratory activities. This will help teachers and students explore the misconceptions students may have and will increase students' enthusiasm concerning their ability to learn and understanding photosynthesis and respiration (Treagust, 1987). Teachers should also provide students with appropriate questions and place greater emphasis on reasons for answers and less emphasis on "the right" answer. This will help students become more actively involved in understanding the meaning of the concepts they are learning.

4. The Institute for the Promotion of Teaching Science and Technology and the Curriculum Development Center, both in Thailand, should use the results and recommendations from the present study to conduct inservice and preservice teacher educational programs to help teachers teach science concepts effectively based upon
use of appropriate classroom activities. These activities must have the sanction of the
teachers; they should be simple to prepare and implement, safe, nondisruptive, and
inexpensive.

In educational programs, the understanding of science content should be
emphasized along with science content. In addition, teachers should be provided with
experiences through which they can develop more self-confidence in teaching science.
The data collected from the classes who participated in this study showed that of 107
teachers, only 20 teachers reported that they had majored in science in college and
only eight reported a minor in science. Only 36 teachers stated that they had
sufficient self-confidence to teach science.

5. From the results of the present study, the mean scores of students in
schools located in urban areas was significantly higher than those for students in
schools located in rural/suburban areas. This may imply that students from subur-
ban/rural areas have more misconceptions than those from urban areas. In part, this
may have been the result of a lack of facilities and materials for teaching science.
Administrators of the Ministry of Education should be concerned that schools located
in suburban/rural areas should be provided with the facilities and materials needed to
teach science. Since teachers in elementary schools teach almost every subject, they
do not have the time to produce or find out about effective teaching aids. Teacher
training science programs should also be considered and promoted, because the
teachers are important resource persons and, as this study and other studies have
indicated, teachers influence student misconceptions about science concepts.
Administrators should also provide more teacher positions in suburban/rural schools. Data collected for this study showed that the average load for suburban/rural teachers was 50 periods per week, and that they had other school responsibilities in addition to teaching. That teachers did not have sufficient time to prepare themselves and activities for teaching science to students might have enhanced the presence of student misconceptions.

Recommendations for Further Study

The following suggestions for further study are provided:

1. The instrument developed for this study had a moderate reliability rating of 0.70, and the difficulty indices for some items were too low. Further study will be required to improve this instrument.

2. The findings of this study showed that a majority of Thai students in the fourth, fifth, and sixth-grades held misconceptions of photosynthesis and respiration concepts. Further study will be required to identify the sources of these misconceptions and to design teaching and learning activities that could help to change student misconceptions.

3. This study diagnosed the only misconceptions among Thai students in the fourth, fifth, and sixth grades. Further study using the developed instrument will be required to determine whether students in the seventh to twelfth grades understand these two selected concepts. However, the reliability and validity of the instrument must be further established for appropriate use with students of these age groups.
4. This study was concerned with the development of a two-tier multiple-choice test on photosynthesis and respiration concepts. Further study will be required to develop instruments, based upon the instrumental model from this study, to measure and diagnose student misconceptions of other science concepts taught at the elementary school level. These should include the basic concepts that serve to enhance students' ability to comprehend more complicated concepts at higher grade levels. These types of studies would be useful to both teachers and science curriculum developers.

5. A number of studies have indicated that teachers are one factor affecting student misconceptions of science concepts. Further study will be required to examine whether misconceptions exist among elementary teachers and the effects of teacher misconceptions on student learning. The instrument developed for this study could be modified for this purpose. Such research would be useful for the development of educational programs to help teachers become more effective science instructors.
REFERENCES


APPENDICES
Appendix A

Photosynthesis and Respiration Content Taught in Elementary Schools in Thailand

Content taught to fourth, fifth, and sixth grade students about photosynthesis (P1-P9), respiration (R1-R6), and the exchange gases between plants and animals (PR1).

Photosynthesis

P1. Green plants have chlorophyll.

P2. Chlorophyll make plants green.

P3. Light energy helps green plants green.

P4. Green plants can photosynthesize (but animals cannot).

P5. Photosynthesis takes place (mainly) in the leaves (but green stems make food too).

P6. The essential factors in photosynthesis are light, chlorophyll, water, and carbon dioxide.

P7. During the process of photosynthesis, plants produce food and oxygen.

P8. After photosynthesis, plants change food that they produce into a starch, which can be tested.

P9. Plants (and other living things) use food for living (growth and energy).

Respiration

R1. Living things respire continually.

R2. Every (living) part of living things respire.

R3. Living things need energy for living.

R4. Oxygen is taken in during respiration.

R5. Energy and carbon dioxide (and water) are end products of respiration.
R6. Both plants and animals release carbon dioxide during respiration.

**Photosynthesis and Respiration**

PR1. The process of photosynthesis of green plants and respiration of plants and animals creates the exchange of oxygen and carbon dioxide, which benefits plants and animals.

A following chart shows how these contents were addressed by items in the instrument in this study. Parentheses indicate that the content was also implicitly addressed by the item.

<table>
<thead>
<tr>
<th>Item</th>
<th>Contents</th>
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<tbody>
<tr>
<td>1</td>
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<tr>
<td>2.</td>
<td>(P1), (P2), P4</td>
</tr>
<tr>
<td>3.</td>
<td>P2, P3</td>
</tr>
<tr>
<td>4.</td>
<td>(P6), P7, P9</td>
</tr>
<tr>
<td>5.</td>
<td>P2, P3</td>
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<tr>
<td>6.</td>
<td>(P1), P2, P5, P6</td>
</tr>
<tr>
<td>7.</td>
<td>P7, P8</td>
</tr>
<tr>
<td>8.</td>
<td>R2, R3</td>
</tr>
<tr>
<td>9.</td>
<td>P6</td>
</tr>
<tr>
<td>10.</td>
<td>R1, R3, R5</td>
</tr>
<tr>
<td>11.</td>
<td>R1, R3, R5</td>
</tr>
<tr>
<td>12.</td>
<td>R1, R3, R5</td>
</tr>
<tr>
<td>13.</td>
<td>P6</td>
</tr>
<tr>
<td>14.</td>
<td>(P6), P7; R1, (R3), (R4), R5, R6</td>
</tr>
<tr>
<td>15.</td>
<td>(R1), R4, R5, R6</td>
</tr>
<tr>
<td>16.</td>
<td>(P6), P7; R1, R3, R4; PR1</td>
</tr>
<tr>
<td>17.</td>
<td>P6; (PR1)</td>
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</table>
Appendix B

Expert Panel Members

1. Expert Prof. Aksorn Sripleng
   Botanist, Kasetsart University.

2. Mr. Ampai Chitwattana
   The Demonstration School of Srinakarinwirot (Prasarnmitr) University.

3. Ms. Ampai Meejunpetch
   The Demonstration School of Srinakarinwirot (Prasarnmitr) University.

4. Dr. Jariya Suchareekul
   General Science Department, Chulalongkorn University.

5. Ms. Kacheerat Jiraarune,
   General Science Design Team
   The Institute for the Promotion of Teaching Science and Technology (IPST).

6. Ms. Malinee Nimsamer
   Biology Design Team, IPST.

7. Ms. Nantiya Boonklurb
   General Science Design Team, IPST.

8. Dr. Pimpan Dachakupt
   Faculty of Education, Chulalongkorn University.

9. Asst. Prof. Ratchada Sutra
   Chulalongkorn University Demonstration School.

10. Ms. Rungtip Laokum
    Research and Evaluation Team, IPST.

11. Ms. Yupa Tanticharoen
    Director (retired), IPST.
Appendix C
Instrument Developed for this Study: Thai Version

ตอน 1

แบบสอบถามนักเรียน

คำถาม โปรดตอบคำถามทุกข้อความเบี้ยจริง โดยเขียนคำตอบลงในช่องว่าง หรือเขียนเครื่องหมาย x ลงใน ( ) หน้าคำตอบที่เลือก

1. สิ่ง ____________ อายุ __________ ปี
   เพศ ( ) 1. ชาย ( ) 2. หญิง
2. โรงเรียน ____________________________________________________________
   อ้างอิง ___________________________________ จังหวัด ________________________
3. กำลังศึกษาชั้นปี ( ) ป. 4 ( ) ป. 5 ( ) ป. 6
4. ผลการสอบครั้งสุดท้ายวิชา สัง. ได้ระดับคะแนน ( ) 1 ( ) 2 ( ) 3 ( ) 4

5. นิทานเล่าเรื่องการศึกษาดีที่ ( ) 1. ประถมศึกษา ( ) 2. มัธยมศึกษาตอนต้น
   ( ) 3. มัธยมศึกษาตอนปลาย ( ) 4. อาชีวศึกษา ( ) 5. ปริญญา
6. นิทานอื่นๆ ( ) 1. ข้าราชการ ( ) 2. เกษตรกร ( ) 3. ทหาร ( ) 4. วันข้า
   ( ) 5. อื่นๆ ( ) 6. อื่นๆ

7. มาตราส่วนเรื่องการศึกษาดีที่ ( ) 1. ประถมศึกษา ( ) 2. มัธยมศึกษาตอนต้น
   ( ) 3. มัธยมศึกษาตอนปลาย ( ) 4. อาชีวศึกษา ( ) 5. ปริญญา
8. มาตราส่วนอื่นๆ ( ) 1. ข้าราชการ ( ) 2. เกษตรกร ( ) 3. ทหาร
   ( ) 4. วันข้า ( ) 5. อื่นๆ ( ) 6. อื่นๆ
ต่อน 2

บทคัดย่อวัตถุความเจ้าใจ

เรื่องการสังเคราะห์ตัวผสมและการทานใจ

คำถามแรก

1. แบบทดสอบฉบับที่ 17 ข้อ มีจุดละเอียดแบบเลือกตอบ ให้เวลา 60 นาที

2. ข้อสอบแต่ละข้อ มี 2 ตอน นักเรียนต้องตอบทั้ง 2 ตอน

ตอน ก. แบบคำถามเกี่ยวกับความรู้ความเขาใจเรื่องการสังเคราะห์ตัวผสมและการทานใจ ให้นักเรียนเลือกคำตอบที่คุ้มกับต้องที่สุด แล้วเรียงเครื่องหมาย X ที่ตัวเลือก 1 2 หรือ 3 ในกระดาษคำตอบตอน ก.

ตอน ข. แบบคำถามที่ให้แสดงเหตุผลเลือกตอบในตอน ก. ให้นักเรียนเลือกคำตอบที่คุ้มกับที่สุด มีเหตุผลตรงกับแนวความคิดที่สุด แล้วเรียงเครื่องหมาย X ที่ตัวเลือก 1 2 3 หรือ 4 ในกระดาษคำตอบตอน ข. ถ้านักเรียนมีเหตุผลแตกต่างจากที่ได้ไว้ ให้นักเรียนเขียนเครื่องหมาย X ที่ตัวเลือก 5 แล้วเรียงแสดงเหตุผลของนักเรียนเองในช่องว่างที่กำหนดให้

ตัวอย่าง

<table>
<thead>
<tr>
<th>ชั้น</th>
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<tbody>
<tr>
<td>0</td>
<td>1 ½ 3</td>
<td>1 2 3 X 5………………</td>
</tr>
</tbody>
</table>
1. อุปกรณ์ที่ใช้ในเรื่องโดยทั่วไปไม่มีสารมวลสารเคราะห์ตัวย่อยหรือสารสร้างอาหารเองได้
   1. ต้นทานตะวัน
   2. คน นก และทุ้น
   3. ต้นทานตะวัน คน นก และทุ้น

2. เทคโนโลยีแอนตรายตัวอย่าง
   1. ต้นทานตะวันเม็ดออกโรไฟล์ขึ้นใช้ในการสังเคราะห์ตัวย่อย ล้วคน คน และทุ้นไม่มี
      มวลสาร
   2. ต้นทานตะวัน คน นก และทุ้น ต้องการอาหารเพิ่มมากกว่า
   3. คน นก และทุ้น สามารถผลิตภัณฑ์ได้จึงไม่ต้องสร้างอาหารเอง
   4. คน นก และทุ้นใช้ส่วนในการสร้างไวโภคภัณฑ์ ต้นและต้นทานตะวันใช้แสงในการสังเคราะห์-
      ตัวย่อย
   5. อื่นๆ .................................

3. เรียบง่าย มันกันสีเสีย reminiscent ลักษณะของชนิดเฉพาะสังเคราะห์-
   ตัวย่อยหรือไม่
   1. เหมาะเรียบง่ายสังเคราะห์ตัวย่อยได้
   2. ที่เรียบง่ายและมากกว่าสังเคราะห์ตัวย่อยได้
   3. ที่เรียบง่ายและมากกว่าไม่สามารถสังเคราะห์ตัวย่อยได้

4. เทคโนโลยีแอนตรายตัวอย่าง
   1. เรียบง่ายและมากกว่าสังเคราะห์ตัวย่อยได้
   2. เรียบง่ายและมากกว่าไม่สามารถสังเคราะห์ตัวย่อยได้
   3. แม้จะมีสารออกโรไฟล์แต่ยังไม่เสื่อมสภาพและมีเกิดเหตุหน้า แต่ยังคงกันเข้าไปไม่ได้
   4. สีเรียบง่ายและมากกว่าไม่ใช่สารออกโรไฟล์ จึงไม่สามารถสังเคราะห์ตัวย่อยได้
   5. อื่นๆ .................................
3. บริเวณให้นักเรียนเสนอแนะอย่างไม่ถูกต้อง นักเรียนควรจะพูดจากใจจริงหรือไม่
   1. นี่
   2. ไม่

4. เครื่องมือที่ใช้ในการแก้ไข
   1. ข้อความ
   2. _MESH
   3. ลาย
   4. ลาย
   5. ลาย

5. เครื่องมือที่ใช้ในการแก้ไข
   1. ข้อความ
   2. ลาย
   3. ลาย
   4. ลาย
   5. ลาย
6. บวิวชีวิที่เกิดการฝังเข้าหัวทั่วถึง
1. บวิวชีวิทที่ 2
2. บวิวชีวิทที่ 1 และ 2
3. บวิวชีวิทที่ 2 และ 3

5. เทศยมีสีเขียว
1. บวิวชีวิทที่ 1 และ 2 เบื้องบวิวชีวิทที่ 2
2. มีคลอโรฟิลส์ทั้งบวิวชีวิทที่ 2 และ 3 แต่ไม่เกิดการฝังเข้าหัวทั่วถึงส่งบวิวชีวิทที่ 3
3. สีเขียวที่มากยิ่งขึ้น
4. บวิวชีวิทที่ 2 และ 3 มีคลอโรฟิลส์ จึงส่งเข้าหัวทั่วถึงได้
5. อื่นๆ ..........................................................
7. (ก) บริเวณในเรื่อง 6 หลังการสิ้นเช้าที่ตัวและแล้ว เราสามารถตรวจพบสารใด
   1. แนง
   2. คลอโรฟิลล์
   3. กิวาร์บอนไอออกไซด์

(ข) เหมือนกันต่อค่าด้วยเนื้อกระหวา
   1. หลังสิ้นเช้าที่ตัวและแล้ว อาหารที่ได้ถูกเปลี่ยนไปเป็นป่า
   2. ในบางต่างๆ ใช้กิวาร์บอนไอออกไซด์ในการสิ้นเช้าที่ตัวและ จึงตรวจพบสารนั้น
   3. เมื่อสิ้นเช้าที่ตัวและแล้วจะได้คลอโรฟิลล์
   4. อาหารที่สิ้นเช้าที่ตัวและสัมพันธ์กัน ซึ่งเห็นเป็นระยะต่างๆ
   5. อื่น ๆ ........................................

8. (ก) ในข้าวค้างเมื่อถูกตัดอยู่บนต้น บริเวณที่มีการหายใจ
   1. บริเวณที่ 1 และ 2
   2. บริเวณที่ 2 และ 3
   3. บริเวณที่ 1, 2 และ 3

(ข) เหมือนกันต่อค่าด้วยเนื้อกระหวา
   1. เนื่องบริเวณใบชิ้นที่มีการหายใจ
   2. มีคลอโรฟิลล์ซึ่งในการสิ้นเช้าที่ตัวและหายใจ
   3. ทุบทะวันต้องมีการหายใจ เนื่องจากกล่องใบในการดำรงชีวิต
   4. ทุบทะวันมีฟิลิฟเวทและบาง ทำให้การหายใจได้ละเมา จึงมีการหายใจ
   5. อื่น ๆ ........................................
9. [กา] สิ่งใดต่อไปนี้มักเข้าสู่สังคมได้ดีในการสังเคราะห์ตัวเลข
1. น้ำ
2. กิจฮ่องกง
3. แสง

[บ.] เหตุผลที่สิ่งต่างๆนี้เข้าสู่สังคม
1. แสงไม่ใช่สิ่งเจ้าเนื่อง ต่อมโอกาสสังเคราะห์ได้ดี
2. สิ่งเจ้าเนื่องในการสังเคราะห์คำว่าจะต้องอยู่ในสถานที่ จึงจะเข้าสู่ไปได้ แต่บ้าน
เสน่ห์ของแสงเป็นพิษ
3. กิจฮ่องกงเจ้าเนื่องกิจที่ได้จากการสังเคราะห์คำว่าค่อนข้างจะมักถูกไป จึงไม่ใช่สิ่งเจ้าเนื่องในการ
สังเคราะห์คำว่า
4. กระดาษกระดาษสีมีสีลักษณะและก็สามารถเจ้าเนื่องไปเกี่ยวข้องกับไป จึงไม่ใช่สิ่งเจ้าเนื่องในการ
สังเคราะห์คำว่า
5. อื่นๆ .............................................................

10. [กร] การหายใจของพืชเกิดขึ้นเมื่อใด
1. กลางวัน
2. กลางคืน
3. กลางวันและกลางคืน

[ด.] เหตุผลที่สิ่งต่างๆถูกสังเคราะห์
1. เวลากลางวัน ซึ่งมีการสังเคราะห์คำว่าอยู่ในว่าง พืชหายใจ ส่วนในเวลากลางคืนไม่มี
การสังเคราะห์คำว่า จึงหายใจ
2. ไข่ไก่ถนอมในว่างในการสังเคราะห์คำว่าและหายใจไปไม่ได้
3. เวลากลางวันพืชหายใจภายนอกวานออกไข่ค่อนข้างส่วนในเวลากลางคืนพืชหายใจภายนอกไข่
4. ฟักต้องการแสงว่างในการสังเคราะห์วานต้องหายใจก่อนกลางวันและกลางคืน
5. อื่นๆ .............................................................
11. ในเวลากลางวัน ซึ่งใครจะไปมีการหายใจ

1. พูดและขับถ่าย
2. คุณสิ่งและเรียก
3. คุณสิ่ง เอียด พูด และขับถ่าย

2. เทคโนโลยีด้านการกลั่นแกล้ง

1. คุณสิ่งและเรียก เป็นตัวabetic ไม่ต้องระวังอาหาร จิ้งจาง
2. พูดและขับถ่าย ต้องการผลักดันในการหลีกเลี่ยงการติดอยู่ จิ้งจาง
3. คุณสิ่งและเรียกหายใจโดยใช้กั้นออกซิเจน สำหรับพูดและขับถ่าย

โดยใช้กั้นคาร์บอนไดออกไซด์
4. คุณสิ่ง เอียด พูด และขับถ่ายดื่มอาหาร เพื่อให้ได้ผลลัพธ์มากที่สุดในการดูแลรักษา
5. อื่นๆ .........................................

12. ในเวลากลางคืนที่ไม่มีแสงสว่างเลย ซึ่งมีชีวิตใจใด้ต่อไปยังมีการหายใจ

1. พูดและขับถ่าย
2. คุณสิ่งและเรียก
3. คุณสิ่ง เอียด พูด และขับถ่าย

2. เทคโนโลยีด้านการกลั่นแกล้ง

1. ในเวลากลางคืน พูดและขับถ่ายไม่ให้ตื่นนอนอาหาร จิ้งจางใจเพื่อตื่นนอนหลัง
2. คุณสิ่งและเรียกต้องการหลีกเลี่ยงผลลัพธ์ เวลาหลังคืนด้วย
3. คุณสิ่งและเรียกเป็นผลิตภัณฑ์ที่มีการผลิตอาหารได้
4. คุณสิ่ง เอียด พูดและขับถ่าย ต้องการผลักดันในการดูแลรักษา จิ้งจางใจเพื่อลดเวลา

ร่วมกันเวลาหลังคืนด้วย
5. อื่นๆ .........................................
13. จีรวิทยาพันธุ์ความตายหนึ่งวันวิวัฒนาศัย พื้นที่ 1 คืน แล้วสามารถอยู่ และเนื่องออกเป็น 2 พวกเท่ากัน เขยื้องผนังผลิตภัณฑ์ ที่แตกต่างกว่า ถูกต้องที่ 1 มีที่ทำคาร์บอนโดยออกไซErot อยู่ ส่วนในถูกต้องที่ 2 จะมีสารที่สลักคาร์บอนโดยออกไซErotต่างกัน ทำให้มีการทำคาร์บอนโดยออกไซErotใน ถูกต้อง ดังภาพ

สุดท้าย 1
มีการทำคาร์บอนโดยออกไซErot

สุดท้าย 2
ไม่มีการทำคาร์บอนโดยออกไซErot

สารเคมีทำคาร์บอนโดยออกไซErot

แก้ไขเรียบร้อย ไม่มีผู้ใหญ่ในถูกต้องผลิตภัณฑ์ที่มีการทำสังเคราะห์ด้วยแสง
1. ถูกต้องที่ 1
2. ถูกต้องที่ 2
3. ทรัพย์ 2 ถูก

เหตุผลที่ต้องดำเนินการใดๆ
1. มีการทำออกซิเจนขึ้นอยู่ในการทำสังเคราะห์ด้วยแสง
2. มีการทำคาร์บอนโดยออกไซErotซึ่งจ่านั้นเป็นการทำสังเคราะห์ด้วยแสง
3. ทรัพย์ 2 ถูกได้รับแสงแดดอย่างเพียงพอเพียงพอในการสังเคราะห์ด้วยแสงแล้ว
4. ไม่มีผู้ใหญ่ในทรัพย์ 2 ถูก มีออกไซ Erot และได้รับแสงแดดดังวิธีการทำสังเคราะห์ด้วยแสง
5. อื่น ๆ ...........................................
14. น้ำเรียกคิววะ ในเวลากลางวัน ต้นไม้ที่อยู่กลางแจ้งผลิตกัลกิชาระบอนโดยออกไซด์ หรือกัลกิชาระ-
บอน หรือไม่

1. ผลิตแล้วกัลกิชาระบอน
2. ผลิตทั้งกัลกิชาระบอนและกัลกิชาระบอนโดยออกไซด์
3. ไม่ผลิตกัลกิชาระบอนโดยออกไซด์

15. เทคโนโลยีเลือกตัวคุณภาพ

1. ต้นไม้ไม่มีการส่งเครื่องทำลายแสงเนื่องจากรัง โรงงานกัลกิชาระบอน

2. ในกรณีส่งเครื่องทำลายแสงต้นไม้ผลิตกัลกิชาระบอน และกัลกิชาระบอนโดยออกไซด์ออกมาก

3. ต้นไม้ไม่มีกัลกิชาระบอนโดยออกไซด์ และกัลกิชาระบอนไปในสิ่งเจาะทั่วส่วน และ

4. ในภาวะความชื้นไม่มีผลิตกัลกิชาระบอนโดยออกไซด์ออกมาก และในกรณีส่งเครื่องทำลายแสง

5. ต้นไม้ผลิตกัลกิชาระบอนจะออกมาก

ตอบคำาถาม 15-17 โดยอ้างอิงสถานการณ์ต่อไปนี้

บริษัทเอกได้ยินว่า เรายามาตรรสมองปลาสวยงามติดใส่การณ์ที่ใส่ตับ โดยไม่ต้อง ให้อาหาร
ไม่ต้องเปลี่ยนน้ำ เขาจึงทดแทนเลี้ยงปลาสวยงามอยู่ในอ่างเลี้ยงปลาแล้วไม่ค่อยถูก ดังภาพ

15. น้ำเรียกคิววะ ในอย่างเลี้ยงปลาจะมีปริมาณกัลกิชาระบอนสูงหรือกัลกิชาระบอนโดยออกไซด์

เปลี่ยนแปลงหรือไม่ อย่างไร?

1. มีโดยกัลกิชาระบอนเพิ่มขึ้น กัลกิชาระบอนโดยออกไซด์ลดลง

2. มีกัลกิชาระบอนโดยออกไซด์เพิ่มขึ้น กัลกิชาระบอนลดลง

3. ไม่มีการเปลี่ยนแปลงของกัลกิชาระบอน

ข.

1. ปลาใช้กัลกิชาระบอนในการหายใจ และแล้วผลิตกัลกิชาระบอนโดยออกไซด์ออกมาก

2. ไม่มีการเปลี่ยนแปลงปริมาณกัลกิชาระบอนเรื่อยมา

3. ปลาเผาผลิตกัลกิชาระบอนโดยออกไซด์ โดยหายใจเข้าไป และแล้วเปลี่ยนเนื้อกัลกิชาระบอนออกมาก

4. ปลาจะอยู่ใช้กัลกิชาระบอนโดยออกไซด์

5. อย่างไร

ตอบคำาถาม 15-17 โดยอ้างอิงสถานการณ์ต่อไปนี้

บริษัทเอกได้ยินว่า เรายามาตรรสมองปลาสวยงามติดใส่การณ์ที่ใส่ตับ โดยไม่ต้อง ให้อาหาร
ไม่ต้องเปลี่ยนน้ำ เขาจึงทดแทนเลี้ยงปลาสวยงามอยู่ในอ่างเลี้ยงปลาแล้วไม่ค่อยถูก ดังภาพ

15. น้ำเรียกคิววะ ในอย่างเลี้ยงปลาจะมีปริมาณกัลกิชาระบอนสูงหรือกัลกิชาระบอนโดยออกไซด์

เปลี่ยนแปลงหรือไม่ อย่างไร?

1. มีโดยกัลกิชาระบอนเพิ่มขึ้น กัลกิชาระบอนโดยออกไซด์ลดลง

2. มีกัลกิชาระบอนโดยออกไซด์เพิ่มขึ้น กัลกิชาระบอนลดลง

3. ไม่มีการเปลี่ยนแปลงของกัลกิชาระบอน

ข.

1. ปลาใช้กัลกิชาระบอนในการหายใจ และแล้วผลิตกัลกิชาระบอนโดยออกไซด์ออกมาก

2. ไม่มีการเปลี่ยนแปลงปริมาณกัลกิชาระบอนเรื่อยมา

3. ปลาเผาผลิตกัลกิชาระบอนโดยออกไซด์ โดยหายใจเข้าไป และแล้วเปลี่ยนเนื้อกัลกิชาระบอนออกมาก

4. ปลาจะอยู่ใช้กัลกิชาระบอนโดยออกไซด์

5. อย่างไร

ตอบคำาถาม 15-17 โดยอ้างอิงสถานการณ์ต่อไปนี้

บริษัทเอกได้ยินว่า เรายามาตรรสมองปลาสวยงามติดใส่การณ์ที่ใส่ตับ โดยไม่ต้อง ให้อาหาร
ไม่ต้องเปลี่ยนน้ำ เขาจึงทดแทนเลี้ยงปลาสวยงามอยู่ในอ่างเลี้ยงปลาแล้วไม่ค่อยถูก ดังภาพ

15. น้ำเรียกคิววะ ในอย่างเลี้ยงปลาจะมีปริมาณกัลกิชาระบอนสูงหรือกัลกิชาระบอนโดยออกไซด์

เปลี่ยนแปลงหรือไม่ อย่างไร?

1. มีโดยกัลกิชาระบอนเพิ่มขึ้น กัลกิชาระบอนโดยออกไซด์ลดลง

2. มีกัลกิชาระบอนโดยออกไซด์เพิ่มขึ้น กัลกิชาระบอนลดลง

3. ไม่มีการเปลี่ยนแปลงของกัลกิชาระบอน

ข.

1. ปลาใช้กัลกิชาระบอนในการหายใจ และแล้วผลิตกัลกิชาระบอนโดยออกไซด์ออกมาก

2. ไม่มีการเปลี่ยนแปลงปริมาณกัลกิชาระบอนเรื่อยมา

3. ปลาเผาผลิตกัลกิชาระบอนโดยออกไซด์ โดยหายใจเข้าไป และแล้วเปลี่ยนเนื้อกัลกิชาระบอนออกมาก

4. ปลาจะอยู่ใช้กัลกิชาระบอนโดยออกไซด์

5. อย่างไร
16. ตัวอย่างที่ 1 ว่าเราควรจะทำให้เกิดเรื่องราวในสิ่งที่เกิดขึ้นได้ในเวลาที่
ไม่ผิดพลาดเหมือนเดิม แต่เรื่องราวควรจะเป็นเรื่องราวที่เกิดขึ้นโดยได้
รู้ว่าการเกิดขึ้นอย่างไร ไม่ใช่เพียงๆ เพื่อให้เรื่องราวนั้นเกิดขึ้น

นั้น เรื่องราวควรจะเป็นเรื่องราวที่เกิดขึ้นโดยได้รู้ว่าการเกิดขึ้นอย่างไร

1. สรรพสิ่ง
2. กิจกรรมภาษี
3. ผู้นำ เช่น สาขาวิชาทางธรรมวิทยา

17. เทคนิคที่ 2 ให้คิดค้นนี้

1. ซื้อไอซ์ครีม ขายอาหารเช้าและออก แต่ผู้นำ ทำให้เกิดเรื่องราวอยู่
   ได้แก่
2. ซื้อไอซ์ครีม แต่ผู้นำไม่ก่อการเกิดขึ้น ที่ในอาหารเช้าบางที่
   ขาย
3. ปรากฏว่าผู้นำมีการคิดรู้เรื่องราวโดยที่ไม่ได้ให้ผู้นำเข้าไปใน
   เรื่องราว
4. ผู้นำจะรับอาหารให้ผู้นำ ทำให้เกิดเรื่องราวอยู่
5. ต่อ ๆ ........................................

18. ในการเลือกปลูกครั้งใหม่ บริหารควรวางอย่างละเอียดไป ที่ตรงไหน

1. วันที่ต่าง ๆ มีการต่าง
2. ตลาดที่ต่าง ๆ ต่างสามารถดูแล
3. วางให้ต่าง 1 และ 2

19. เทคนิคที่ 3 ให้คิดค้นนี้

1. ช่วงช่วงที่ต่าง ๆ ต่างในอาหารปลาที่จะต้องไป
2. แสดงถึงความคาดหวังอย่างละเอียดเกี่ยวกับปลาที่จะต้องไป
3. เบื้องหลัง ซึ่งน่าจะสังเกตเหตุการณ์ แล้วให้การยอมรับจ่ายแก่ปลา
4. แสดงไม่มีความจำเป็นต้องการเกิดอาหาร และการดำรงชีวิตของปลาเลย
5. ต่อ ๆ ........................................
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Appendix D

Instrument Developed for this Study: English Translation

STUDENT QUESTIONNAIRE

PART 1
Directions: Please fill in the blank or mark X in ( ) in front of the choice you select.

1. Name ......................... Age ....... years.
   Gender ( ) 1. Female ( ) 2. Male

2. School ..............................
   District .................. Province ...........

3. Grade ( ) 4 ( ) 5 ( ) 6

4. Your last grade from Life Experience subject area is
   ( ) 1 ( ) 2 ( ) 3 ( ) 4

5. Father’s educational level
   ( ) 1. Elementary
   ( ) 2. Lower Secondary
   ( ) 3. Upper Secondary
   ( ) 4. Vocational
   ( ) 5. College

6. Father’s occupation
   ( ) 1. Government service
   ( ) 2. Farmer
   ( ) 3. Own business
   ( ) 4. Employee
   ( ) 5. Househusband
   ( ) 6. Other (......................)

7. Mother’s educational level
   ( ) 1. Elementary
   ( ) 2. Lower Secondary
   ( ) 3. Upper Secondary
   ( ) 4. Vocational
   ( ) 5. College

8. Mother’s occupation
   ( ) 1. Government service
   ( ) 2. Farmer
   ( ) 3. Own business
   ( ) 4. Employee
   ( ) 5. Housewife
   ( ) 6. Other (......................)
PART 2
Directions:

1. There are 17 items in this test. Each item is multiple-choice. You have 50 minutes to work on the test.

2. There are 2 parts for each item. You must answer both parts.

   Part a. This part is the question testing the knowledge about photosynthesis and respiration. Select the one answer that you think is the best one. Then mark an X on 1, 2, or 3 in the answer sheet Part a.

   Part b. This part is the statement that asks you to give the reason for your answer in Part a. Please select the choice that best matches your own reason. Then mark an X on 1, 2, 3, or 4 in the answer sheet Part b. If your reason is different from the given reason, please mark X on 5 and write your own reason in the space provided.

Example

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<table>
<thead>
<tr>
<th></th>
<th>1. There are 17 items in this test. Each item is multiple-choice. You have 50 minutes to work on the test.</th>
</tr>
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<tbody>
<tr>
<td>2. There are 2 parts for each item. You must answer both parts.</td>
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<tr>
<td>Part a. This part is the question testing the knowledge about photosynthesis and respiration. Select the one answer that you think is the best one. Then mark an X on 1, 2, or 3 in the answer sheet Part a.</td>
<td></td>
</tr>
<tr>
<td>Part b. This part is the statement that asks you to give the reason for your answer in Part a. Please select the choice that best matches your own reason. Then mark an X on 1, 2, 3, or 4 in the answer sheet Part b. If your reason is different from the given reason, please mark X on 5 and write your own reason in the space provided.</td>
<td></td>
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<tr>
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<tr>
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<tr>
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<td>1</td>
</tr>
</tbody>
</table>
1. a. Which of the following living things can photosynthesize or make their own food?
   1. Sunflower
   2. Human, bird, and rat
   3. Sunflower, human, bird, and rat

   b. You selected this answer because
   1. Sunflower has chlorophyll used in photosynthesis, but human, bird, and rat do not have chlorophyll.
   2. Sunflower, human, bird, and rat need food to eat.
   3. Human, bird, and rat can move so they do not have to photosynthesize.
   4. Human, bird, and rat use light to make vitamin D, and sunflower uses light in photosynthesis.
   5. Other reason

2. a. Could a toad which has green skin and a parrot which has green feathers photosynthesize?
   1. Only the toad could photosynthesize.
   2. Both could photosynthesize.
   3. Both could not photosynthesize.

   b. You selected this answer because
   1. Both toad and parrot have a green color which come from chlorophyll.
   2. The toad has chlorophyll and photosynthesizes when it gets both water and light.
   3. Even though having chlorophyll, the toad has the thick skin and the parrot has the thick feather so light cannot get through.
   4. The green color of the toad and the parrot is not chlorophyll so they cannot photosynthesize.
   5. Other reason

3. a. Can we find green plants in the deep sea where light cannot get through?
   1. Yes.
   2. No.

   b. You selected this answer because
   1. We can find green plants everywhere in the world.
   2. We find living things in the deep sea, this means that green plants are also there.
   3. Light is one factor that makes green color in green plants, if there is no light we cannot find green plants.
   4. There are no living things, including green plants in the deep sea.
   5. Other reason
4. a. Nisa left a pot of Pug Boong\(^1\) in a dark box and she found that all the plants died not long after that. So she put plants in the dark again but added fertilizer and water.

Will plants die if she leaves them in the dark box for along time?
1. Yes.
2. No.

b. You selected this answer because
1. Fertilizer and water are plants' food and are sufficient for living.
2. Pug Boong must have food from photosynthesis; since there is no light this plant does not have food and dies.
3. Even though left in the dark box, it can photosynthesize in the day time.
4. There is no carbon dioxide in the dark box so it cannot photosynthesize.
5. Other reason

5. a. Do you think the leaves of the plant in question 4 are still green?
1. Yes.
2. No.

b. You selected this answer because
1. Water gradually fades the green color until there is no green color.
2. Light is one factor that makes the green color in green plants, the leaves will not be green since there is no light.
3. Chlorophyll makes plants green whether there is light or not.
4. Air (gas) makes plants green, and there is no air in the dark box so the green color changes.
5. Other reason

---

\(^1\)Thai plant similar to watercress; has many stems.
Answer questions 6 to 8 by using the picture below.

6. a. In which areas does photosynthesis occur?
   1. Area 2.
   2. Areas 1 and 2.
   3. Area 2 and 3.

   b. You selected this answer because
   1. Areas 1 and 2 are areas on a leaf.
   2. There is chlorophyll in both areas 2 and 3, but photosynthesis does not occur on area 3 since it is not the leaf.
   3. Only the green color at area 2 is from chlorophyll.
   4. Areas 2 and 3 have chlorophyll so photosynthesis can occur.
   5. Other reason__________________________

7. a. After photosynthesis occurs, which substance can we test for?
   1. Starch.
   2. Chlorophyll.
   3. Carbon dioxide.

   b. You selected this answer because
   1. After photosynthesis occurs, food is changed to starch.
   2. The leaf needs carbon dioxide in photosynthesis, so we can test for this gas.
   3. Chlorophyll is the product of photosynthesis.
   4. Starch is the product of photosynthesis, which we can see in the white area.
   5. Other reason__________________________
8. a. In which areas does respiration occur?
   1. Areas 1 and 2.
   2. Areas 2 and 3.
   3. Area 1, 2, and 3.

  b. You selected this answer because
     1. They are the areas of the leaf.
     2. There is chlorophyll helping in respiration.
     3. Every area must respire since the plant needs energy for living.
     4. Every area is flat and thin so gases get into or out easily.
     5. Other reason

9. a. Which of the following is not an essential factor for photosynthesis?
   1. Water.
   2. Oxygen.
   3. Light.

  b. You selected this answer because
     1. Light is not necessary since there is chlorophyll which is sufficient.
     2. The essential factors must be gases so they can get into the leaf, but water is a liquid not a gas.
     3. Oxygen is the product of photosynthesis so it is not the essential factor.
     4. Water supports only the stem and branches not the leaf.
     5. Other reason

10. a. When do plants respire?
    1. During the day time.
    2. At night.
    3. Both day and night.

   b. You selected this answer because
      1. Plants photosynthesize during the day time so they stop respiration, but plants do not photosynthesize at night so they respire.
      2. Plants use chlorophyll in photosynthesis and respiration at the same time.
      3. Plants take in carbon dioxide during day time, and take in oxygen at night time.
      4. Plants need energy to live so they must respire both day and night.
      5. Other reason
11. a. During daytime, which of the following respire?
   1. Grass and rose tree.
   2. Human, monkey, and toad.
   3. Human, monkey, toad, grass, and rose tree.

b. You selected this answer because
   1. Human, monkey, and toad are animals; they do not have to photosynthesize, so they respire.
   2. Grass and rose tree need energy while photosynthesizing, so they respire.
   3. Human, monkey, and toad respire by taking in oxygen, and grass and rose tree respire by taking in carbon dioxide.
   4. Human, monkey, toad, grass, and rose tree need energy for living.
   5. Other reason

12. a. At night, when there is no light, which of the following respire?
   1. Grass and rose tree.
   2. Human, monkey, and toad.
   3. Human, monkey, toad, grass, and rose tree.

b. You selected this answer because
   1. At night, plants do not photosynthesize, so they respire to get energy.
   2. Human, monkey, and toad need energy all the time so they also respire at night.
   3. Human, monkey, and toad have lungs and hearts.
   4. Human, monkey, toad, grass, and rose tree need energy for living, so they must respire all the time including at night.
   5. Other reason
13. a. Jira leaves a pot of Pug Boong in a dark box one night and takes it out to water in the morning. Then she divides the plants, which are in a pot, into two groups and covers each group with a plastic bag. In the first plastic bag there is carbon dioxide. There is no carbon dioxide in the second one, since she put in a substance that can absorb this gas.

![Diagram of two bags with plants: Bag 1 has carbon dioxide, Bag 2 has a substance that absorbs carbon dioxide.]

In which bag does photosynthesis occur?
1. Bag 1.
2. Bag 2.
3. Both bags 1 and 2.

b. You selected this answer because
1. There is oxygen, which is necessary for photosynthesis.
2. There is carbon dioxide, which is necessary for photosynthesis.
3. Plants in both bags get only light, which is enough for photosynthesis.
4. Plants in both bags have chlorophyll and get light, which is enough for photosynthesis.
5. Other reason

14. a. During the daytime, do plants outside in the sun give off carbon dioxide or oxygen, or neither one?
1. Give off only oxygen.
2. Give off both oxygen and carbon dioxide.
3. Give off neither oxygen nor carbon dioxide.

b. You selected this answer because
1. Plants only have photosynthesis, so only oxygen is given off.
2. Plants give off oxygen and carbon dioxide from photosynthesis.
3. Plants use all the carbon dioxide and oxygen in photosynthesis and respiration.
4. Plants give off carbon dioxide from respiration, and oxygen from photosynthesis.
5. Other reason
Answer questions 15 to 17 using the following situation.

Preecha heard that we could feed some fish in a jar covered tightly with a lid, without adding any food or changing the water. He set up the experiment as pictured below.

15. a. Do you think the quantity of oxygen and carbon dioxide change?
   1. Yes, there will be more oxygen but less carbon dioxide.
   2. Yes, there will be more carbon dioxide but less oxygen.
   3. No, there will not be any change.

b. You selected this answer because
   1. A fish uses oxygen in respiration and gives off carbon dioxide.
   2. There is no air getting in or out of the jar.
   3. A fish decreases the amount of carbon dioxide by taking it in and changing it to oxygen and giving it off.
   4. A fish will not move; it does not need any energy, so it does not respire.
   5. Other reason

16. a. Later, the fish is dead. Preecha is sad but he would like to experiment again. He thinks that he should improve the experiment by adding something to help the fish stay alive for a long time.

Which of the following should he add?
   1. Food.
   2. Oxygen.
   3. Green water plants such as Hydrilla.

b. You selected this answer because
   1. Even though jar lacks air, food will help a fish stay alive for a long time.
   2. Oxygen for respiration is enough for a fish to be alive for a long time.
   3. A fish will give off carbon dioxide for plants to photosynthesize, and plants will give off oxygen for the fish to respire.
   4. Plants will make food for the fish.
   5. Other reason
17. a. Where should Preecha put his jar?
   1. By the window where there is light.
   2. In the middle of a room which has the door and window closed all the time.
   3. Either 1 or 2.

b. You selected this answer because
   1. Light will kill germs in the food that he adds.
   2. Light will take air through the jar.
   3. Green plants need light for photosynthesis and give off oxygen for the fish to respire.
   4. Light is not necessary for the fish to live.
   5. Other reason