Journal of Elementary Science Education, Vol. 18, No. 1 (Spring 2006), pp. 1-14.

Relationships Among Measures of Learning Orientation, Reasoning Ability, and Conceptual Understanding of Photosynthesis and Respiration in Plants for Grade 8 Males and Females

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This study investigated the contributions of students' reasoning ability and meaningful learning orientation to their understanding of the photosynthesis and respiration in plants concepts. Data were gathered through the use of the Test of Logical Thinking (Tobin & Capie, 1981), the Learning Approach Questionnaire (Cavallo, 1996), and the Two-Tier Diagnostic Test (Haslam & Treagust, 1987). These instruments were administered to 117 8th-grade students to determine their reasoning ability, learning orientations, and conceptual understanding. Correlational and regression analyses revealed that both reasoning ability and meaningful learning orientation were related to students' understanding of photosynthesis and respiration in plants concepts. Reasoning ability explained more of the variance in the test scores as compared to meaningful learning orientation. Moreover, it was found that although reasoning ability was associated with both male and female students' conceptual understanding, meaningful learning orientation was associated only with female students' conceptual understanding. Findings of this study highlighted the importance of reasoning ability as well as meaningful learning orientation in students' understanding of photosynthesis and respiration in plants.

Introduction

Studies within educational psychology have revealed that learning arises from a continual integration of cognitive and affective factors (e.g., Alexander & Jetton, 1996; Pintrich, Marx, & Boyle, 1993). Recently, learning in an academic domain has been conceptualized as a multidimensional process involving cognitive and affective variables such as knowledge, strategic processing, and interest. Among the characteristics of these emerging conceptions of learning are hypothesized relationships between certain cognitive and motivational variables that vary as the student progresses from a state of acclimation (or novice) to competence and, possibly, to proficiency (or expertise). One such conceptualization is the Model of Domain Learning (MDL) (Alexander, 2003). This model depicts learning in terms of changes within and between the cognitive and motivational components of this lifelong process (Alexander & Jetton, 1996; Alexander & Murphy, 1997). In this model, a facet of motivation (interest) is combined with other aspects of learning (knowledge and strategy use) to explain differences in learning. The MDL defines changes in the state of learning in terms of corresponding developments in student interest. Alexander (2003) distinguishes between situational interest, which is related to specific circumstances and therefore transitory, such as the desire to get good grades, and individual (personal) interest, which is longer lasting since the student is intrinsically interested in the domain and forms a personal association with it (Alexander & Jetton, 1996). Alexander and Jetton indicate that situational interest had a strong, positive relationship to comprehension, which is due to the close relationship between personal interest and prior knowledge. Earlier research suggests that prior knowledge is more closely related to individual rather than situational interest, although it is significantly related to both (see Schraw & Lehman, 2001). Moreover, the MDL differentiates between two forms of subject-matter knowledge: (1) domain and (2) topic. While domain knowledge represents how much one knows about a field, topic knowledge represents how much one knows about specific domain topics. The MDL is a domain specific model of learning, which allows us to build predictions about cognitive (knowledge and strategic processing) changes (Alexander & Jetton, 1996). Alexander and Jetton claim that when students' knowledge base regarding the given topic or the domain is strong, students seem better able to distinguish the structurally important information. Furthermore, they are less influenced by the highly interesting but unimportant details. Besides, students with a high subject-matter knowledge level are less in need of situationally interesting or personally involving content (Alexander & Jetton, 1996; Schraw, Flowerday, & Lehman, 2001; Schraw, & Lehman, 2001). Specifically, students with limited knowledge and interest make use of more surface-level strategies in their processing of domain knowledge as compared to the deeper processing strategies employed by the more knowledgeable and more interested students (Jetton & Alexander, 2001).

The MDL focuses on three components: (1) acclimation, (2) competency, and (3) proficiency (Alexander, 2003). Alexander uses the model to describe changes in knowledge, strategic processing, and interest that occur simultaneously as someone progresses from acclimation to competence to proficiency/expertise. Acclimation is the initial stage in domain expertise. Acclimated students are at-risk students. These students generally have limited and fragmented knowledge. They may have little interest in the domain and have difficulty in deciding on appropriate learning strategies. They may have remembered information as isolated facts rather than in an integrated way. Moreover, they rely on general strategies but may not use them effectively due to their lack of a knowledge base. Competent individuals, on the other hand, demonstrate a foundational body of domain knowledge, which is more organized and principled in structure; whereas proficient students have high levels of interconnected knowledge. They are highly efficient strategy users and have permanent interests and personal investments in the domain. They repeatedly use self-questioning strategies to probe their conceptions, reflect on their performance, and consider how their knowledge may be of use in future situations. The final dimension of Alexander's model is strategic processing of knowledge; this includes the procedural knowledge that students apply to maximize learning or performance, comprising general cognitive and metacognitive processes.

According to Alexander (2003), MDL has several implications. First, educators should not expect that students will leave the K-12 system as experts in any academic domain; however, they should expect to see marked changes in students' knowledge, strategic processing, and interest throughout the educational experience. Second, traditional approaches to expertise and the MDL converge in their recognition that the progress towards competence or proficiency requires strategic tools for analyzing and responding to the problems encountered. Finally, not only knowledge and strategies but also individuals' investment in their learning and development are equally critical to expertise. Schools can do much to foster competency by allowing students to follow topics of interest and by immersing them in meaningful learning experiences.

The present study is designed on a model of learning that considers specific attributes of students' reasoning abilities, approaches to learning, conceptual understanding, gender, nature of content, and the teaching approach. This study aims to contribute to the growing body of literature on elementary students' learning by investigating the variables of learning—specifically, reasoning abilities, approaches to learning, conceptual understanding, and gender.

Background

Although attaining meaningful understanding of a scientific concept is one of the important goals of science education, the presence of topics at a grade level in textbooks or curriculum guides is not reliable evidence that it can be learned meaningfully at that grade (AAAS, 1993). It is emphasized that while overestimation of what students can learn at a particular grade results in lack of confidence, frustration, and unproductive learning strategies, like memorization without understanding, underestimating what students can learn causes overconfidence, boredom, and poor study habits. Therefore, it is proposed that it is crucial to decide what to expect of students and when on the basis of as much good information as possible.

Research on learning consistently points out that the students' limited understanding of science concepts is often masked by their ability to learn by rote. For meaningful learning to occur, researchers (e.g., Novak, 2002; Pintrich et al., 1993) have suggested the necessity of at least three conditions: (1) the classroom instructional context must encourage meaningful learning and conceptual change; (2) students must have the appropriate motivational attitudes and behaviors; and (3) students must have the appropriate prior knowledge and cognitive skills and strategies. When any one of these conditions is lacking, meaningful learning does not take place, and only rote learning may occur. In rote learning, students do not construct relationships between concepts nor do they integrate new concepts to their prior knowledge to form coherent frameworks. Instead, they rely on memorizing or compartmentalizing facts and ideas (Novak, 2002). Meaningful students, on the other hand, have a deep approach to learning. They tend to use evidence, build a holistic description of content, reorganize new content by relating it to prior knowledge and to personal experiences, and maintain a critical and more objective view. Rote students tend to employ a surface approach to learning. They have a tendency to memorize facts and are motivated extrinsically by fear of failure rather than the need to learn and understand (Woods, Hrymak, & Wright, 2001). Researchers agreed that students who frequently employ rote learning tend to generate misconceptions concerning scientific concepts (BouJaoude, 1992; Williams & Cavallo, 1995).

Studies on the developmental view have claimed that concept acquisition is also dependent on students' reasoning ability. The ability to reason has been found to be the strongest predictor of meaningful understanding in science (Lawson &

Renner, 1975; Lawson, Alkhoury, Benford, Clark, & Falconer, 2000). In accordance with the Piagetian model, formal thought begins to develop at the age of 11 or 12 and reaches an equilibrium state at around 15 or 16. The model asserts that concrete reasoners are unable to develop sound understanding of abstract concepts. While concrete-operational students are able to understand only concrete concepts; formal-operational students are able to understand both concrete and formal concepts. Concrete and formal operational concepts as defined by Lawson and Renner (1975) are as follows:

> *[C]oncrete operational concepts are concepts whose meaning can be developed from first-hand experience with objects or events. These concepts may arise through direct experiences in which the entire meaning of concept is given through the senses. . . . Formal operational concepts are concepts whose meaning [is] derived through position within a postulatory-deductive system. . . . Meaning is given to these concepts not through senses but through imagination or through their logical relationships within the system. To fully comprehend the meaning of a formal concept it is hypothesized that one must be able to operate formally or logically in a hypothetico-deductive manner. (p. 348)*

In one of their earlier studies, Lawson and Renner (1975) assessed understanding of concrete and formal operational concepts by concrete and formal students in three secondary-level science—biology, physics, and chemistry—classes. Individuals and the major concepts taught during the year were categorized as concrete or formal. Lawson and Renner indicated that the majority of students in their sample were below the levels of intellectual development, and major concepts taught during the year were isolated and categorized as formal. They recommended that a substantial portion of secondary-level science subject mater may not be suitable in terms of the intellectual level of the students. Their biology sample revealed that about 65% of the students were still at the concrete level and were found to be unable to develop an appreciable understanding of abstract concepts. In a separate study, Lawson and Thompson (1988) test the hypothesis that formal reasoning ability is necessary for 7th-grade students to overcome misconceptions and develop valid biological concepts in regards to genetics and natural selection. Since formal reasoning patterns are used to evaluate misconceptions in a logical hypothetico-deductive manner, the authors predicted that concrete-operational students who did not utilize these patterns effectively failed to eliminate their misconceptions. They provided support for their hypothesis that formal reasoning ability is necessary for overcoming some biological misconceptions. They pointed out that formal-operational students who possessed the formal reasoning necessary for evaluating competing hypotheses by comparing the predicted outcomes can overcome biological misconceptions which interfere with further meaningful learning. On the other hand, concrete-operational students continue to use their misconceptions to make predictions, failing to recognize the limitations of these misconceptions or to appreciate the merits of the scientific conception. Johnson and Lawson (1998) conducted a research study to investigate the relative effects of reasoning ability and prior knowledge on biology achievement in expository and inquiry classes. They predicted that reasoning ability should be a significant predictor of achievement in inquiry classes and that prior knowledge should be a significant predictor of achievement in expository classes. Since expository classes focus on facts and concepts, the best predictor of achievement in expository classes is domain-specific prior knowledge. Although results of their study revealed that reasoning ability was a significant predictor of achievement in inquiry classes, prior knowledge did not predict achievement in either instructional mode.

In addition to reasoning ability, another factor that affects learning might be the students' approaches to learning (i.e., meaningful, rote). How students approach learning has been the focus of several studies (BouJaoude, 1992; Cavallo & Schafer, 1994; Cavallo, Potter, & Rozman, 2004; Cavallo, Rozman, Blickenstaff, & Walker, 2003). Students' decisions to use memorization as a mode of learning has been called a surface or rote learning orientation. On the other hand, when students choose to deal with a learning task by forming relationships between newly learned concepts and previously learned concepts, this learning orientation is called deep or meaningful (Cavallo & Schafer, 1994). Cavallo (1996) reported that students tend to employ either rote or meaningful approaches in learning science concepts. Studies focus on the possible gender differences that cause mixed results in the use of these approaches. For example, Ridley and Novak (cited in Cavallo, 1994) claimed that rote learning occurs more frequently among females. The prevalence of use of rote learning by females might be attributed to the socialization factor. It is thought that "females may be socialized to 'do as they are told' and to not question authority. Conversely, it is generally acceptable for males to diverge from an authoritative way of thinking" (p. 348). In her 1994 study, Cavallo investigated the learning approaches of males and females and their subsequent understanding of and achievement in biology. Teachers were also asked in this study to classify their students as meaningful or rote. The teachers rated the females as being more rote in their orientation than the males. This means that while they viewed female students as more likely to memorize or learn by rote, they viewed males as more likely to learn meaningfully or make sense of information when learning biology. Results of the students' responses showed no significant differences between the males' and females' learning orientation, however. This study revealed that females may not learn biological topics by rote or meaningful learning any more than males do. BouJaoude (1992) reported that students who learned by rote had less understanding and more misconceptions than meaningful students concerning chemistry concepts. Cavallo and Schafer (1994) indicated that students with a meaningful learning approach accomplished more meaningful understanding of genetics concepts than those with a rote learning approach. In another study, Cavallo (1996) reported that meaningful learning orientation best predicted students' understanding of genetic interrelationships, whereas reasoning ability best predicted students' achievement in solving genetics problems. The study conducted by BouJaoude and Giuliano (1994) demonstrated that prior knowledge, logical thinking ability, and meaningful learning orientation accounted for 32% of the variance on chemistry achievement. Another study indicated that formal reasoning ability and not meaningful learning predicted students' understanding of physics concepts (Williams & Cavallo, 1995). Recent research reported that both learning orientation and formal-operational reasoning contributed significantly to understanding conceptual chemistry problems (BouJaoude, Salloum, & Khalick, 2004).

The present study investigated the relationship between meaningful learning orientation, reasoning ability, and students' conceptual understanding of photosynthesis and respiration in plants. These topics were chosen due to their curricular significance. They are complex biological topics and have a number of conceptual aspects, namely ecological, biochemical, anatomical-physiological, and energy change, which make them integrated concepts. Therefore, understanding concepts of photosynthesis and respiration in plants require the ability to relate meaningfully to different concepts in biology, chemistry, and physics; however, studies showed that these topics are often learned by rote. Students often tend to learn photosynthesis and respiration in plants as separate, isolated topics and may not formulate conceptions of how the topics are related. In addition, photosynthesis and respiration in plants, though taught repeatedly at all levels of education, were perceived by teachers and students to be problematic concepts (Finley, Stewart, & Yarroch, 1982; Johnstone & Mahmoud, 1980) and were identified as being on an abstract level in science curricula, requiring formal reasoning (Lawson & Renner, 1975).

Purpose of the Study

In line with these findings, the present study explored the relationship between learning orientation, reasoning ability, and students' conceptual understanding of photosynthesis and respiration in plants.

The specific questions to be addressed in this study are as follows:

1. Is there a relationship among learning orientations, reasoning ability, and students' understanding of photosynthesis and respiration in plants concepts?
2. What is the contribution of reasoning ability and meaningful and rote learning orientations on students' understanding of photosynthesis and respiration in plants concepts?
3. What are the relative predictive influences of meaningful and rote learning orientations and reasoning abilities on male and female students' understanding of photosynthesis and respiration in plants concepts?

Method

This is a case study of intact classes of 8th-grade students who were studying plants. A total of 117 students (59 females and 58 males; mean age = 13.5 years) 8th-grade participated in the study. Intact classes were used because it would have been too disruptive to the curriculum and too time consuming to take students out of their classes for instrument administration. The socioeconomic status of the students were similar, with the majority of them coming from middle class families. All classes were taught by the same science teacher. All students were exposed to the same content for the same duration. Duration of lessons was four 40-minute periods. In the regular classroom instruction, the teacher taught concepts through lecture and discussion. The students were required to read the related topic of the lesson from the textbook utilized in the course before class. The teacher made frequent use of the chalkboard to illustrate the various concepts of photosynthesis and respiration in plants. The main concepts at issue are the process of photosynthesis and respiration in terms of input and outputs. The focus during the instruction is on naming the reactants and products of photosynthesis and respiration. Little emphasis was given to the idea of energy transformation. After an explanation was given, concepts were discussed through teacher-directed questions. The majority of instruction time (70 to 80%) was devoted to instruction and engaging in discussions stemming from the teacher explanation and questions. The remaining time was taken up with the worksheet study. In short, teaching strategies relied on teacher explanation, textbooks, and worksheet study.

Data Collection

Three kinds of data were collected from students: (1) responses to the Two-Tier Diagnostic Test, (2) responses to the Learning Approach Questionnaire, and (3) responses to the Test of Logical Thinking. All instruments were administered to the participants at the end of the related unit. The students responded to the instruments during the regular science class hours under the supervision of their science teacher.

The Two-Tier Diagnostic Test

Students' conceptual understanding of photosynthesis and respiration in plants was measured using a 13-item, two-tier, multiple-choice test, designed to get at higher-level conceptual learning rather than the recall that is normally associated with objective tests (Haslam & Treagust, 1987). The first tier of each item relates to content based on propositional knowledge statements. The second tier includes reasons based on students' responses to interviews, open-ended questions, and previous research studies. These reasons included identified misconceptions and one scientifically acceptable answer. The internal consistency reliability (Cronbach's alpha) of the test was .72 when both parts of the items were analyzed. Authors reported that difficulty indices of the test ranged from .12 to .78, with a mean of .38, providing a wide range of difficulty in the items. Discrimination indices were also found to be acceptable, ranging from .36 to .60, with a mean of .48. The reading age of the instrument, however, was the 7th- to 8th-grade level and was considered to be appropriate for any high school student from 8th to 12th grade (p. 204).

For this study, content validity of each item in the test was determined by a group of experts in biology, biology education, measurement, and evaluation. The classroom teacher also analyzed the relatedness of the test items to the instructional objectives. The reliability coefficient computed by Cronbach alpha estimates of internal consistency was found to be .76 when both parts of the items were analyzed. Students need to have both the content choice and the reasons (combination) correct to be awarded a 1.

Learning Approach Questionnaire (LAQ)

The LAQ is a 22-item, 4-point Likert instrument, which measures students' approaches to learning as meaningful or rote (Cavallo, 1996; Cavallo et al., 2003). The LAQ scale consists of two subscales: (1) Learning Approach Questionnaire-Meaningful (LAQ-M), which measures the degree of meaningful learning orientation and (2) the Learning Approach Questionnaire-Rote (LAQ-R), which measures the degree of rote learning. The LAQ-M and the LAQ-R consist of 11 items each. On the meaningful scale, a high score indicates students have a high meaningful learning approach; on the rote scale, a high score indicates students have a high rote learning approach. Students responded to each statement by indicating their agreement, ranging from A (always true) to D (never true). The Cronbach alpha reliability was reported as $r = .81$ for the meaningful scale and $r = .76$ for the rote scale (Cavallo et al., 2003). For this study, the Cronbach alpha internal consistency is $r = .78$ for the meaningful scale and $r = .62$ for the rote scale.

Test of Logical Thinking Ability (TOLT)

In this study, the TOLT was used to determine the formal reasoning ability of students (Tobin & Capie, 1981). The TOLT consists of 10 items designed to measure controlling variables and proportional, probabilistic, correlational, and combinational reasoning. Each item requires the correct response and justifications for the response. The authors reported the coefficient alpha for the TOLT as .85. They also reported that the internal consistency estimate of each two-item subset ranged from .56 to .82. Item difficulties ranged from .18 to .41, with an average of .30. Item discrimination indices ranged from .39 to .71, with an average of .55. For this study, reliability of the TOLT was found to be .81.

Results

Descriptive statistics for the learning orientation, reasoning ability, and conceptual understanding with respect to total sample as well as gender is summarized in Table 1. Table 1 shows that participants of this study have a higher mean score on the meaningful learning approaches scale (*M* = 33.4) than on the rote learning approaches scale (*M* = 26.1). Higher mean scores on the meaningful learning orientation scale as compared to rote scale indicates that participants of this study generally use meaningful learning approaches more than rote learning approaches. Participants' scores on the LAQ-M and LAQ-R indicate a wide range of approaches to learning. A possible range of both scales was 11 to 44. Actual ranges were 18 to 44 for LAQ-M and 17 to 37 for LAQ-R scales. While participants' LAQ-M scores offer low to high meaningful approaches to learning, scores on LAQ-R present low to moderate rote approaches to learning. The maximum score on LAQ-M was equal to the highest possible score; whereas the maximum LAQ-R scores were lower than the highest possible score. In regards to other variables of the study, overall mean scores for the TOLT (*M* = 2.8) and the Two-Tier Test (*M* = 6.2) show that study participants have a relatively low reasoning ability and inadequate understanding of concepts of photosynthesis and respiration in plants, respectively. When the mean scores are examined with respect to gender, it appears that there is a slight difference between female and male students regarding learning orientations and conceptual understanding in favor of females. On the contrary, students' scores on the TOLT reveal a slight difference between male and female students with respect to reasoning ability in favor of male students.

Table 1. Descriptive Statistics for the Combined Group, Females and Males

	N	LAQ-M		LAQ-R		TOLT		Understanding	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Female	59	34.48	3.9	26.31	5.1	2.39	2.2	6.58	2.9
Male	58	32.35	5.5	25.88	3.9	3.26	2.7	5.78	2.9
Total	117	33.43	4.9	26.10	4.5	2.82	2.5	6.18	2.9

Tables 2, 3, and 4 present Pearson correlation analysis, multiple regression analysis, and a stepwise multiple regression analysis for total sample and for female and male students, respectively. The Pearson correlation analysis was computed to see the relationship that might exist among students' learning orientations, reasoning ability, and understanding (Table 2). Analysis reveals that participants' meaningful learning orientations and reasoning abilities correlated significantly with conceptual understanding ($r = .32$, $p = .001$; $r = .57$, $p = .000$, respectively). The positive correlations showed that the higher the students' reasoning ability, the greater the students' conceptual understanding and, similarly, the greater the students' meaningful learning orientation, the greater the conceptual understanding. Moreover, no statistically significant correlation between meaningful learning orientation and reasoning ability was found ($p > .05$). These data led to the conclusion that reasoning ability was not related to meaningful learning. Students who had a more meaningful learning approach did not necessarily have high reasoning ability. Similarly, rote learning orientation correlated with neither reasoning ability nor conceptual understanding ($p > .05$). Finding no statistically significant correlation between the rote learning approach and conceptual understanding means that learning by rote did not support the students' conceptual understanding in this topic.

Table 2. Correlation Coefficient Among Variables

	LAQ-M	LAQ-R	TOLT
LAQ-M	-		
LAQ-R	-0.036	-	-
TOLT	0.168	-0.156	-
Understanding	0.321*	-0.106	0.566*

*Correlation is significant at the 0.01 level.

The correlation of -.036 ($p > .05$) between meaningful learning approaches and rote learning approaches indicates that participants' use of meaningful learning approaches was not related to their use of rote learning approaches. The results show that meaningful and rote learning are unrelated approaches to learning. Students who use meaningful learning strategies may or may not necessarily use rote learning strategies (or vice versa). Although the negative correlation between meaningful and rote learning was expected, the low value indicated a sizeable group of students without differentiated orientations (being either strongly oriented toward meaningful or rote approaches).

Multiple Regression Correlation (MRC) Analysis was used to explore the contribution of students' reasoning ability and meaningful learning orientation to their understanding of the photosynthesis and respiration in plants (Table 3). The multiple correlation (R) was .615, with $R^2 = .36$. The results showed that the model significantly accounted for 36% of the variation in students' understanding of the photosynthesis and respiration in plants ($F = 21.089$, $p < .05$). Reasoning ability and meaningful learning orientation each made a statistically significant contribution to the variation in students' understanding of photosynthesis and respiration in plants. A stepwise multiple regression analysis was applied to the data to determine which variables were the best predictors of concept understanding. Results revealed that reasoning ability was the main predictor of concept understanding, explaining 31% of variance, while meaningful orientation accounted for the remaining 5%. Although significant, the portion of the variance explained by meaningful learning orientation was relatively low.

Table 3. Independent Contribution of Meaningful Learning Approaches to Understanding of Photosynthesis and Respiration in Plants

Independent Variables	B	β	t	P
Constant	1.312		0.628	0.531
LAQ-M	0.135	0.231	2.939	0.004
LAQ-R	-5.089	-0.077	-0.987	0.326
TOLT	0.589	0.516	5.528	0.000

Another stepwise multiple regression analysis was conducted to determine the relative predictive influence of the reasoning ability and meaningful learning orientation on female and male students' understanding of photosynthesis and respiration in plants (Table 4). The results showed that the model significantly accounted for 46% and 32% of the variation in male and female students' conceptual understanding, respectively. For female students, reasoning ability was found to be the main predictor of conceptual understanding, explaining 25% of variance, while meaningful orientation accounted for the remaining 17% ($F = 19.136$, $p < .05$; $F = 13.581$, $p < .05$, respectively). For male students, reasoning ability was a unique predictor of conceptual understanding, accounting for 46% of variance ($F = 46.166$, $p < .05$). No statistically significant contribution of meaningful learning orientation to male students' conceptual understanding was found ($p > .05$). The use of meaningful learning may not have been useful for male students.

Table 4. Stepwise Multiple Regression Analyses for Female and Male Students on Conceptual Understanding

Predictor	B	β	t	P
Female				
TOLT	0.538	0.423	3.539	0.001
LAQ-M	0.214	0.296	2.477	0.017
Male				
TOLT	0.726	0.686	6.795	0.000

Discussion

The principle conclusion to be drawn from the findings of the study is that although both reasoning ability and meaningful learning orientation have positive effects on students' understanding of concepts of photosynthesis and respiration in plants, reasoning ability explains more of the variance in students' conceptual understanding as compared to meaningful learning orientation. Although participants of this study have a meaningful learning orientation rather than a rote learning orientation, a relatively low mean score of 2.8 on a 0 to 10 scale indicates that a large portion of students in this study have not developed formal thought yet. Similarly, of a possible 13 correct responses on the Two-Tier Test, a relatively low mean score of 6.2 was attained by the participants. This means that the participants responded correctly to nearly half of the questions, indicating a low level of conceptual understanding in photosynthesis and respiration in plants.

Findings of this study are consistent with those of BouJaude et al. (2004) and Williams and Cavallo (1995) who found that reasoning ability was the best predictor of conceptual understanding followed by meaningful learning orientation. BouJaude et al. (2004) asserted that reasoning ability was the main predictor of performance on conceptual chemistry problems, accounting for 18% of variance, while learning orientation accounted for the remaining. Similarly, Williams and Cavallo (1995) reported that both reasoning ability and meaningful learning were positively correlated to physics understanding. The authors mentioned that reasoning ability was the significant predictor of physics understanding and explained 37.3% of variance. Findings of the present study were not in line with results obtained by Cavallo (1996), however, who reported that meaningful learning orientation explained more of the variance in the test genetic meaning (13%) as compared to reasoning ability (3%). In the present study, stepwise multiple regression analysis revealed that reasoning ability was the main predictor of concept understanding, explaining 31% of variance, while meaningful orientation accounted for the remaining 5%. The finding of no statistically significant correlation between reasoning ability and meaningful learning orientation was in line with the previous research studies, implying that these are unique variables of learning (Cavallo, 1996; Cavallo et al., 2003; Cavallo, Potter, & Rozman, 2004).

When stepwise multiple regression analysis is computed for female and male students separately, a different pattern emerged. Meaningful learning orientation is significantly related to the conceptual understanding for females but not for males, and reasoning ability is significantly related to the conceptual understanding for both sexes. For both females and males, higher reasoning ability was a significant predictor of conceptual understanding of photosynthesis and respiration in plants. Among females, the tendency to form relationships between newly learned concepts and previously learned concepts was important for conceptual understanding. Therefore, meaningful learning orientation appeared to be necessary for female students' conceptual understanding of concepts of photosynthesis and respiration in plants. These results show that different variables of learning may be important for female and male students' understanding of photosynthesis and respiration in plants.

The topics of photosynthesis and respiration in plants is a basic concept in life science and is common to the *Benchmarks for Science Literacy* (AAAS, 1993). Literature, however, indicates that many students have difficulties learning these concepts. The reasons for these difficulties might be attributed to the presence of formal concepts in science. Researchers indicated that students' ability to cope with formal concepts, such as photosynthesis and respiration in plants, in a meaningful manner is correlated with their level of intellectual development (Lawson & Renner, 1975; Lawson et al., 2000). Williams and Cavallo (1995) claimed that when concrete operational individuals try to learn formal concepts, a mismatch occurs between the students' reasoning ability and what they need to comprehend the concept. Therefore, matching the concept to the reasoning ability of the students may be the vital step to enhancing greater reasoning and understanding. More recently, Stern and Roseman (2004) pointed out that currently available curriculum materials provide little support for the attainment of the key ideas of energy transformation, more specifically, photosynthesis and respiration in plants. Generally, these materials did not take students' prior knowledge into consideration and were lacking in their presentation of abstract ideas. They reported that the topics of photosynthesis and respiration in plants are distributed over 6th through 8th grades. As a result, key ideas are treated in different chapters, such as cells, organisms, and the ecosystem, making it difficult for students to see the connections among the ideas. Moreover, authors mention that these concepts may seem too ambitious for the concrete operational reasoner and, thus, might not be developmentally appropriate for elementary school students. Stavy, Eisen, and Yaakobi (1987) pointed out two possibilities regarding the teaching of these concepts in elementary school: (1) either give up the teaching of these subjects at this level or (2) change the way of teaching it. As they suggested, due to the importance of understanding photosynthesis and respiration in plants for a basic understanding of how the world functions, we cannot give up teaching it at this level; therefore, finding better ways of teaching it would be more appropriate.

The present findings have some instructional implications for elementary science teachers. First, the findings highlight the importance of reasoning ability as a main predictor of conceptual understanding; teachers should provide a rich learning environment for the students to deal with individual differences. For example, multiple representations such as models, simulations, diagrams, or analogies may help make abstract concepts understandable to students (Posner, Strike, Hewson, & Gertzog, 1982). Also, to promote formal operations, teachers should pose problems to students and present them with questions and conflicting situations, encouraging them to analyze their own thinking either individually or in groups (Mwamwenda, 1993). Moreover, teachers can promote the development of their students' reasoning abilities by the integration of inquiry-oriented teaching strategies such as the learning cycle (Johnson & Lawson, 1998). Learning cycle teaching provides students with direct experiences with the materials, data collection, and guided discoveries needed to stimulate the cognitive challenges and social interactions required for reasoning abilities to develop (Gerber, Marek, & Cavallo, 1997). Second, in addition to reasoning ability, meaningful learning orientation is an important factor to consider. Regardless of the low variance, the results highlighted that meaningful learning orientation contributed to a portion of the overall learning. Therefore, science teachers must select instructional strategies, such as Vee diagrams and concept mapping, that encourage students to develop meaningful learning approaches. Teaching should help students to relate new information to old information and to integrate knowledge from one area to another. Only then will these students be better able to maintain and apply information in new situations.

In this study, both reasoning ability and meaningful learning have been found to be variables that can be developed and improved among students to understand the concepts of photosynthesis and respiration in plants. These learning approaches can then be applied to more complex concepts as the students continue in school.

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Manuscript accepted April 20, 2005.