THE EFFECT OF A COMPUTER PROGRAM DESIGNED WITH CONSTRUCTIVIST PRINCIPLES FOR COLLEGE NON-SCIENCE MAJORS ON UNDERSTANDING OF PHOTOSYNTHESIS AND CELLULAR RESPIRATION

by

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Chapter 1

Introduction

Firsthand experience with many students who expressed frustration with trying to understand photosynthesis and cellular respiration has inspired me to look for better ways to engage students in learning about these topics. In my search, I discovered two CD-ROM programs from a German company called IWF, written by professors at the University of Frankfurt. One is called, “Life from Light and Air, the Cell 1”, and the other is called, “The Powerhouse – Mitochondrion and Catabolic Metabolism, The Cell 2” (Bereiter-Hahn, 2003). These have various animations that allow students to perform common laboratory experiments on the computer in a virtual laboratory setting. These CD-ROM programs show the students what the results of their experiment would look like as well as showing the process at a microscopic and a macroscopic level. For example, the program allowed students to drag a leaf with a cut out letter on it into the light and the computer program would show the steps of the iodine test for starch and what the leaf looked like at the end of the test. These programs were designed to supplement classroom instruction rather than function as an instructional unit that directs students toward a final product or assessment, so I did not use them for this project. Lastly, I read about a program called Alien Rescue that made many cognitive tools available to elementary students to solve a problem regarding which habitat best suits each stranded alien (Liu & Bera, 2005). These experiences stand out as influential to me in pursuing the creation and testing of a computer program to help students better and more deeply understand the processes of photosynthesis and cellular respiration.

Computer-based Instruction

College students do not all have access to the same level of resources for effective learning in science courses. This may be due to several factors, such as proximity to a good college, lack of funds or space at their college, or the interest and expertise of their instructor. I believe that one way to give students more equitable access to instruction is to use computers to help with instruction, which is also supported by others (Blaylock & Newman, 2005). While computers and the internet can be costly, they can allow college students access to a standard level of instruction that is not dependent upon having the supplies for lab experiments or upon the teacher's level of expertise in science. Computers can be used as a tool for instruction that frees the teacher's time for assessing student understanding and giving students feedback. Computer-based instruction is becoming more and more common in college instruction today (Sundberg, Armstrong, & Wischusen, 2005). Using the computer allows learners to have access to a large amount of information in a wide variety of formats. Computers may be used to present images, videos, and interactive activities as well as organize discussions and allow students to work individually or collaborate on their own schedule. Online courses using the computer could cut down on costs and time taken in experimental work (Carnevale, 2003).

As distance learning courses are offered as alternatives to traditional science classes with a lecture and a hands-on laboratory, the question arises as to whether a computer program can satisfactorily replace the hands-on laboratory in increasing student learning. The literature on computer-aided instruction has a wide variety of results on how effective computer-aided instruction is in comparison to other forms of instruction. One study on replacing traditional tutoring with a tutorial program showed no increase on test scores in cell biology with the tutorial program (Blackmore & Britt, 1993). Other studies give mixed reviews with slight improvement or improvement only in some areas, (Chen-Yung Lin & Reping Hu, 2003; Hsu & Thomas, 2002; Winn et al., 2006) however, a meta analysis of 42 computer-aided instruction studies showed that the data trend for computer aided instruction compared to other forms of instruction supports computer instruction as an effective method of instruction (Bayraktar, 2001). Thus computer programs may be useful for improving access to effective methods of instruction for college students.

Instruction for Difficult Topics

Some topics are more difficult for students to understand conceptually because they are unfamiliar to the students, and their scale makes them unobservable to the naked eye. Traditionally, photosynthesis and cellular respiration are taught using observations of the results of these processes as it is not possible to directly observe most of the processes of photosynthesis and cellular respiration. Students find these topics so challenging that some colleges omit them or minimize them to avoid frustrating the students. Other topics that are not directly observable include phenomena such as the particulate nature of matter, chemical transformations, energy transformations, and molecular genetics. Because photosynthesis and cellular respiration are unobservable at the molecular level, students often begin with many ideas about them that are based on previous experiences with the observable aspects of photosynthesis and cellular respiration (Ardac & Akaygun, 2004). Some of these preconceived ideas will be misconceptions.

Misconceptions, also called alternate conceptions, are incorrect or incomplete ways of thinking about a concept. Misconceptions are very difficult to eliminate once they are established. For example, one common misconception held by students relates to mass gain in plants. Many students think that plants gain mass from the soil or from water rather than from carbon dioxide in the air. When technology in the form of probes allowed students to directly measure factors in growing plants such as carbon content, the students using the technology still had the same misconceptions as students who were not able to directly measure factors related to mass gain in plants (Kuech, Zogg, Zeeman, & Johnson, 2003). Since alternate conceptions arise from experiences, experiences that challenge the alternate conception can be effective in correcting them. Even in early elementary children, alternate conceptions exist from early experiences with the world around them. If just knowing the right answer is rewarded rather than understanding why an answer is correct, alternate conceptions go unchallenged and remain. Alternate conceptions often parallel older scientific explanations, such as Lamarckian evolution (Wandersee, Mintzes, & Novak, 1994). Students' understanding of photosynthesis and cellular respiration may have many different misconceptions that persist after traditional instruction. The traditional laboratory observations for a college non-science major act as a black box where something incomprehensible happens between the start of the demonstration and the results that the students see. For example, students set up an aquatic plant underwater with a light on it, but they have little idea what gas is in the bubbles that form or where that gas came from. Giving students the opportunity to investigate what happens in this black box would challenge their misconceptions and help correct them.

Why it is Important to Study Photosynthesis and Cellular Respiration

Despite the difficulties in coming to an understanding of photosynthesis and cellular respiration, knowledge of these topics is important for students. Simply omitting these topics from the college biology course for non-science majors is not the answer to solving this difficulty. Although abstract, these topics are necessary if students are to understand the over-arching concept of movement of matter and energy. College students, as adult learners want their efforts at learning to be tangibly worthwhile. They want to know why they are learning and of what use that knowledge will be to them (Knowles, Holton III, & Swanson, 2005). It is particularly difficult for college students who are not science majors to see why it might be important to understand the molecular events in photosynthesis and cellular respiration. Without the understanding of cellular respiration, they cannot fully understand their own body; specifically, why people need food, why people need to breathe, and how people can manage body weight. Without the understanding of photosynthesis, students cannot fully understand the principles of ecology and crop agriculture; specifically, how carbon dioxide cycles, how plant productivity is determined, or how energy flows though an ecosystem (Anderson, C. W., Sheldon, & Dubay, 1990). The non- science major college students should be able to make informed decisions about their own health and about environmental policy.

Improving Students' Understanding

Several programs of study have been implemented to try to improve students' understanding of photosynthesis and cellular respiration. All of these programs of study seek to provide opportunities for students to take the new information presented and make sense of it for themselves, rather than simply taking in information for memorization. This requires students to construct new conceptions from prior knowledge and new knowledge in the face of observations of results which do not support their prior conceptions. Students who construct knowledge for themselves will remember more and understand concepts more deeply than if they simply receive the information like water poured into an empty container. Examples of these studies include using probes to directly measure the results of experiments and comparing the results to predictions made before the experiment (Kuech et al., 2003) as well as various experiments with aquatic plants using direct measurement or measurement of changes in pH, then comparing their results to their hypothesis (Ray & Beardsley, 2008). Other studies used strategies such as building models of chloroplasts based on instructor input and prior knowledge along with role play of photosynthesis (Ross, Tronson, & Ritchie, 2006), or using a computer (computer-assisted instruction material) to allow students to interact with static images and animations and then discuss them in groups (Cepni, Tas, & Kose, 2006). Several studies focused on using strategies to expose misconceptions and challenge them, forcing students to re-construct their ideas when faced with evidence that did not support their ideas (Akpinar, 2007; Barker & Carr, 1989b). Another study combined problem sets with traditional laboratory demonstrations and modeled chemical change with manipulatives to challenge students' misconceptions and allowed them to represent their knowledge externally in the models (Bishop, Roth, & Anderson, 1986). Computer instruction, such as that used in Cepni, Erol, and Tas (2006), could give all students equal access to instruction thus making a computer program that provides students opportunities to construct their own knowledge worth creating. In order to correct misconceptions, students must be aware of their own misconceptions and have those misconceptions challenged. Students must correct their own understanding by building their own knowledge. A computer program that not only presents information, but also encourages students to construct their own understanding of photosynthesis and cellular respiration is needed.

In order to learn whether a computer program positively influences academic achievement in understanding energy flow in biological systems, students' understanding of photosynthesis and cellular respiration must be assessed. Not only is understanding the concepts of photosynthesis and cellular respiration an important aspect of scientific literacy, students' attitude toward instruction is also important (Nasr & Asghar, 2011; Partin et al., 2011). If students have a negative or indifferent attitude toward instruction and understanding photosynthesis and cellular respiration, then their motivation to learn about it will be affected. In addition, their attitude toward applying the concepts in photosynthesis and cellular respiration, such as how calories are used in the body or how plants affect the carbon dioxide levels in the atmosphere, will also be affected. Students with a poor attitude toward photosynthesis and cellular respiration may choose to apply incorrect conceptions rather than correct conceptions in making decisions as voting citizens and as consumers. It is important to assess both students' understanding of energy flow in biological systems and their attitude toward instruction in order to determine the effectiveness of the method of instruction and of the students' efforts toward learning.

Assessments

In order to know whether students understand photosynthesis and cellular respiration, an assessment of their understanding must be used. There are many ways to do this. True and false questions as well as multiple-choice questions give limited data that are easy to score. Tiered assessments, with another tier added to the multiple-choice or true and false questions to give information on why students chose their answer, or even a third tier for students to state their confidence in their answers, may be used. Short answer questions and concept maps are more open-ended and may give more data about the students' conceptions, but they are also more difficult to score and may fatigue students if used excessively. In addition, attitudes toward the subject matter may play a large part in how well students perform. Attitude toward biology is typically assessed with a survey of choices in a Likert scale format.

Assessing Content

Multiple-choice

One type of assessment that is commonly used to assess understanding of a concept or learning of knowledge is the multiple-choice question based test. These tests may make use of multiple-choice questions only (one-tier tests), multiple-choice questions with reasons for their answer (two-tier tests), or multiple-choice questions with reasons for their answer and their confidence in their answer (three-tier tests).

One-tier multiple-choice tests are often popular in biology because they are easy to score and use in a large lecture class. They can be useful for assessing student's conceptual understanding, but sometimes they do not truly assess conceptual understanding because students may view the test as a multiple-guess test and not answer the questions from their knowledge, but rather guess at the answers. Furthermore, a student's answer to a multiple-choice question may not accurately reflect his understanding of a concept if he misunderstands the question or conceptualizes the question in a different way than was intended. A student may also know the answer by memorization without knowing why her answer is correct.

Adding a second tier or even a third tier to the test that makes a place for students to give their reasons for choosing their answer, and their confidence in that answer in a three tier test, helps to alleviate these problems. To go further toward truly measuring conceptual understanding, more open- ended conceptual questions should be used in short answer and fill in the diagram types of questions. If alternative conceptions have been established, multiple-choice items can be constructed to diagnose them, using the alternative conceptions as distracters. Still, the open-ended questions will yield a richer picture of the student's understanding than a multiple-choice question. To have a conceptual understanding of a topic, students must commit knowledge to memory with a purpose, integrate the new knowledge with related knowledge, be able to transfer and apply knowledge to new situations, be able to reason analogically about the concept, and be able to reason locally and globally (apply the implications of their knowledge to local and global effects) (Schönborn & Anderson, 2008). Because having a two-or three-tiered test may actually give the students clues about what the correct answer might be, a tiered assessment may not accurately measure achievement (Griffard & Wandersee, 2001; Tamir, 1989). Therefore, despite some advantages of tiered tests, multiple-choice only assessments are commonly used in assessing understanding of science topics, often in conjunction with other assessments.

Concept maps

Concept maps are thought to be effective assessments as well as effective learning tools because they help externalize the learner's cognitive framework and emphasize making links that indicate relationships from one concept to another, including linking prior knowledge to new knowledge; this is consistent with the constructivist view of learning (Hill, 2005; Novak, 1980). Concept maps may be scored based on the concepts used, the correctness and completeness of the links given, the correctness and completeness of both the concepts and the links, and/or the overall structure of the map. While some students may find using a concept map a little disorienting at first, many students find them helpful and even enjoyable to work with (Hill, 2005). Concept maps are much more open-ended than multiple -choice questions, although they can be given more structure by specifying the type of map or the concepts to be mapped. Scoring the concept map requires that the learner be familiar with using concept maps, so some training is needed to produce reliable results. McClure, Sonak, and Suen (1999) tested six different scoring methods for evaluating concept maps and found that when the raters are all equivalent in their knowledge of the topic being mapped, score reliabilities for the various scoring methods, as estimated by generalizability coefficients range from .23 to .76, with the most reliable scoring method being a relational scoring with a master map. When map scores for each method were correlated with map similarities, the Pearson product moment correlation ranged from .193 to .608, with the relational with master map being the highest in correlation. This measure was used to calculate the validity of the scoring method. The time to construct a concept map was also recorded, and it took about 30 minutes on average, while scoring time ranged from 1.3 minutes to 5.2 minutes. Concept maps can be scored reliably and with validity, as well as with relative time efficiency (McClure et al., 1999). Even though the concept map is a useful tool for assessing academic achievement, it does not reflect the factors that affected that academic achievement. One of those factors, attitude toward instruction, may play a significant role in supporting or hindering academic achievement. This makes measurement of attitude toward instruction important in studying the effect of any form of instruction.

Assessing Attitude

Frustration can be an obstacle to students' learning. The source of frustration could be from an overwhelming amount of material to learn, concepts that are out of reach for the student, or material that seems to be irrelevant to the students' lives, among other factors. Since attitude influences learning in science, it was important to measure students' attitude toward instruction in science(Partin et al., 2011). To measure students' attitude toward science in general, an attitude instrument is used. Instruments to measure attitude typically consist of statements with a Likert scale that the student uses to rate how much he or she agrees with or disagrees with that statement. The Likert scale may give a middle ground with five ratings or force the student to choose to agree or not to agree with the statement by offering only four ratings. An attitude scale may be used as a pretest and a posttest to measure the change in attitude after an intervention has been completed. Attitude scales using Likert scales have been used to measure changes in attitude after science instruction by Nwagbo (2006), Cepni , Tas & Kose (2006), and Yesilyurt & Kara (2007).

Definition of Terms

Online Instruction

Online instruction in this research is instruction that is fully completed online. In this form of instruction, tests are administered online, labs are submitted by email, graded, and then returned to an online grade book. All of the content is delivered digitally and no kit is sent to the students to perform experiments outside of the online content. The student and the instructor may never meet in person in online instruction.

Traditional Instruction

Traditional instruction in this research is instruction given by short lectures in the laboratory setting, reading the textbook, and following the instructions given in the laboratory activities packet. In the traditional instruction included in this study, students observe models and demonstrations and fill out their answer sheets in the laboratory activities packet from these materials.

Cognitive Tools

Cognitive tools are devices to help the learner perform tasks with information as opposed to with physical materials. They may include tools for organizing information, tools for storing information so that the learner doesn't need to devote cognitive resources to as much information storage, tools for presenting information, and others. Vygotsky (1978) thought of cognitive tools as language and culture. The computer itself has many cognitive tool functions. A chart to be filled in that organizes information in a particular way is also a cognitive tool.

Computer-Aided Instruction

Computer-aided instruction is the use of computers to help with instruction. Teachers may choose different times to use computer-aided instruction. This form of computer use for instruction does not comprise all of the instruction given, but is used for supplemental instruction. In computer-aided instruction an animation, game, tutorial, or simulation may be used to stimulate discussion and represent the content in another format in the classroom.

Computer-based Instruction

The term computer-based instruction is used in this research to mean that the instruction comes primarily from the computer. A teacher still interacts with the students, but he does not provide most of the content. In this form of computer use for instruction, students interact with the computer program and gain feedback from the program to solve problems or answer questions. The students receive feedback from the teacher in final products that they submit to the teacher, or in discussions that arise from interacting with the computer.

Constructivist Principles

Constructivist principles describe a way of perceiving the world and how we learn about the world around us. According to these principles, meaning is generated by the learner's interpretations of what their senses tell them. Teaching according to constructivist principles takes the learner's thinking process into account, including prior conceptions and what observations and experiences may be needed to challenge incorrect prior conceptions. Learning is an active process of organizing information and requires both individual effort and social interaction.

Research Question

This study examined the use of computer-based instruction on academic achievement, student held misconceptions, and attitudes toward microscopic cellular processes. This study examines the effect of a computer program called the CELE program (Carbon, Energy, and Life on Earth) versus traditional instruction in a packet-driven course with some instructor interaction in a traditional laboratory setting. The topics taught were photosynthesis and cellular respiration.

Three questions are investigated in this study.

1. What difference can be seen in academic achievement between college students using the CELE program and those using packet driven, textbook assisted and instructor assisted instruction?
2. What difference can be seen in student held misconceptions between college students using the CELE program and those using packet driven, textbook assisted and instructor assisted instruction?
3. What difference can be seen in attitude toward microscopic cellular processes between college students using the CELE program and those using packet driven, textbook assisted and instructor assisted instruction?

I expected this study to demonstrate that this new computer program, designed using constructivist principles, would positively affect academic achievement, reduce misconceptions, and improve attitude toward microscopic cellular processes as compared to instruction delivered via a packet or a textbook, with minimal instruction from the instructor as students enrolled in this course did not have a traditional lecture. Students read their textbook and participated in an online flash card system called Connect ("McGraw Hill's Connect," 2012) for their lecture activities, and had some introduction from the instructor to each topic at the beginning of their laboratory sessions.

Chapter 2

Literature Review

Teaching photosynthesis and cellular respiration to support academic achievement is a challenging task. Students come to college with misconceptions about how plants and animals use energy. In order for students to correct their own misconceptions, students must reconstruct their knowledge. Otherwise, they accumulate new knowledge in a pile of unrelated facts that don't interact with each other and most of this new knowledge will simply be discarded once it is no longer useful for the class. Only by linking concepts from prior knowledge and from new information together in a way that makes sense and that works to explain everyday phenomena can new knowledge be truly learned. Computer-based instruction can be used to help students reconstruct their knowledge. Students also come with attitudes toward science that may help or hinder their desire to learn and that may, in turn, affect their academic achievement. Both academic achievement and attitudes need to be assessed in determining whether science instruction is effective in supporting academic achievement.

Teaching photosynthesis and cellular respiration

Photosynthesis and cellular respiration are often difficult topics for non-science majors to grasp, as Dr. Gull (2007) writes in her article for students entitled, "Photosynthesis-most hated topic?". Non-science majors have a greater difficulty understanding since they have very little background in the activities of a cell at the molecular level which requires a basic understanding of chemistry, bonding, cellular organelles, and energy (Koba, 2009). In addition, the amount of terminology introduced in an introductory biology course was estimated to be 1600 terms, which exceeds the amount of vocabulary introduced in a first-year language course (Vogel, 1987). This terminology often gets in the way of students' understanding cellular processes by making the meaning inaccessible or more difficult to find as students have to spend time looking up terms or find it easier to copy what the book says verbatim than to actually understand the processes being described.

Yet these topics are important for students to understand. Photosynthesis and cellular respiration are one part of the movement of matter and energy. They play a role in carbon cycling and energy flow through trophic levels in ecosystems on a global scale. At the molecular scale, photosynthesis and cellular respiration are responsible for converting energy from one form to another and for building molecules as well as breaking molecules apart. Without understanding the concept of how matter and energy move, the idea of how food gives us energy or how carbons from our food are exhaled in carbon dioxide cannot be grasped. Where molecules come from or where they go will not be understood. Understanding cellular respiration is the key to understanding why it is necessary to breathe oxygen and how one of the cell's most important metabolic processes works. This helps students to make informed decisions about how to control their weight and which diet plans and supplements will be effective. It helps students to be able to better evaluate supplements that claim to give them energy with products such as NADH available in stores. Students need to understand photosynthesis in order to understand why plants need light to stay healthy and green, and how plants and algae are important to the balance of carbon dioxide in the atmosphere.

Students tend to have more difficulty when testing hypotheses and interpreting results for topics that are not directly observable due to their scale, which is either too large or too small (Lawson, 2002). Photosynthesis and cellular respiration are among the chemical processes in cells that are too small to directly observe. Molecular events are also too small to directly observe. In a study on conceptual understanding of chemical change, students were able to draw more accurate representations of chemical change after viewing an animation that portrayed the particles interacting than were students with traditional instruction (Ardac & Akaygun, 2004). Williamson and Abraham (1995) found similar results with an animation of matter as particulate, increasing scores on the Particulate Nature of Matter Test instrument. Interactive animations gave the greatest gain in correct explanations in interviews (Marbach-Ad, Rotbain, & Stavy, 2008). Photosynthesis and cellular respiration involve chemical changes similar to the ones represented in this study. When a topic is difficult to comprehend, students may fall back on incorrect prior conceptions of the topic. These misconceptions are difficult to overcome.

Misconceptions

Misconceptions about photosynthesis and cellular respiration are numerous. Many students know that photosynthesis involves light, but do not understand that it produces a carbohydrate product (Barker & Carr, 1989a). Ozay & Oztas (2003) asked students seven open-ended questions before instruction and found that students held as many as 6 misconceptions about photosynthesis: 1) plants are producers because they produce oxygen rather than food, 2) plants gain mass from the soil rather than from carbon dioxide, 3) animals depend on plants for survival only because plants are food for animals, 4) plants only respire at night, 5) sunlight keeps plants warm and healthy rather than giving them energy, and 6) photosynthesis is a form of gas exchange rather than a form of energy conversion. Students often do not connect breathing with converting food energy into readily available chemical energy and equate respiration with simply breathing. This is an incomplete conception of respiration. Students do not know that plants respire, or believe that photosynthesis is also simply gas exchange. These misconceptions were detected in eighth grade students, but many of these persist into adulthood (Stavy, Eisen, & Yaakobi, 1987). In addition to these misconceptions about photosynthesis and respiration in plants, Yenilmez & Tekkaya (2006) list the following 7 misconceptions: 1)respiration in plants uses carbon dioxide, 2) respiration in plants only occurs when light is not available, 3) respiration only takes place in leaves, 4) respiration is gas exchange through the stomata, 5) respiration in green plants is taking in carbon dioxide and giving off oxygen, 6) photosynthesis provides energy for plant growth only (an incomplete conception), and 7) plants only respire when they can't get enough energy from photosynthesis. For a more complete listing of the known misconceptions about photosynthesis and cellular respiration, see Table 16.

Teaching may actually cause some misconceptions, as Vogel (1987) points out. The following are some examples of misconceptions that he lists as being propagated by teaching that apply to photosynthesis and cellular respiration. The first example is that the definition commonly used for respiration includes consumption of oxygen, yet anaerobic respiration does not use oxygen. A second example is that cellular respiration is contrasted with photosynthesis as catabolic and students are led to believe that only plants can synthesize large molecules outside of proteins. A third example is that high energy bonds, as described in ATP, do not have more energy than carbon to carbon bonds and the energy is not contained in the bond. Instead, the energy is better conceived as being in very small packets and the third phosphate is unusually easy to hydrolyze, releasing the packet of energy for use.

Misconceptions come from a variety of sources and are very hard to remove. They become embedded in the learner's organization of their thinking and protected as a building block for building other conceptions on. One of the more effective ways to eliminate misconceptions is based on facilitating the learner's construction of knowledge. This is effective because it actively engages the learner in removing the misconception in order to make a better construction of other conceptions that were built on the misconception.

Constructing knowledge

Constructivism describes learning as a process of building knowledge from experiences, both prior experiences and new ones. In this view, learners use prior experiences to organize new information, and learners actively participate in knowledge organization with help from various sources. This active approach to learning is thought to be more effective since it engages learners to build conceptions for themselves. The CELE program was built using constructivist principles and it was intended to be a tool for students to use to facilitate making external representations of their knowledge as they shaped it. Computers can be well-suited for use as a tool in this activity. When students engage in constructing their own knowledge using a computer program, cognitivist theory also comes into play as the amount of information that the student interacts with, called cognitive load, must be chunked into meaningful packets in order for them to use it to construct their ideas.

Cognitive Load

In order to be an effective tool for constructing knowledge, a computer program must be optimized for facilitating knowledge organization in the learner. Cognitivist learning theory focuses on what is going on in the mind instead of focusing on the external behavior only as behaviorism does. Some branches of cognitivist learning theory treat the mind as a computer that can be analyzed and instructions can be structured to facilitate processing by this computer-like mind (Knowledgebase, 2011a). In this analogy of the mind to a computer, there is a limit to the processing capacity in the mind, measured as the cognitive load of incoming information. Cognitive load theory is attributed to John Sweller (1994), although Dr. George Miller (1956) first came up with the idea of chunking information and the capacity of short term memory for seven chunks of information plus or minus two. Organization of information and how it makes it possible to learn within the physical limitations of the human ability to process incoming information is the emphasis in the cognitive load theory. The incoming information is packaged into chunks and then linked to prior knowledge to store it in a way that the new information will be retrievable when the correct cues associated with the links to that same prior knowledge are activated. When cognitive load is too high, this process of chunking and storing information is impaired. Cognitive load is the demand made upon working memory when processing information. Intrinsic cognitive load is part of the nature of the material and cannot be altered, but extraneous cognitive load can be. For example, DNA transcription uses more specialized terms than cell organelle function, so DNA transcription has an inherently higher cognitive load than cell organelle function. When instruction is designed in a way to decrease extraneous cognitive load, the germane load (the cognitive effort made toward developing schemas – ways of looking at things) increases.

Worked examples, using partially worked completion problems, integrating types of information to avoid the split attention effect, using multiple modalities such as audio and visual rather than putting all of the information into one modality, avoiding redundant information, and varying the forms of the tasks help reduce cognitive load (Sweller, Van Merrienboer, & Paas, 1998). Mayer tested the effect of using multiple modalities with audio and animation compared to text and animation and found that audio and animation reduced cognitive load (Mayer, 1997). Moreno and Valdez (2005) also showed that using multiple modalities reduced cognitive load (words and pictures together). Interestingly, having students organize the information for themselves rather than having it organized for them was detrimental in this case. The researchers thought it might be due to time constraints and lack of prompting to check their response before receiving feedback; students may have been randomly sorting things and getting feedback to tell them the right answer.

Schemas, accommodation, and assimilation

The CELE program was built with a drag and drop laboratory to allow students to predict outcomes and then test them. This would allow students' prior knowledge to be exposed to new observations to challenge misconceptions in the process of accommodation and assimilation which were ideas put forth by Piaget. Jean Piaget (1896-1980) was a developmental psychologist. Piaget's theories about how knowledge is constructed also apply to college students as they construct or re-construct knowledge about photosynthesis and cellular respiration. Even though many college students may not have a correct conceptual understanding of photosynthesis and cellular respiration, most college students have had some exposure to these topics, and therefore will try to construct the new information around the old information that they bring with them. In Piaget's (1980) theories, learners construct their own knowledge from their experiences. He termed knowledge constructions schemas as the mental representations of how a set of related observations and ideas fit together and may be used to make sense of the world. Learners take experiences and attempt to connect them to their knowledge from previous experiences in their development of a schema.

Developing schemas is part of learning and part of making an internal representation of knowledge by linking both prior knowledge and new information into a new mental representation; this is the goal of constructivist learning. When a diagram looks like something familiar, it activates a schema to look at the diagram as similar to that familiar thing. For example, if a hierarchy on a concept map looks like connected building blocks, they can be visualized in this way. Diagrams combine text and image, reducing cognitive load over text only representations (Carlson, Chandler, & Sweller, 2003). Using icons rather than text also reduced cognitive load and cutting down the amount of information presented on one screen also reduces cognitive load (Lee, Plass, & Homer, 2006). The CELE program was designed to enhance student cognitive function in the way information is organized and in providing many tools for students to use in constructing knowledge, such as a search bar to find terms and a notepad which recorded the results of all the tests run in the drag and drop laboratory.

If the previous experiences and the new experiences don't support the same knowledge structure, then cognitive disequilibrium occurs and the learners must change their previous schema to accommodate the new experiences, or assimilate the new experiences in to their schema in some way. Accommodation is changing the existing knowledge structure/schema to fit the new knowledge while assimilation is making the new knowledge fit within the prior organization of knowledge, sometimes by ignoring the new knowledge or making it an exception to the general rule (Bhattacharya & Han, 2001; Knowledgebase, 2011d; Piaget, 1980). An example of assimilation of knowledge from photosynthesis is for a student to observe a plant dying in the absence of light and for that student to explain what they see as the plant having a disease that does not allow the plant to take food up from the soil. Misconceptions like this were specifically addressed in the CELE program by using diagrams to help students visualize photosynthesis and cellular respiration and by presenting students with experiments to test their own ideas. An experiment may cause students to re-think their prior conceptions of photosynthesis and to develop new models which better reflect the data.

In Akpinar's (2007) experiment with photosynthesis and respiration instruction, a dual situated learning model which employs both a challenge to pre-existing knowledge (Piaget's cognitive disequilibrium) and a new mental set that will be useful for building later concepts, was used. Thus this model was situated in two roles: challenging misconceptions and providing new possible explanations that fit the observations more closely. The students who predicted outcomes of experiments with photosynthesis and respiration and compared their results to their predictions in the dual situated learning model showed more understanding of these topics than those in traditional instruction who were given the results of the experiment before they did the experiment (Akpinar, 2007). The CELE program's drag and drop laboratory was designed to challenge prior knowledge by having students make predictions and test them in areas where misconceptions are common, such as the source of mass gain in plants.

Although having students engage in learning by making predictions, forming hypotheses, and designing their own experiments is helpful, students need scaffolding, which is support given in the learning process, such as modeling a task, to give them the skills to do these activities (De Jong & Joolingen, 1998). The student's own beliefs about how they learn may also have an impact on their learning, which will affect whether the student attempts to accommodate the new information, assimilate the new information, or simply ignore the new information when their hypothesis is not supported (Wallace, Tsoi, Calkin, & Darley, 2003).

Many traditional lab activities give students both the question to answer and prescribed steps to take in order to answer the question. This is not the most effective method to support accommodation and assimilation. For example, in studying osmosis and diffusion, students in a smaller lab with discussion and a semantic network diagramming activity performed better than students in a large lecture and small traditional lab on an instrument designed to test their understanding of osmosis and diffusion (Christianson & Fisher, 1999). Another example is when students modeled the behavior of fish rather than completing a worksheet, they were able to model other processes better than those using worksheets only (Papaevripidou, Constantinou, & Zacharia, 2007).

Cultural tools and social learning

Working in the same time period as Piaget, Lev Vygotsky (1930) was a Russian psychologist who also thought that knowledge is constructed by the learner. Both Piaget and Vygotsky thought that social interaction was important for learning, but Piaget focused on the relationship between the development of knowledge in individuals and the development of knowledge in culture, while Vygotsky emphasized that construction of knowledge must happen in a social context, which is derived from culture. Vygotsky described how cognitive functions (tools) are influenced by culture (people) and culture influenced by cognitive functions, including tools of intellectual adaptation and the cognitive tools that are learned from a more knowledgeable other, such as mnemonics. Vygotsky uses the development of language as an example of developing a cultural tool. When a child was given the task of getting candy from a cupboard with a stick and several stools as tools, she began to try the different tools, but also began to talk about what she was doing and was planning what to do aloud. Language is learned as part of culturally organizing the ability to solve problems (Vygotsky, 1978). Based on Vygotsky's ideas of how learning is inherently social, the CELE program incorporated two forms of social learning environments: the collaborative concept map and the discussion board. These environments facilitated social development of tools for approaching problems.

Scaffolding

The CELE program used scaffolding, a term proposed by Bruner, in the form of tools and information to help students construct and re-construct the information they are learning. The CELE program also made use of guided inquiry, also known as discovery learning, as one form of instruction that was available to students. Jerome Bruner (born in 1915) is an American educational psychologist who studied perception in children and later, learning in children. Jerome Bruner was influenced by Jean Piaget, in the idea that children are active problem-solvers, not passive recipients of information. Bruner used the term scaffolding to describe knowledge and tools that children use to build new knowledge. An example of Bruner's scaffolding is social learning. Social learning can provide a bridge between the student's current problem solving abilities and the new abilities that are needed to solve the problem at hand. Vygotsky's zone of proximal development describes this bridge. This zone is defined by the difference between a person's ability to accomplish a task with help from a more knowledgeable other and a person's ability to accomplish that same task independently. Scaffolding is a way of expanding the zone of proximal development, providing support for a person to take steps toward being able to accomplish a task independently.

Scaffolding may include such things as dictionaries, expert modeling, and animations to help students visualize a process, and practice problems to help prime the student to use a particular problem solving approach. In these ways, the computer itself can also function as a more knowledgeable other, and it will be added to the other students and the instructor as a source of information and feedback for the student to use in organizing their knowledge (Knowledgebase, 2011c; Vygotsky, 1978). The instructor is commonly the other human involved in forming this bridge, but other students may also be involved. The CELE program allowed both instructors and students to interact to facilitate tool building with a more knowledgeable other for the student who needs help with a problem they are trying to solve.

Discovery learning is a form of instruction where students are given some direction on how to explore concepts and the student make discoveries of the principles behind the concepts. Jerome Bruner (1977) advocated for discovery learning. In discovery learning, students use some data and directions to interact with the material in the form of problem solving, manipulating objects, or performing experiments. There are several models of instruction that follow the principles of discovery learning such as problem based learning, simulation-based learning, guided inquiry, and pure inquiry. Pure inquiry based learning has the learner answering questions that the learner himself asks and the learner designs a way to answer his own question. It does not give direction to the learner on how to proceed. Even though this is very engaging for the learner, it can also be very frustrating for students who have never tried to learn in this way for a class. It tends to create cognitive overload and potential misconceptions that might not be corrected (Bruner, 1977; Knowledgebase, 2011b; Smith, 2002). Guided inquiry gives more direction and helps avoid a high cognitive load, usually by posing the question for the students.

Computers as tools for learning

Piaget, Vygotsky, and Bruner all conceived of their ideas before the idea of artificial intelligence, the idea that a computer could learn, was proposed. Computers may also be used as a tool for students to use to construct their own knowledge. Seymour Papert is a mathematician, programmer, and educator at MIT. Papert worked with Jean Piaget and he applied Piaget's theories of learning to computers as a tool for learning, extending the idea of constructivism to using materials to produce a meaningful product, called constructionism. Papert initially created the Logo computer programming language as a tool for children to use to understand geometric relationships by giving directions to the Logo computer program to draw shapes. He advocates the use of computers as tools that can do the basic tasks so that the student can focus on problem solving and constructing knowledge rather than on the mechanics of the problem. For example, rather than the student simply learning how to do calculations, the computer can be used to do the calculations so that the student can focus on learning how to think mathematically. The computer allows the student to manipulate ideas so that the mechanics of working problems comes naturally once the mathematical thinking is in place (Papert, 2003). Papert describes education as behind the times and not part of today's computer-saturated culture. He does not advocate the computer as doing something to cause learning, but as a tool among many other tools that may be used to foster construction of new knowledge (Papert, 1987). This parallels Vygotsky's idea of culture as a tool among other tools for learning.

Computer-aided instruction

Benefits of computer-aided instruction

Computers are increasingly being used in science instruction, sometimes as a supplement to hands-on laboratory activities and sometimes as fully online courses (Sundberg et al., 2005). There is ongoing testing of computer programs to see how well they hold up to traditional instruction or other forms of instruction (such as field trips) in increasing academic achievement as well as improving attitude toward science. The digital platform has its benefits and its challenges, and both of these are most noticeable when the course is delivered online, as in a distance learning course. Digital delivery allows for uniform access to resources for students as long as all have internet access and bandwidth is not an issue. They get equal time with the instructor. Costs are reduced. Multiple representations of concepts are made relatively easy. Student schedules can be flexible and locations not limited by geography. Instruction may be made more engaging and capture the interest of the learner, making learning more effective (Annetta, Klesath, & Meyer, 2009). Yet with all these benefits, digital delivery lacks the hands-on feel of a science laboratory. The experience is vastly different between watching the video of a dissection and doing the actual dissection. The context for learning is removed in many cases. However, many educators suggest that there are topics and courses that could benefit from the use of computer programs to replace traditional instruction. Where the phenomena being studied are too small or too large, or otherwise difficult to directly observe, a computer program can give the students a window into these phenomena that could not be done in the physical lab (Lawson, 2002). It is possible to observe some of the effects of photosynthesis such as oxygen production or carbon dioxide intake, and it is also possible to observe ATP synthase rotating by attaching a green fluorescent protein to it (Duser, Bi, Zarrabi, Dunn, & Borsch, 2008; Radwan, 2011). Other processes in photosynthesis and cellular respiration are theoretically derived and have never been directly observed.

Computer-aided instruction compared to other forms of instruction

In some cases, computer-aided instruction is equally effective as other forms of instruction. In a weather forecasting activity where students had to problem solve to use data to make their predictions, no difference was detected on the post test scores on the paper and pencil achievement tests among students using a computer simulation with logged data, students using a computer simulation without logged data, and students viewing real-time weather forecasts without using the computer simulation. Interviews of these students showed that some students made significant gains in understanding whereas others, who did not demonstrate all the stages of problem solving, did not. In this case, a factor other than the form of instruction such as lack of problem solving skills influenced student achievement (Hsu & Thomas, 2002). Another study showed marginal improvements in student scores on an achievement instrument for Earth Science with a program to promote problem solving compared to a lecture, internet, and discussion format (Chun-Yen, 2002). A comparison of a field trip to the ocean and a simulation of physical oceanography showed that each experience had a different benefit. The field trip allowed students to contextualize the information better; however, the simulation allowed students to apply their learning to other courses and produce better sketches (Winn et al., 2006).

Some studies support the idea that computer-aided instruction was more effective than other forms of instruction. For example, student test scores were increased with use of computer-based instruction in college students taking a neuroscience course. By replacing a traditional lecture with videotaped lecture and animations available online, the average test scores for the treatment group increased by 14 percent (Goldberg & McKhann, 2000). In another example, both an edutainment program and a tutorial program had positive effects on student achievement. Edutainment is using visual material in a less didactic format to make education more entertaining, usually in a game or narrative format (Yesilyurt & Kara, 2007).

The differences in students' prior knowledge of science and the students' attitude toward science may influence achievement in a science course. Lifelab is a virtual molecular biology lab developed by Zumbach, Schmitt, Reimann and Starkloff (2006). It makes use of several tools to help students collect and organize information with four levels of expertise. The first level activates prior knowledge with analogies, authentic scenarios that are familiar to students, and challenging missions. Once prior knowledge is activated, new knowledge is acquired with tutorials, guided experiments, and an information kiosk with a search agent and a search helper (Dr. Drop). The third level of expertise allows students to create their own experiments, plan and reflect on what they are learning with tools to organize the information, and enhance metacognition. Lastly, students exchange research questions and findings by reporting their research and collaboratively plan new experiments. Each level of expertise is a separate module. This program also has remedial lessons available in the middle of experiments in case students get stuck. Students using this program in a small-scale initial evaluation had equal gains regardless of prior biology knowledge. The benefit of this particular computer-aided instruction is promising because it indicates that it is not just the highly motivated student that benefitted from this mode of instruction. Using LifeLab, students were able to make equal gains in knowledge from a pretest to a posttest, regardless of prior knowledge or interest in science. This program is being used in Germany, both as a supplement to regular instruction and also as a replacement for traditional instruction. Some studies showed significant gains in knowledge, such as a computer program used in veterinary school that significantly increased final exam scores by facilitating problem solving in diagnosing diseases (Danielson, Bender, Mills, Vermeer, & Lockee, 2003).

Other studies showed definite improvement in learning with computer-aided instruction as reflected in test scores, but major misconceptions were unchanged. Simply using PowerPoint and images can increase achievement test scores, as noted in a study with high school students studying photosynthesis, yet leave major misconceptions intact and students' attitude toward science education unchanged (Cepni et al., 2006). Tutorials and edutainment software increased student scores on the Cell Division Achievement test and improved attitude toward Biology; although it did not remove some major misconceptions (Kara & Yesilyurt, 2008). Bayraktar's meta-analysis of the literature on computer-aided instruction (CAI) indicated that it tends to increase student knowledge over traditional instruction. The form of CAI made a significant difference in the results. Simulations followed by tutorials were the most effective and drill and practice were the least when the subject was specific to science. Simulations may be more effective simply because they facilitate more active learning than tutorials or drill and practice activities. The effectiveness of CAI to increase test scores is reported to be lower in more recent years, although still positive, possibly due to the newness of computers in classrooms in earlier years. Bayraktar's recommendation is to supplement instruction with CAI, but not completely replace traditional instruction with it (Bayraktar, 2001).

Misconceptions

As stated above, some computer-aided instruction increased academic achievement yet did not correct some major misconceptions. A computer program, like other forms of instruction, can be structured to specifically counter misconceptions. Students' misconceptions on chemical equilibrium were discovered with a questionnaire where students represented chemical phenomena in drawings, and then a computer program was designed to correct these misconceptions. This program used an information section that represented chemical equilibrium at an empirical level and an atomic level, allowed students to observe a process at the empirical level and observe the chemical equilibrium law, and noted their observations. A second section allowed students to perform experiments with chemical equilibrium. The software was designed using constructivist principles and had not yet been field-tested (Solomonidou & Stavridou, 2001). This suggests that animations to represent the processes of photosynthesis and cellular respiration at a molecular level and at a whole-plant level would be beneficial.

Effective design

Another way of structuring a computer program to help learners solve problems or work cases is called the knowledge mediator framework. This program is designed to mediate between prior knowledge and new information needed to solve the problem. It has several steps involved and also uses some cognitive tools such as using representational affordances of technology – using images, videos, animations, and linking them together in an organized fashion rather than a linear sequence of representations. It also includes the design element of representing knowledge in context; this means it is in the context of cases or problems and connected to a rich representation of concepts using images, video, etc. (Jacobson & Archodidou, 2000).

Making instruction interactive seems to be an effective application of computer-aided instruction, as in the use of an interactive videodisk to prepare students for a real dissection (Kinzie, Strauss, & Foss, 1993). An interactive animation used to teach molecular biology also gave significant increases in achievement on a post-test over traditional instruction (Rotbain, Marbach-Ad, & Stavy, 2008). Other subjects, such as ecological modeling, are enhanced by computer simulations, but simulations alone were not enough to gain a full understanding of some ecological concepts (Korfiatis, Papatheodorou, Stamou, & Paraskevopoulous, 1999).

Cognitive Tools

Social interaction among people enhances cognitive function in the learner, and the computer can function to represent a person's knowledge as well as to provide feedback to the learner and thus provide a modified social environment. The CELE program presents cognitive tools such as a notepad to record data or a concept map to help organize data, thus acting as a more knowledgeable other to enhance learning in a social context. Cognitive tools should reduce students' cognitive load. Cognitive tools can act as scaffolding that allows students to process information in ways they could not on their own. Different types of cognitive tools help students with different tasks. Information seeking technology, such as search engines, can help them find the information they are seeking. This reduces the amount of memory that students have to dedicate to remembering where things are and frees them to focus on other tasks. Information presentation tools such as visualization tools or maps can help students organize the information.

This allows students to lay out the information in a way that makes sense as a whole and promotes their being able to explain it to someone else. Knowledge organization tools, such as notebooks, can help students establish conceptual relationships among ideas. These serve as extra memory space and function like scratch paper for students to evaluate the information they have. Knowledge integration tools such as simulations and concept mapping tools can help students link prior knowledge to new ideas. These tools help evoke the familiar world that the student already knows with the new information they are working with. Simulations may use images of familiar processes or simply make a concept easier to grasp by making it visual. Concept mapping tools can help students recognize patterns in the information. Knowledge generation tools can help students present what they have learned, such as a template or a presentation generator. These make it easier to produce a final product to show what they have learned. Some cognitive tools may fall into more than one category (Iiyoshi, Hannafin, & Feng, 2005).

An example of a computer program that used cognitive tools is a project called the "Alien Rescue" program that created a scenario for sixth grade students where aliens had crashed to Earth and needed new homes (Liu & Bera, 2005). The project has cognitive tools to help the students solve this problem, including information databases, analysis tools, a notebook for collecting and organizing information, a bookmark that saves a screenshot, expert modeling, a probe building room where students design probes to send to potential planets, a launcher room where the probes to launch are chosen within a budget, a control room where raw data from the probes is displayed, and a final solution form for their answers and rationale. This project looked at students' use of these tools to solve the problem.

As with any form of instruction, computer-aided instruction has both promises and challenges. Providing cognitive tools can help break a task down, but difficulty reading the text or navigating the virtual space can also hamper learning. Some students prefer to go online and search for the right answer rather than try to use the program to understand the material. Students may become fatigued or not become engaged and randomly click their way though activities or assessments (Kim, Hannafin, & Bryan, 2007). I believe that these difficulties may be reduced with good navigational design, open-ended assessments that do not have a right answer posted online to discourage searching for the right answer, and making the material relevant to college students to engage them.

Social aspects of computers

The instructor functions as part of social knowledge construction, and this may be done through the medium of the computer. It is evident by the popularity of social networking services like Myspace and Facebook that many people are attracted to interacting with other people with a computer. Discovery learning is a student-centered form of learning that allows students to construct their own knowledge, but it is not effective without some interaction with an instructor. One of the roles of the instructor is to help bridge between science concepts, terms, and the commonsense knowledge that students already have (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Additional interaction from the instructor was more effective in an online problem based learning class on molecular biology and biochemistry, especially, for students with poor problem solving skills (Anderson, W. L., Mitchell, & Osgood, 2008). Sometimes a computer can act as an instructor, especially when a pedagogical agent, an interactive character that gives directions, leading questions, and feedback to learners, is used. It has been found by Moreno, Meyer, Spires & Lester (2001) that using pedagogical agents that speak rather than present text increase test scores, information retention , and transfer of problem solving skills to new situations. It was also found that the pedagogical agent did not need to be visible – the words alone caused increased test scores. Students can also benefit from input from their peers in a learning situation. Students working collaboratively to learn about dc circuits were able to enhance their critical thinking skills more than learners working without other student input because they had to defend their answers (Gokhale, 1995). Creating an environment for social learning in an online situation is challenging. In an online course on inquiry practices in the classroom, pre-service math and science teachers created and improved inquiry based activities for their classrooms by sharing them in a virtual classroom they each created and giving each other feedback, successfully creating a social learning environment (Barab, MaKinster, Moore, & Cunningham, 2001). Methods for enhancing peer learning include guided reciprocal peer questioning, peer tutoring, and strategic questioning from the instructor to structure group problem solving (King, 2002).

Another program with similarities to CMap is a Computer Supported Intentional Learning Environment (CSILE). In this program, students share virtual space for producing, searching, classifying, and linking knowledge. Students can comment on each other's products. This type of program can be used as an inquiry based activity, with the same benefits and pitfalls – misconceptions can be represented and never corrected (Dani & Koenig, 2008; Hakkarainen, 2003). An online concept mapping tool called MindNet appears to be no longer available, but it included expert maps, a chat area, threaded discussions, and a concept library to increase social interaction and social construction of knowledge in the map being generated. The author gives good background information on collaborative concept mapping (Cheung, 2006). Concept maps that receive feedback are more representative of the actual process than those that don't get feedback from either instructors or peers. In fact, one study found that concept maps with no feedback do not affect student performance significantly on exams in comparison with the control group that did not use a concept map (Morse & Jutras, 2008).

Discussion boards and chat rooms are another way that students may construct knowledge socially online. However, the research is not conclusive. In a computer program designed to support problem solving for eighth grade students in Turkey, students made use of many of the tools available, but did not prefer to use the chat room or discussion board (Ozden & Åžengel, 2009). In one study, three students did most of the posting while the rest of the class either did not participate or minimally participated and did not get the full benefit of the discussion board (Wickstrom, 2003). Another study showed that discussion boards can be used successfully to build online community. Student interns in teaching used discussion boards to discuss their experiences with a reading buddy in a school and found the experience to be very beneficial. They also formed an online community that continued discussions outside of class (Nicholson & Bond, 2003). When a classroom community instrument was used to assess how well an online course created community, females indicated more community than males, who were more likely to try to do their work on their own (Rovai, 2001). Day (2004) provides some background for enhancing learning communities online with adults. Adult learners are pragmatic learners and want to learn only what they will actually use. Clear guidelines for participation must be used, such as respecting other's opinions and thoughts and proper netiquette. If participants on a discussion board see the discussion board as helpful to the process of solving these problems, they will use it for feedback and social construction of knowledge. Some students, however, may feel more comfortable figuring things out on their own (Day, 2004). Several authors have reported ideas for making discussion boards more appealing to students, as well as ways to assess student postings (Markwell, 2005; Marra, Moore, & Klimczak, 2004).

Attitude toward science

Many of my non-science major students have stated that they chose biology over other sciences because they perceived it as less difficult, primarily that it involved less math, and more interesting than other sciences. Their attitude toward science, including biology, influences their level of apprehension in the class and their motivation to learn deeply rather than simply try to pass the class (Nasr & Asghar, 2011; Partin et al., 2011). Their attitude toward biology after experiencing a biology course will influence their decisions concerning medical issues, environmental issues, and other important issues that they will be voting on and deciding on for themselves in their own lives. Students' attitude toward science begins to form early on, and most people start out with a positive attitude toward it (Prokop, Prokop, & Tunnicliffe, 2007).

Several attitude scales for biology exist (Cepni et al., 2006; Kara & Yesilyurt, 2008; Nwagbo, 2006; Yesilyurt & Kara, 2007). A Biology Attitude Scale, with a test-retest reliability of .90, has been developed by Russel and Holland (1975) for use with college students, and has been used by other researchers as well (Partin et al., 2011). This attitude assessment was selected because it was written for college students rather than elementary students, yet focused on simple aspects of attitude such as dislike, fear, fun, and enjoyment. It was also easy to modify to specify topics within biology such as photosynthesis and cellular respiration.

Attitude instruments are usually based on Likert scale statements, some with forced choice (only four options) or a middle ground (five options) for rating how much the student agrees or disagrees with a statement. Validity of these instruments is not often reported. Likert scales result in ordinal data. Likert scale results can be compared using an F-test or Pearson's correlation as long as they have at least 5 Likert response choices (Carifio & Perla, 2007).

Assessing Students' Understanding of Photosynthesis and Cellular Respiration

Many studies make use of multiple-choice assessments to measure understanding of topics in science *e.g.*, the biology achievement test (BAT) (Nwagbo, 2006) or the cell achievement test (CAT) to measure student understanding of cell division. The CAT was used in conjunction with the cell division concept test (CCT) that used open-ended questions to assess misconceptions (Yesilyurt & Kara, 2007). These instruments used together measured both the students' understanding of a subject and the students' misconceptions.

Open-ended instruments give the most flexibility outside of interviews in capturing the student's conceptual understanding of science topics. They are also more difficult to score since they are time intensive and require a scoring system. Songer and Mintzes (1994) used an open-ended instrument along with interviews and concept maps to assess understanding of cellular respiration. The open-ended instrument posed scenarios such as a swimmer taking a deep breath before diving and asked students to explain why this needs to happen. Four of these scenarios were presented to the students. The instrument was validated with a Fry readability scale level of ninth grade, and a panel of eight scientists and/or science educators evaluated it for clarity and accuracy; also, they evaluated the answers that would be used as a standard to compare the student responses against (Songer & Mintzes, 1994). This instrument allowed them to measure conceptual change in these students and to give more flexibility to capture student conceptualizations.

To give a better picture of the students' knowledge, some researchers combine multiple-choice items with short answer items (Dogru-Atay & Tekkaya, 2008) or use open-ended instruments (Rotbain, Marbach-Ad, & Stavy, 2006). or drawings in conjunction with multiple-choice instruments (Williamson & Abraham, 1995).

Another way to combine multiple-choice questions with more open-ended questions is the tiered assessment. One of the reasons for including multiple tiers into these assessments is to use a conceptual change learning perspective that takes prior knowledge and alternate conceptions into account (Tsui & Treagust, 2010). The two-tiered instrument could be used to look for misconceptions, and a lack of misconceptions with this instrument means that students have a correct conceptual understanding. A two-tiered instrument has multiple-choice questions as the first tier and the second tier has either multiple-choice options to determine the reason for the student's choice in tier one or, it has an open-ended question asking for the students reasoning for their answer in tier one. Some of the initial development of the two-tiered instrument was done by David Treagust in 1988. He developed a method for choosing multiple-choice items to detect misconceptions from interview questions to be used by teachers in their classrooms (Treagust, 1988). An example of a three-tiered assessment was used to assess tenth grade physics students' understanding of the nature and propagation of waves. In this instrument, each multiple-choice question is paired with multiple-choice options for a reason for their answer and a confidence rating scale. The confidence scale gave the researchers data on how strongly the students held their alternate conceptions (Caleon & Subramaniam, 2010).

Two-tiered instruments have been used to assess understanding of several topics in science. A two-tiered instrument, originally designed by Odom and Barrow (1995), was used to measure college biology students' understanding of diffusion and osmosis, as well as their ability to answer factual questions correctly. The researchers used this instrument to measure the difference between instruction in a constructivist classroom and a traditional classroom (Christianson & Fisher, 1999). Another two-tiered instrument was developed to diagnose tenth grade students' understanding of reasoning in genetics. The instrument was refined based on teacher feedback, student interviews, and student interactions with a computer program used to teach genetics (Tsui & Treagust, 2010). A two-tiered instrument has also been developed for measuring conceptual understanding (in the form of misconceptions) of photosynthesis and respiration. This instrument, called the "What do you know about photosynthesis and respiration in plants?" instrument, consists of 13 multiple-choice questions with choices of reasons for students' answers in the second tier. Included in the second tier is one choice with blank lines for the student's own reason. When both tiers were used, this instrument had a Cronbach's coefficient alpha measurement of internal consistency reliability of .72. It was also analyzed for reading level, difficulty level of questions, and discrimination index and found to be acceptable for grades 8-12 (Haslam & Treagust, 1987). This instrument has been used by several researchers to assess conceptual understanding of photosynthesis and respiration. Griffard and Wandersee (2001) offer a critique of the "What do you know about photosynthesis and respiration in plants?" instrument. They compare the two-tiered instrument to an open-ended instrument or an interview in its ability to externalize the student's reasoning for their choice. When multiple-choice items are present, they may give clues as to the correct answer in the second tier of reasons for making that choice. Students may use logic, test taking strategies, or other less valid ways to answer questions that do not represent their conceptual understanding. One way to test the validity of an instrument is to have students think aloud and record their thoughts as they take the instrument and then compare their thoughts with the choices on the instrument. In this critique of the two-tiered instrument, Griffard and Wandersee asked six college students to think aloud while taking the assessment and interviewed them immediately after taking the assessment. The think aloud results showed that the test underestimated the students' knowledge. These six students treated the second tier, which was intended to be used to justify their answer in the first tier, as a second multiple choice question. Multiple-choice instruments, with or without tiers to them, rely heavily on wording to assess conceptual knowledge. Tamir (1989) also showed that altering the first tier may affect responses to the second tier by presenting a biology test with three types of first tiers, one to each group, with a second tier for the students to write a short justification for their answer to the first tier. Having the correct answer circled in the multiple choice question of the first tier increased the justification scores, but presenting only the correct answer with the question significantly decreased the justification scores. This indicates that students may be getting clues from the other choices in the first tier for their justifications (Tamir, 1989). There are some major problems with using the "What do you know about photosynthesis and respiration?" instrument as it has been used by other researchers. Considering Tamir's findings, this instrument could be used as a short answer test where a correct statement is given and the student writes a short justification on why the statement is correct. This approaches an open-ended question set in form and in analysis.

Another more open-ended assessment is the concept map. Concept maps are a way of representing knowledge and how the information is connected. Mapping can facilitate students' construction of knowledge by allowing them to place their internal conceptualizations of ideas in a tangible format. Concept maps are commonly used as assessment tools in science. They may be used with a given set of concepts to map, as in a study done with seventh grade students in Taiwan where students were asked to map 12 concepts relating to matter cycling and energy flow in relationship to food chains, photosynthesis, and respiration (Lin, C. Y. & Reping, 2003). Concept maps have been used in conjunction with other assessments, as in a concept map of photosynthesis used before and after instruction alongside multiple-choice items on an exam and a questionnaire on study habits to determine whether a student was a rote learner or a deep learner. This concept map was also constructed with a given set of 13 concepts (Hazel & Prosser, 1994).   Concept maps have also been used with no given sets of concepts. A concept map was used in conjunction with a multiple-choice exam to assess student understanding of momentum and inertia in physics, and the correlation between the concept map and the exam was weak. This may be due to the different aspects of knowledge that are measured by each – structure of knowledge in the map and knowledge without relationships between concepts in the exam (Ingec, 2009). In mathematics, no correlation was found between multiple-choice exam performance and concept maps scored with a synthesis of Novak (2003) and McClure et al. (1999)'s scoring methods. However, there was a meaningful correlation between the concept map scores and traditional math exams where students work problems (Ozdemir, 2005). The correlation between concept map scores may vary with the type of assessment that the concept map is being compared to, with multiple-choice assessments being low in correlation and short answer, essay, and problem solving assessments being higher in correlation. The low correlation between concept maps and traditional multiple-choice tests actually makes concept maps useful if they measure a different aspect or a more complete aspect of student knowledge. A concept map used in conjunction with an instrument that has some multiple-choice and some more open-ended questions should help triangulate the students' knowledge; both from a structure of knowledge perspective from the concept map and from a broad range of specific questions designed to elicit misconceptions in the multiple-choice items. Ingec's (2009) scoring system, which assigns points for specific accomplishments in the concept map, and McClure's relational scoring system with a master concept map appear to be some of the better ways to score concept maps (McClure et al., 1999). There is also work being done on automated concept map analysis that looks promising, but does not appear to be available yet (Ifenthaler, 2008).

Concept map quality may be improved by student feedback as well as instructor feedback. Giving students practice at making a concept map with feedback will generate the best representations of the students' knowledge on their concept maps. When concept maps were compared between those prepared individually and those prepared by consensus in groups, group prepared concept maps were much more organized and complete. Concept maps of energy metabolism in photosynthesis and cellular respiration tended to show a lack of connections between these two related processes in the form of horizontal links, even when students were instructed to give special attention to making horizontal links between them (Morse & Jutras, 2008). The use of concept mapping as an instructional tool, with proper preparation and peer feedback, increased final exam scores and decreased failure rate, as well as increased retention of knowledge at the beginning of the next year. Morse and Jutras also used a free computer tool that allowed for concept map creation and even collaboration on a concept map called CMAP tools (Canas et al., 2004). Other computer programs have been used for concept mapping, including SemNet, which was replaced with Semantica 2.1 (Ahmed et al., 2003; Christianson & Fisher, 1999). A computer tool makes concept mapping more efficient, with less time taken to modify concepts or links. The CMap program from the University of West Florida allows for formation of online discussion groups and attachments of icons (pictures, video, urls, other concept maps) to concepts in the students' concept map. The CMap program may be downloaded free of charge at: http://cmap.ihmc.us/download/.

Several instruments have been developed specifically to measure students' understanding of photosynthesis and cellular respiration, such as the PRCAT, the Photosynthesis and Respiration Concept Achievement Test. In its final form, it consisted of seventeen multiple-choice questions. It was examined by a group of experts for content validity and had a reliability of .73. It was used in conjunction with six open-ended questions both as a pretest and a posttest to test whether dual situated learning situations were effective. The open-ended questions were scored with a rubric that gave the response a score of two for a complete understanding, a score of one for a partial understanding (with no misconceptions), or a score of zero for no understanding (nonsensical or having misconceptions) (Akpinar, 2007). A second study to use an all-multiple-choice assessment in conjunction with other assessments used the photosynthesis achievement test (PAT) (Cepni et al., 2006). A third assessment, which is the photosynthesis concept test, was developed from Anderson's (1990) written test on photosynthesis and respiration and modified on the basis of interview data. Anderson's test was included in his article and it had 13 questions made up of multiple-choice, drawing missing parts, circling the best answer, and open-ended questions. Anderson checked the validity of the written test by conducting interviews before and after instruction with seven students to see if the test results matched the interview results. The test was field-tested and was a combination of modified questions generated by Anderson and questions from other researchers. Each test item went through a process of hypothesizing about the student's conceptions about a specific item, writing and testing the item, interviewing the students, coding the interviews, and making modifications to the item as needed. Each item went through this cycle until a satisfactory product was produced (Anderson, C. W. et al., 1990).

Non-science majors' apprehension about science tends to make them more comfortable with the multiple-choice format, even though that reveals less about their conceptualization of a topic than open-ended questions. Even open-ended questions have limitations, such as how many misconceptions they can reveal and how quickly a student gets fatigued in answering these questions. By combining multiple-choice questions with some short answer questions, an instrument can have flexibility in the kind of data it captures without fatiguing the students.

The photosynthesis concept test has a wider variety of types of test questions and Anderson's version has items for both photosynthesis and respiration in it, making it a better choice over the photosynthesis achievement test, which only measures students' understanding of photosynthesis. Having both multiple-choice and open-ended questions gives a more accurate picture of students' understanding. In using a multiple-choice, true false, and short answer instrument in conjunction with a concept map, the data may be triangulated to get a better picture of what the students understand about photosynthesis and cellular respiration.

Summary

Photosynthesis and cellular respiration are difficult concepts to comprehend due to their unobservable nature, incorrect or incomplete conceptions that college students bring with them from prior experiences, and a lack of background knowledge of chemical reactions. Computer-aided instruction has been shown to be beneficial in helping students understand difficult concepts. A primary consideration in designing a computer program to help students learn about a difficult topic is the incorporation of constructivist principles. Furthermore, reducing cognitive load on students allows them to free up more resources to work on the problem, and spend less effort on side tasks such as remembering definitions or how the new knowledge fits in with the prior knowledge. Cognitive tools can be used to help reduce cognitive load. A clean and well-designed user interface with only pertinent information concerning the problem also helps to reduce cognitive load. Students need tools to promote construction of their own knowledge, such as investigative labs where they can test their own predictions or concept maps to help them visualize how the information connects to familiar ideas. Tools that promote social construction of knowledge are also useful to help the students work with other students and instructors to test and generate ideas. Information may also be represented in multiple formats. For example, animations, text definitions, and images may be used to represent an idea thus giving the student multiple views to use in constructing his or her knowledge. Students' academic achievement may also be affected by their attitude toward science, so a computer program should also be designed to make the content interesting and engaging.

Students' understanding (beyond the simple definitions of terms) may be determined by using several different types of assessments. Multiple-choice is easy to score but limited in the breadth of information it yields. Short answer or open-ended questions give a little more information, but may fatigue students if too many are used. Tiered assessments combine multiple-choice questions with reasons for correct answers; however clues about the correct answer may be included with the reasons. Concept maps help elucidate the structure of students' knowledge to find missing parts or incorrect links. They can give more information than a multiple-choice test because of the many possible ways students can structure their concept map, but they are also time-consuming to score. Students can improve their concept making skills with practice. Combining multiple-choice questions, a few short answer questions, and a concept map, that the students have had some practice at making, gives information on specific known misconceptions in the multiple-choice and short answer questions. Also, the combination gives a good picture of the overall understanding of photosynthesis and cellular respiration, which may show problems in understanding that the multiple-choice and short answer do not.

This research seeks information on how these design principles, when combined in a computer program designed to work online, can influence college students' understanding of photosynthesis and cellular respiration. It stems from a desire to create a way for students to have equal access to resources for learning. The college non-science major often enters a biology course fearing that the material will be too hard and he or she will not be able to pass the course. Photosynthesis and cellular respiration are two topics that are difficult for them to grasp. If these topics could be made more comprehensible, it could make biology less scary and help the non-science major rekindle the love of science that so many students lose somewhere in elementary school.

Chapter 3

This chapter describes how this research was conducted, including the sample, the design of the study, and how the data were collected and analyzed. The design of the CELE program is also included in Appendix A.

Research questions

This study examined the effects of computer-based instruction on academic achievement, student held misconceptions, and attitudes toward osmosis/diffusion and photosynthesis/cellular respiration. It compared the CELE program to traditional instruction in a packet-driven course with text book support and some instructor interaction in a traditional laboratory setting for students learning about photosynthesis and cellular respiration.

There are three questions that were investigated in this study.

1. What difference can be seen in academic achievement between college students using the CELE program and those using packet driven, textbook assisted and instructor assisted instruction?
2. What difference can be seen in student held misconceptions between college students using the CELE program and those using packet driven, textbook assisted and instructor assisted instruction?
3. What difference can be seen in attitude toward studying microscopic cellular processes between college students using the CELE program and those using packet driven, textbook assisted and instructor assisted instruction?

It was predicted that the CELE program, designed using constructivist principles, would more positively affect academic achievement, reduce misconceptions, and improve attitude toward microscopic cellular processes in comparison to the instruction delivered via a packet or a textbook, with minimal instruction from the instructor.

Participants

The study sample included college students who took a biology class for non-science majors at a community college in Texas. Participants were recruited from 114 students who were enrolled, 51 students chose to participate, and 42 completed the study. Of the nine students who did not complete the study, four students dropped the course before the academic achievement pretest, another four students did not complete the post-instruction attitude survey, and one student who completed the post-instruction attitude survey did not complete the academic achievement posttest. Only 32 students submitted the concept map due to time constraints and lack of a clear grade value given to the concept map.

The participants were enrolled in the first semester of biology for non-majors, and received instruction on the scientific method, basic chemistry, cells, and energy in cells before beginning the topics of photosynthesis and cellular respiration. The students were enrolled in this class in the summer of 2012 for the first session of the summer. At the beginning of the study, there were 26 students randomly assigned to the treatment group and 25 students randomly assigned to the control group. Participants for the study were recruited based on being enrolled in the course and consenting to participate in the study.

Materials

Materials for Regular Instruction

In this study, students in the control group used the text book Biology Concepts and Investigations (Hoefnagels, 2012) and the laboratory activities packet that they printed from ecampus before coming to class. This packet included directions for the activities and an answer sheet section, where the students filled out answers to questions. Laboratory activities in the control group included observing pigments in leaves, the absorption spectrum of chlorophyll, observing gas bubbles on *Elodea* under light, labeling models of a chloroplast and a mitochondrion, and observing fermentation in yeast by the volume of gas produced by the yeast in various solutions.

Assessments

Because the pretest and the posttest were both modified from other instruments, they were both piloted with five people to establish the clarity of the questions and to establish whether the questions will elicit responses that could be used to measure misconceptions. The instrument was given to each of these five people on a computer, and each person wrote both his or her answer and what he or she was thinking as he or she answered the questions. This included thoughts about what the question was asking, or what a word meant, or whether one answer or another was correct and why. The responses from this pilot were used to edit the pretest and the posttest for clarity and for the best wording to elicit a response pertinent to the misconception being measured.

To determine whether the groups of students that were compared in this study had comparable prior knowledge in biology, the pretest was administered to each group of students (see pretest items in Appendix B). The pretest consisted of: seven questions to determine what students knew about photosynthesis and cellular respiration before they received instruction about it, four questions about genetics to determine prior knowledge of another topic in the course that students had not received instruction in aside from photosynthesis and cellular respiration, one question on matter to determine the students' conceptualization of matter conversion, and four questions about diffusion and osmosis that pertain to the unit that they had just completed before the unit on photosynthesis and cellular respiration. The pretest was modified from Anderson's (1990) instrument and Haslam and Treagust's (1987) two-tiered instrument into a single tier test. The four questions about diffusion and osmosis were modified to one tier test questions from the Diffusion and Osmosis Diagnostic Test, which was also a two-tiered instrument (Odom & Barrow, 1995).

To assess students' understanding of photosynthesis and cellular respiration after instruction, a posttest was used in conjunction with a concept map of the two processes together (see Appendix C for posttest items). The posttest was modified from Anderson's (1990) instrument that was used to assess college non-science majors' understanding of photosynthesis and cellular respiration and was influenced by an instructional model developed by Bishop et al. in 1986, as well as Haslam and Treagust's (1987) "What do you know about photosynthesis and cellular respiration in plants?" two-tiered instrument and Tamir's (1989) lists of misconceptions. A test blueprint was created to include nine of the major misconceptions about photosynthesis and cellular respiration and test items were specifically chosen to address these misconceptions about food, energy, and mass gain in plants and animals.

Students created concept maps of photosynthesis and cellular respiration using CMap tools (Canas et al., 2004) and a list of twenty-six concepts in photosynthesis to include in their map, as well as directions to make at least five connections from their map of photosynthesis to their map of cellular respiration. Students labeled their own propositions between the concepts.

An attitude instrument was used in order to determine whether students' attitude toward science changed over the course of this study (see Appendix E). This instrument was administered to the students before instruction as a pretest and at the end of the summer session as a posttest to determine if there were any changes in student attitude toward osmosis, diffusion, photosynthesis, and cellular respiration after instruction. This attitude instrument included two sets of five repeated items selected from the Biology Attitude Scale from Russel and Hollander (1975). The first set was osmosis and diffusion and the second set was photosynthesis and cellular respiration for a total of ten questions. A total attitude toward instruction score, an attitude toward instruction in osmosis and diffusion, and an attitude toward instruction in photosynthesis and cellular respiration score were calculated from this attitude instrument.

Design

The study used a control-intervention design. Two groups were recruited from classes of students taking a four-week biology course for non-science majors at a community college in the summer. The students in this comparison were randomly assigned to a control group (n=25) and a treatment group (n=26). The control group received regular instruction in the form of a packet of laboratory activities and materials in a traditional laboratory setting as well as a computer lab for computer activities. The control group also had interaction with an instructor as needed while they proceeded through the activities in their packet, meaning that the instructor was checking on student progress and interacting with them to check on their progress and to check their understanding, and students occasionally asked questions. The control group did online activities with McGraw Hill's Connect system with flash cards for their lecture rather than a lecture given by the instructor. The treatment group received this same instruction, except that in the unit on photosynthesis and cellular respiration, for their laboratory activities, they used the CELE program designed to help them build their own understanding online instead of participating in the traditional lab for that unit.

Procedure

Timeline

1. On the first day of class, consent was obtained by the instructors for each course. The students were informed by the researcher that they had the opportunity to participate in a study on how different forms of computer instruction affect their learning for the topic of photosynthesis and cellular respiration. The students were given a paper copy of the consent document to keep that they signed if they chose to participate in the study, which, if they consented to participate, was then digitally photographed and kept in a locked file on a computer at the researcher's home.

Participants were randomly assigned to treatment or control groups and informed of which group they had been assigned to. All participants completed the attitude pretest on paper as part of their orientation session. Participants in the treatment group were given a login to the CELE program and asked to log in once to make sure their login worked.

2. Five class days into the summer session, all participants completed the pretest as part of the unit test for cells and energy, in the form of an online lab quiz.

3. After completing the pretest, participants in the control group completed regular instruction on photosynthesis. Participants in the treatment group completed instruction with the CELE program in one three hour class period, answering the questions posed in the program. The researcher observed the introduction by each instructor and took informal notes on how instruction was carried out, as well as observed and took notes on how the students used the CELE program and how they reacted to it. The CELE program also recorded all activity in the drag and drop laboratory.

4. On the second day of instruction on photosynthesis and cellular respiration, all participants completed a concept map on photosynthesis and cellular respiration and submitted it to their instructor online. Participants were free to collaborate with other students, the researcher, and the instructor on the cellular respiration portion of the concept map, but worked on the photosynthesis portion and the connections between photosynthesis and cellular respiration on their own. The Participants with Instructor 1 had seen a concept map drawn on the board, but had no practice with making concept maps. The students with Instructor 2 did not see a sample concept map drawn on the board, although the evening section did see a sample concept map on the projection screen done by the lab assistant while they were working on their concept maps.

5. On the final exam at the end of the summer session, eight days after instruction in photosynthesis and cellular respiration, 42 participants completed the academic achievement

posttest and 43 participants completed the attitude posttest as part of their final exam on paper. This concluded the data gathering phase of the study.

Data Analysis

Academic Achievement Scoring Methods

Inter-rater reliability was established for the posttest scoring methods before data analysis began. The investigator recruited three additional experts in biology to use the scoring systems in order to establish inter-rater reliability. The master concept map that was used in scoring the students' concept maps was checked by a college biology professor for accuracy.

The pretest, which consisted of all multiple-choice or true/false questions, was scored as percentage correct out of 20 questions. The pretest scores were compared between the treatment and the control group and between the two instructors to determine whether the groups were comparable before instruction in a two-way ANOVA. The items which pertained to photosynthesis and cellular respiration on the pretest were also scored as percentage of questions answered correctly and analyzed between the treatment and the control group and between the two instructors to determine whether these groups were comparable in their knowledge of photosynthesis and cellular respiration before instruction in a two-way ANOVA.

The multiple-choice portions of the posttest were scored as percentage correct. The open-ended questions were scored according to the grading rubric and a score was assigned to each one. Open- ended questions were scored with a modified version of Anderson's (1990) coding system, in which an answer that demonstrated full knowledge of the scientific conception was assigned two points. An answer that demonstrated partial knowledge of the scientific conception was assigned one point. An answer that demonstrated no knowledge of the scientific explanation, was assigned zero points. Additionally, an answer that was partially correct (one point), but gave a very good explanation of the part of the answer that was given was given an asterisk, which was translated into an additional point. Answers that did not demonstrate understanding but used a lot of big scientific terms were marked with two asterisks, which were translated into subtraction of a point. The scores for each item could then range from negative one to two points. In scoring these open-ended questions, after a training session with the first ten posttests, a reliability of 79.3 among raters was obtained by taking the total number of agreements among all four raters for all three questions divided by the total possible number of agreements. The average of the four rater's scores for each question was then used as a percentage correct for each student. These scores were added to the score for the multiple-choice questions to make an overall score for the posttest (see Appendix C). The overall posttest score was analyzed for differences among the treatment and the control groups and students with the two instructors in a two-way ANOVA. Additionally, the number of concepts that were correctly answered was calculated as a percent out of the ten misconceptions measured that were correct conceptions held, and these scores were also analyzed with a 2-way ANOVA to determine if there were any differences between the treatment and the control group and the students with the two different instructors.

The concept maps were scored using a relational method which scores each proposition or connection between concepts individually and then adds up all the proposition scores to make a map score. A master map of photosynthesis and cellular respiration was made using CMap tools and checked for accuracy by a college biology instructor (see Appendix D). The students' maps were compared to this master map of photosynthesis and cellular respiration together using a modification to the relational scoring method described by McClure, et al. (1999). In this scoring system, each proposition (the connection from one concept to another) was scored separately, according to how well it matched the proposition on the master map. If there was no relationship between the concepts, it was assigned a value of zero. If the proposition had a label, but did not indicate a possible correct relationship between the two concepts, it was assigned a value of one. If the proposition had a label that did indicate a possible relationship between the two concepts but some error was present in the proposition such as an incomplete or very general connection or extra information that is incorrect like ATP is a source of energy for the light reactions, it was assigned a score of two. If it had a label that indicated a possible relationship and correctly indicates a hierarchical, causal, or sequential relationship that aligned with the master map, then it was assigned a score of three.

Misconception Scoring Methods

The pretest scores were additionally scored by misconceptions measured. Six possible misconceptions were measured in the pretest. These six misconceptions were compared to the posttest in terms of how many of these same six misconceptions present were still present in the posttest. This was used to create a misconceptions removed score that simply represented the number of misconceptions that were removed after instruction, ranging from zero to six. The misconception scores were analyzed in a two-way ANOVA that determined whether the misconceptions removed were different between the treatment and the control groups and between the two instructors. A second way of analyzing misconceptions was measuring the misconceptions gained from the pretest to the posttest. This was compared between the treatment group and the control group and between the two instructors in a two-way ANOVA to determine if there were any differences in the newly detected misconceptions on the posttest in each comparison. A third way of analyzing the pretest and posttest was to compare the treatment and the control groups and the two instructors in the number of students holding misconceptions that were measured with repeated questions from the pretest to the posttest. Two of the questions on the pretest and posttest were repeated. The changes in their scores were analyzed in a repeated-measures ANOVA to determine if there were any differences between the treatment group and the control group and the two instructors in the change in their scores for these repeated questions.

Attitude Scoring Methods

The shortened Biology Attitude Scale from Russel and Hollander (1975) was modified to assess attitude toward osmosis, diffusion, photosynthesis, and cellular respiration and was rated as an average of participant responses to Likert choice items. All ten questions on the attitude instrument were averaged to calculate an overall attitude rating, while the five items pertaining to osmosis and diffusion were averaged to calculate the attitude toward instruction in osmosis and diffusion rating and the five items pertaining to photosynthesis and cellular respiration were averaged to calculate the attitude toward instruction in photosynthesis and cellular respiration rating. The attitudes survey was scored by totaling the Likert choice items with the negative items scored in reverse so that a one would be a five, a two would be a four, etc. The total was then divided by the number of items; for example, to calculate students' ratings of their attitude toward photosynthesis, the ratings for all five of the items about photosynthesis were totaled and then divided by five.

The attitude pretest scores were compared to the attitude posttest scores for the control group and for the treatment group in a repeated-measures ANOVA that analyzed the effect of time and treatment. This determined whether changes in attitude toward microscopic cellular processes differed with respect to using the CELE program or not using the CELE program, answering the third question about what difference will be seen in students' attitude toward microscopic cellular processes between students who used the CELE program and students who did not use the CELE program. Similarly, the attitude pretest ratings were compared to the attitude posttest ratings for the two different instructors in a repeated-measures ANOVA that analyzed the effect of time and instructor. This determined whether the instructor affected students' attitude toward photosynthesis and cellular respiration.

Chapter 4

Results

Summary

Measurements of academic achievement and attitude were scored and calculated. Descriptive statistics for each measurement, including mean and standard deviation, were calculated. No significant effect of the treatment was seen in academic achievement or change in attitude. No significant effect of the instructor was seen in academic achievement except in the misconceptions gained scores, but the instructor did have a significant effect on the change in attitude toward photosynthesis and cellular respiration.

Results for all Students Combined

Academic Achievement

Academic achievement was measured using the pretest and the posttest. The items on the pretest were subsequently divided into the categories of osmosis and diffusion, genetics, enzymes, matter, and photosynthesis and cellular respiration. Appendix B describes the pretest instrument and the question categories that were used to make the composite scores. The enzyme question category consisted of one question that was either scored as correct (100%) or incorrect (0%). The enzyme category was expected to be answered correctly by most students as it was an application question about the procedure for a laboratory exercise involving catalase enzyme activity from potatoes. Indeed, all but three students answered it correctly. Similarly, the conservation of matter category only had one question and it was included to detect the misconception that matter can be destroyed and the implication that molecules could be built from nothing in photosynthesis. The conservation of matter question was scored in the same way as the enzyme question, with correct being 100% and incorrect being 0%. Twelve students, nearly 30%, answered the conservation of matter question incorrectly. The pretest scores for all students combined had a slightly negatively skewed distribution, with two peaks; one around the mean and one around 65% correct indicating a group of higher-scoring students. The items pertaining to photosynthesis and cellular respiration on the pretest had a positively skewed distribution that was otherwise normal, but most students had a score of 50% correct or less. The standard deviation on the pretest was large (10.6 with a range of 25 to 70, so about 23% of the range). The standard deviation of the items from the pretest on photosynthesis and cellular respiration was also large (18.4 with a range of 0 to 83, so about 22% of the range). The range of scores on the items for photosynthesis and cellular respiration was larger than that for the entire pretest and was more normally distributed. It does not appear that outliers affected the pretest distribution although a possible tendency toward a bimodal population might be what the second peak indicated. No second peak was seen on the items for photosynthesis and cellular respiration.

The posttest consisted of items pertaining to photosynthesis and cellular respiration only, and all but two of the questions were different from those used on the pretest. In general, the number of students answering questions correctly on the posttest was low. The source of energy for plants was only answered correctly by four students, a little less than ten percent of all of the students. The source of energy for animals was only answered correctly by six students, a little less than 15 percent of all of the students. A little less than 29% of all students answered the question about the source of oxygen being water correctly. The posttest sores for all students combined had a large standard deviation of 12.5, with a range of 23 to 73, so the standard deviation covered about 25% of the range of scores. There was a possible outlier on the high end of the scores and a positive skew on the posttest score distribution.

Misconceptions for all Students Combined

In order to answer what difference can be seen in student held misconceptions between college students using the CELE program and those using packet driven, textbook assisted and instructor assisted instruction, students' misconceptions were measured. Table 1 lists the misconceptions that were selected for this study.

Table 1. Selected Misconceptions about Photosynthesis and Cellular Respiration

Code	Misconception	Correct Conception
M1	Plants get their food from something other than carbon dioxide, usable compounds or compounds that may be used as a source of energy, such as water	Plants get their food from fixing carbon dioxide into G3P, forming glucose and other molecules with it. Minerals are also used to build new cell components, so soil minerals may also be food for a plant.
M2	Plants get their energy from something other than light	Light energy powers photosynthesis. Energy is transferred as electrons, so water could also be considered a source of energy (as a source of electrons), but it must be in combination with light.
M3	An animal's energy comes from something other than food/nutrients	Food, in the form of macronutrients, holds potential energy in its chemical bonds that is converted to energy for animals in cellular respiration
M4	Respiration only occurs in the dark in plants	Respiration occurs all the time in plants
M5	Cellular respiration only happens in animals and not in plants	Cellular respiration happens in plants and animals
M6	Respiration in animals is unrelated to the breakdown of nutrients to produce ATP in cells	Respiration (breathing) gives oxygen to the cells to use as a final electron acceptor in the process of breaking down nutrients to produce ATP (cellular respiration)
M7	Mass in plants comes from something other than carbon dioxide	The majority of a plant's body is composed of carbon (cellulose, starch, etc.), which comes from carbon dioxide, not minerals in the soil
M8	Plants do not need light for photosynthesis/light is used for	Light energy is essential for converting the light energy into chemical energy, first as

Code	Misconception	Correct Conception
	something else like keeping plants warm and healthy	ATP and NADPH and then as G3P, glucose, and other organic molecules
M9	Oxygen is produced from something other than photosynthesis/comes from something other than water	Oxygen in photosynthesis comes from splitting water into protons, electrons, and oxygen
M10	Photosynthesis is something other than capturing light energy to build compounds such as G3P, glucose, or starch for energy storage or compounds for building new cell components. For example, that photosynthesis is simply the reverse of respiration.	Photosynthesis is the process of capturing light energy and converting it into food for the plant (G3P, glucose, etc.). Although the reactants and products of cellular respiration and photosynthesis are reversed, these two processes are not the reverse of each other. If the products of cellular respiration were given to mitochondria, the reactants would not be produced.

Four measurements were used to determine which misconceptions about photosynthesis and cellular respiration the students held. These measurements were the misconceptions removed score, the correct conceptions held at the posttest score, the concept maps, and the misconceptions gained score. The pretest and the posttest assessments were used to calculate three of these measurements. The pretest had six questions that specifically asked about selected. The posttest addressed 10 selected misconceptions, with two questions repeated from the pretest to the posttest. These two questions were about energy, one on the source of energy for a plant and one on the source of energy for a human being. These two misconceptions (M2 and M3) about source of energy were analyzed separately as repeated measures to determine whether changes in understanding were due to a different question for each misconception from pretest to posttest or due to changes in student understanding; additionally, these two misconceptions were used in calculating the misconceptions removed score and the misconceptions gained score.

The first measurement, “misconceptions removed” score, was created by checking for each of the six misconceptions on the pretest and looking to see if the same student held the same misconception on the posttest. If the misconception was present on the pretest, but not on the posttest, it was scored as a misconception that had been removed. It is possible that the misconception was removed due to the fact that the misconception was not evaluated on the pretest and posttest with the exact same question and the student understood the posttest question better. The first misconception on the source of food for plants was addressed with four separate questions on the posttest, but one of these questions asked how much of a bean plant’s food was absorbed through the stem and leaves. Students’ response to this question did not correlate well with the other questions about this topic, so this question was omitted from the scoring of this first misconception and the student had to get all three of the other questions about this misconception correct, or partially correct on the short answer question to get a score of not having that misconception on the posttest. This was calculated as the composite score for understanding the source of food for plants. A similar situation arose with a question about whether plants needed light or not and a second question with it followed up with why or why not. All students who answered this question answered that light was needed by plants, but 22 out of 42 participants could not give a correct reason as to why, so only the follow up question about why plants need light was considered in scoring this misconception on the posttest, as it more clearly showed participants’ conceptions of how plants use light.

The second measurement of misconceptions was the correct conceptions held. This measurement came from a count of the correct conceptions out of the ten selected topics that commonly have misconceptions, and it came only from the posttest. The two misconceptions with more than one question addressing them were scored as they were in the misconceptions removed score. The percentage of correct conceptions held out of 10 concepts ranged from 10% to 70% for all students.

The third measurement of the misconceptions held by students is the students' responses on the concept maps. Four misconceptions could be identified on the concept maps, and a count of these four misconceptions was made to create this score. The results from the concept maps are from a very small number of samples, so they can only be used to help corroborate the findings from the other two measures. Other misconceptions or errors outside of the selected 10 could also be detected on the concept maps. Due to students not completing the course or not completing all of the assessments, the number of concept maps gathered was not adequate to score for statistical analysis. The concept maps were scored quantitatively using a relational scoring method with a master map by scoring all of the propositions for a term based on whether the propositions were possible and correct. The number of propositions for each term was counted and then an average number of propositions for each term were calculated. Four of the selected misconceptions to be studied in this experiment (see Table 1) could be verified from the concept maps and a count of the number out of these four misconceptions was made. These misconceptions were about: the source of food for plants, the source of energy for plants, where mass gain comes from in plants, and where oxygen comes from in photosynthesis. A qualitative analysis was made of the concept maps, comparing the overall organization and shape and errors or possible misconceptions about photosynthesis outside of the 10 selected for this experiment (see Table 1). The concept maps were also analyzed for connections between photosynthesis and cellular respiration that were correctly labeled. Several concept maps had to be dropped from the analysis as it was obvious that they were copied from other student's maps, and some did not make any connections between photosynthesis and cellular respiration, so those maps were dropped from the analysis of the connections between photosynthesis and cellular respiration.

The fourth measurement of misconceptions was the “misconceptions gained” score. This measurement was calculated in a similar manner as the misconceptions removed score. The number of misconceptions that were not present on the pretest but were present on the posttest were counted to make the misconceptions gained score. It is possible that the misconception was gained due to the fact that the misconception was not evaluated on the pretest and posttest with the exact same question and the student understood the pretest question better. The repeated questions on the source of energy for plants and the source of energy for animals were also included in the misconceptions gained score.

Figures 1-6 show the percentage of all students combined who held the correct conception for each of the six misconceptions that were assessed on the pretest. Figures 2 and 3 show the difference in understanding the source of energy for plants versus understanding the source of energy for animals. Figure 2 shows a decrease in understanding of the source of energy for plants for all students combined.

Figure 1. Correct Conceptions of the Source of Food for Plants

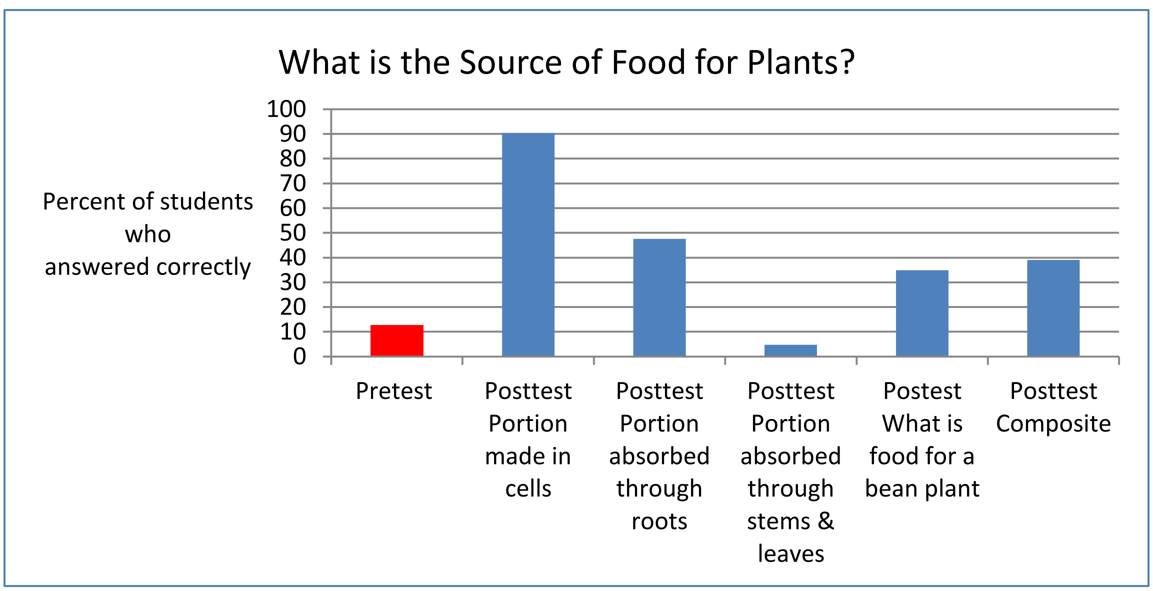


Figure 2. Correct Conceptions of the Source of Energy for Plants

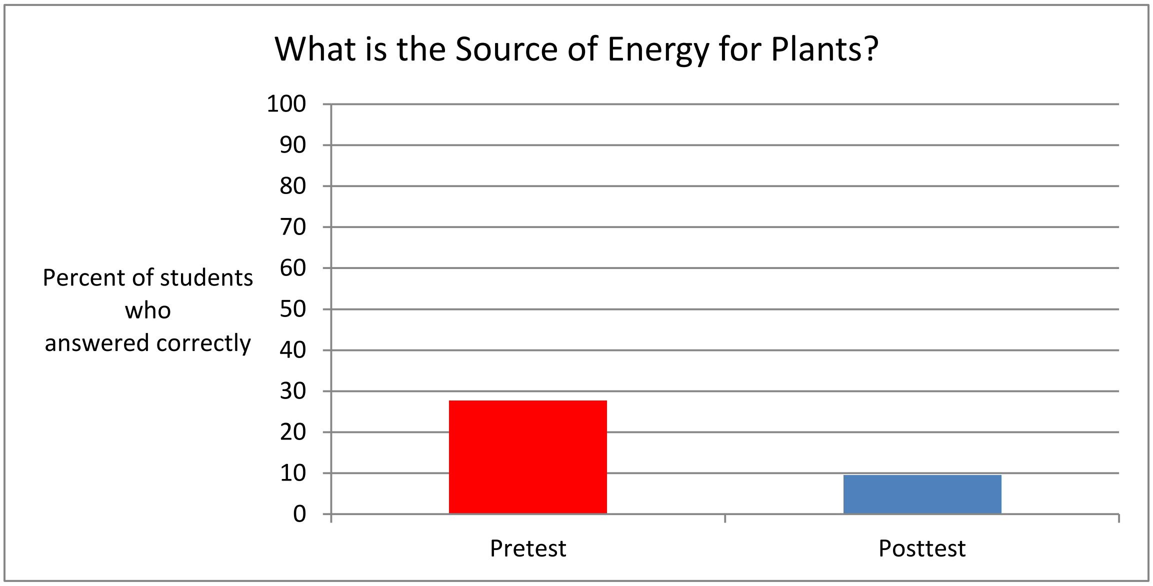


Figure 3. Correct Conceptions of the Source of Energy for Animals

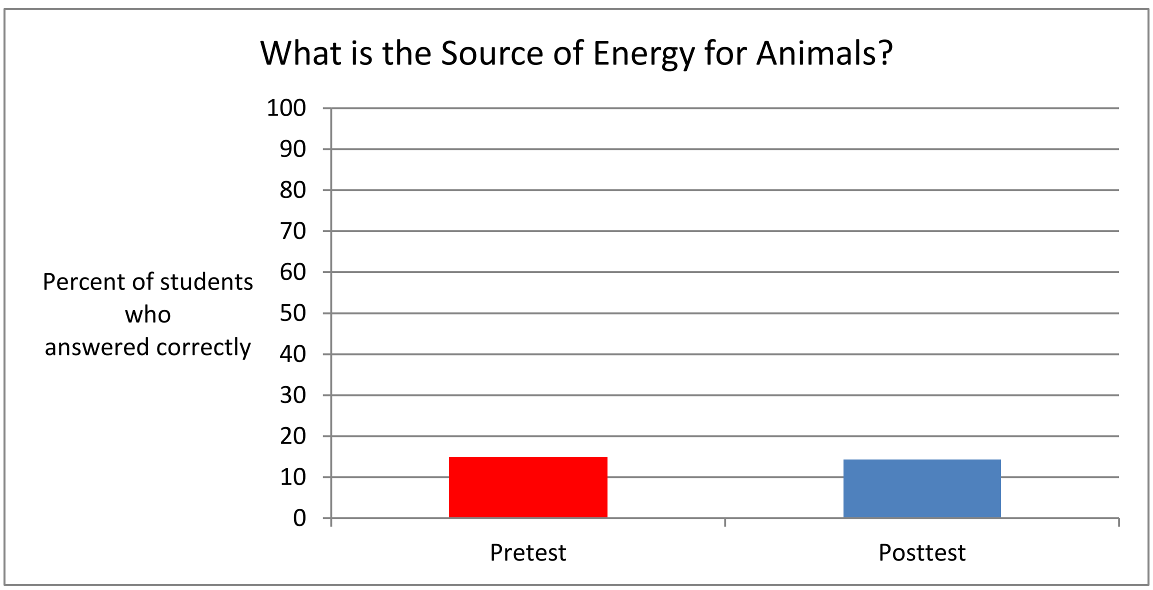


Figure 4. Correct Conceptions of the Timing of Respiration in Plants

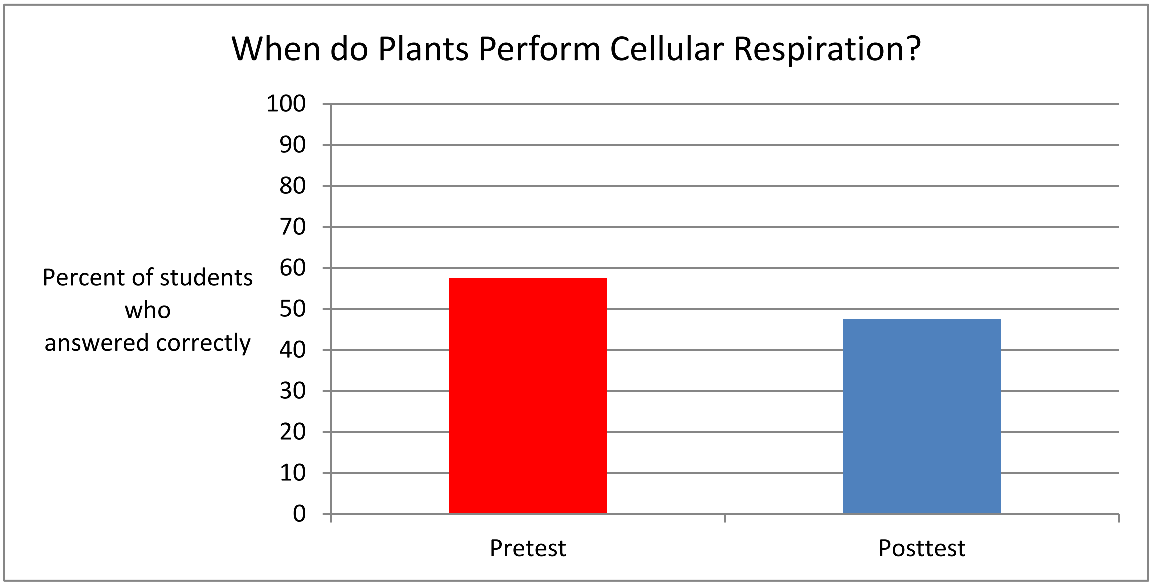


Figure 5. Correct Conceptions of the Source of Mass Gain for Plants

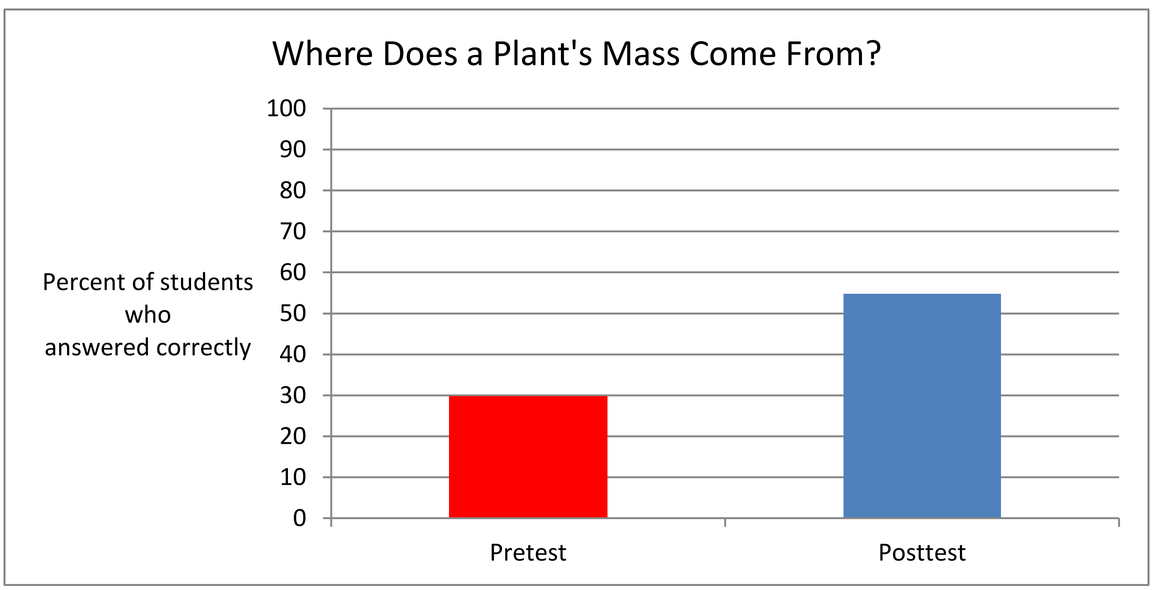
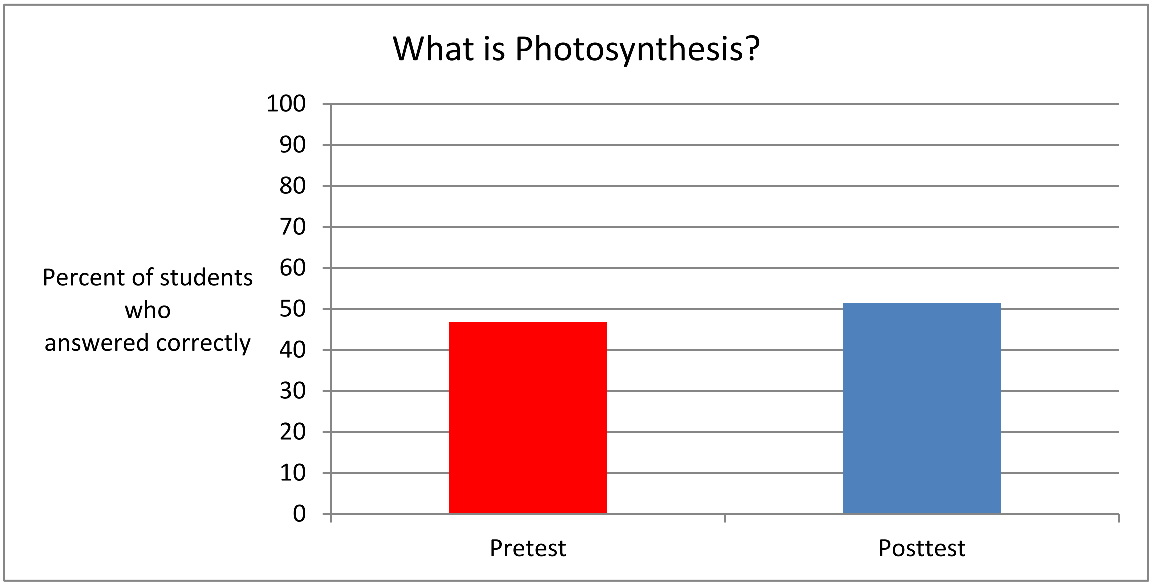


Figure 6. Correct Conceptions of Photosynthesis



Very few misconception measures correlated significantly with each other, either in relating misconceptions detected on the pretest versus those detected on the posttest, or in relating misconception scores within the pretest or within the posttest. Even the two questions that were repeated from the pretest to the posttest did not significantly correlate with each other. An inspection of the number of students who answered correctly on each misconception reveals that there is no difference from the pretest to the posttest between the treatment group and the control group. Table 2 reports individual misconceptions scores as percentage of students answering correctly. Table 3 reports the means for each question on the pretest and posttest that were used to assess these misconceptions.

Table 2. Percent of Students Answering Correctly

Topic	Treatment Pretest	Treatment Posttest	Control Pretest	Control Posttest
Plant source of food	20	10	5	0
Plant source of energy	28	5	27	14
Animal source of energy	0	10	32	19
Timing of respiration	48	55	68	43

Topic	Treatment Pretest	Treatment Posttest	Control Pretest	Control Posttest
Plants have respiration	N/A	55	N/A	48
What is respiration	N/A	5	N/A	0
Source of mass gain	36	50	23	62
Function of light	N/A	45	N/A	48
Source of oxygen	N/A	20	N/A	33
What is photosynthesis	48	15	46	5

Table 3. Percent of Students Answering Correctly for Individual Misconceptions for all Students

Question	N	Mean	Std. Dev.
Pretest_M1 Source of food for plants	47	12.8	33.7
Pretest_M2 source of energy for plants	47	27.7	45.2
Pretest_M3 source of energy for animals	47	14.9	36.0
Pretest_M4 timing of respiration in plants	47	57.5	50.0
Pretest_M7 source of mass gain in plants	47	29.8	46.2
PretestM_10 definition of photosynthesis	47	46.8	50.4
Posttest_M1a source of food for a plant: made in cells	42	90.5	29.7
Posttest_M1b food absorbed through roots	42	47.6	50.6
Posttest_M1c food absorbed through leaves	42	4.8	21.6
Postest_M1_short_answer: what is food for a bean plant	42	35.0	27.7
Posttest_M2 source of energy for a plant	42	9.5	29.7
Posttest_M3 source of energy for an animal	42	14.3	35.4
Posttest_M4 timing of respiration in plants	42	47.6	50.6
Posttest_M5 cellular respiration only happens in animals	42	50.0	50.6
Posttest_M6_short_answer what is cellular respiration	42	25.4	31.5
Posttest_M7 source of mass gain for plants	42	54.8	50.4
Posttest_M8a do plants need light	42	97.6	15.4
Posttest_M8b_explain why do plants need light	42	47.6	50.6
Posttest_M9 source of oxygen in photosynthesis	42	28.6	45.7
Posttest_M10_short_answer what is photosynthesis	42	50.2	33.3
Posttest oxygen is a waste product, not used in photosynthesis	42	40.5	49.7

Attitude

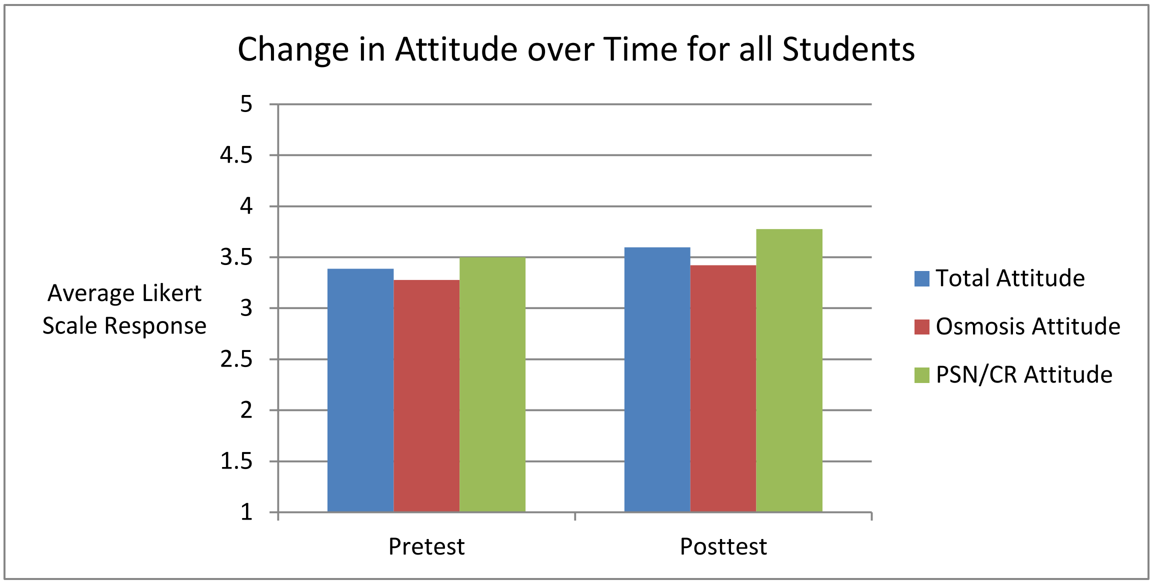
The data on attitude for all students is displayed in Table 4, which shows that mean attitudes ranged from about 3.3 to 3.8 where a five is the strongest positive attitude rating possible. The range of total attitude ratings for all students combined ranged from two to five. The standard deviation on attitude ratings for all students combined was also large, with the smaller one on the pretest of .577 which covered about 21% of the total range of 2.7 (from 2 to 4.7). The mean difference in attitude from the pre-instruction attitude survey to the post-instruction attitude survey was not significant for attitude toward osmosis, diffusion, photosynthesis, and cellular respiration in a 2 X 2 repeated measures ANOVA $F(1,39)= 1.627$, $p= .210$. It was also not significant for the difference in attitude toward osmosis and diffusion $F(1,39)= 1.08$, $p= .305$, but there was a significant difference in attitude toward photosynthesis and cellular respiration for all students from the pre-instruction survey to the post-instruction survey $F(1,39)= 6.485$, $p=.015$. See Figure 7.

Table 4. Attitude Ratings for all Students [a]

Measurement	M(SD)	M (SD)
	Pre (n=51)	Post (n=43)
Overall Attitude toward Instruction	3.42 (.577)	3.6 (.692)
Attitude Toward Instruction in Photosynthesis and Cellular Respiration	3.5 (.572)	3.78 (.742)
Attitude Toward Instruction in Osmosis and Diffusion	3.28 (.636)	3.42 (.771)

[a] ratings from 1-5 with 1 = “strongly disagree” and 5 = “strongly agree”

Figure 7. Change in Attitude Ratings for all Students over Time



Academic Achievement Measures

Table 5 presents the mean pretest scores and the mean composite scores of the percent of questions answered correctly for the six questions on photosynthesis and cellular respiration. A two-way ANOVA revealed that there was no significant difference between the means of the treatment group, control group, students with Instructor 1, or students with Instructor 2 on the pretest scores, meaning that the treatment group and the control group, as well as students with Instructor 1 and students with Instructor 2 could be treated as equivalent before the treatment was administered.

A two-way ANOVA indicated that the participants' knowledge about photosynthesis and cellular respiration in the treatment group and control group, as well as in students with Instructor 1 and students with Instructor 2 was not significantly different before instruction on photosynthesis and cellular respiration. This was measured with a composite score of the percentage of questions answered correctly of the six questions about photosynthesis and cellular respiration on the pretest. The composite score on photosynthesis and cellular respiration had two questions that were repeated on the posttest as well as questions that addressed selected misconceptions that were also addressed on the posttest. The composite photosynthesis and cellular respiration score is more closely equivalent than the pretest score to the posttest score, meaning that the items in this composite score were all related to photosynthesis and cellular respiration like the posttest and unlike the pretest which contained items about other topics such as genetics.

The pretest and the posttest were not the same instrument, so the pretest scores and posttest scores are not directly comparable. Table 5 displays the posttest data. The means of the posttest scores for the treatment and control group, as well as for students with Instructor 1 and students with Instructor 2 were not significantly different in two-way ANOVA, and there was no interaction between treatment and instructor. No significant effect of treatment was seen in the posttest scores.

Table 5. Pretest and Posttest Scores for Treatment and Control Groups

Measurement and Participants	Treatment M (SD) n=25	Control M (SD) n=22	All M(SD) n=47
Pretest Total	49.0 (11.18)	52.73 (9.847)	50.74 (10.631)
Pretest Photosynthesis and Cellular Respiration Items	29.96 (19.119)	33.36 (17.775)	31.55 (18.382)
Posttest Total [a]	43.25 (10.397)	42.73 (14.466)	42.98 (12.544)

[a] N=42, treatment n=20, control n=21

Concept Maps and Academic Achievement

The concept maps showed mixed results. Participants in the treatment group showed better understanding in some areas, but not in others. Table 6 shows the proportion of students whose concept maps revealed different types of understandings and misunderstandings. Overall, the treatment group appeared to have a better understanding of photosynthesis, but not in all areas.

Table 6. Concept Map Data for Treatment and Control Groups

	Treatment	Control
N of maps that were not copied	13	12
Incorrect Conceptions		
Errors in connecting food to other terms	7.69%	0%
Confusing energy and matter	31%	16.67%
Confusing the light dependent reactions with the light-independent reactions	23.08%	41.67%
Incorrectly labeling a pathway, such as ATP making NADPH	38%	50.00%
Confusing cellular respiration and photosynthesis	8%	25%
Labeling photosynthesis as gas exchange	0%	16.67%
N of maps with connections made between cellular respiration and photosynthesis	11	8
Correct Conceptions		
Correctly connecting cellular respiration to photosynthesis in energy use	45.46%	25.00%
Correctly connecting cellular respiration to photosynthesis in food's (glucose) use	63.64%	37.50%
Correctly connecting cellular respiration to photosynthesis in water's role	18.18%	37.50%
Correctly connecting cellular respiration to photosynthesis in the role of oxygen	18.18%	37.50%
Correctly connecting cellular respiration to photosynthesis in the role of carbon dioxide	18.18%	37.50%

Effect of Treatment on misconceptions

Table 7 reports the misconceptions data that were derived from test scores. The treatment and the control groups' mean misconceptions removed scores and the students with Instructor 1 and with Instructor 2's mean misconceptions removed scores did not differ significantly in two-way ANOVA, with no interaction between treatment and instructor. The correct concepts held were not significantly different between the treatment and the control group, or the students with Instructor 1 and the students with Instructor 2 in a two-way ANOVA, with no interaction between treatment and instructor.

Thirty-one students had correct responses to the questions about specific misconceptions on the pretest, but then had incorrect responses to different questions about the same misconceptions on the posttest. The effect of treatment on the misconceptions gained score was not significant in a two-way ANOVA $F(1,37)=.000$, $p=.985$, but the effect of instructor was significant $F(1,37)= 6.799$, $p= .013$, with no interaction between treatment and instructor.

Figure 8 displays the misconceptions data for the misconceptions that were assessed with open-ended questions on the posttest and multiple choice questions on the pretest. Figure 9 displays other selected misconceptions data, including the source of oxygen in photosynthesis.

Table 7. Measures of Misconceptions Removed, Held, and Gained for Treatment and Control Groups

Measurement and Participants	Treatment M (SD) n=20	Control M (SD) n=22	All M (SD) n=42
Percentage of Misconceptions Removed	15.2 (17.0)	15.2 (14.4)	15.2 (15.5)
Percentage of Correct Conceptions Held	27.5 (14.1)	27.3 (16.7)	27.4 (15.3)
Percentage of Misconceptions Gained	24.0 (17.5)	25.0 (17.2)	24.0 (17.1)

Figure 8. Scores on Open-ended Questions for Treatment and Control Groups

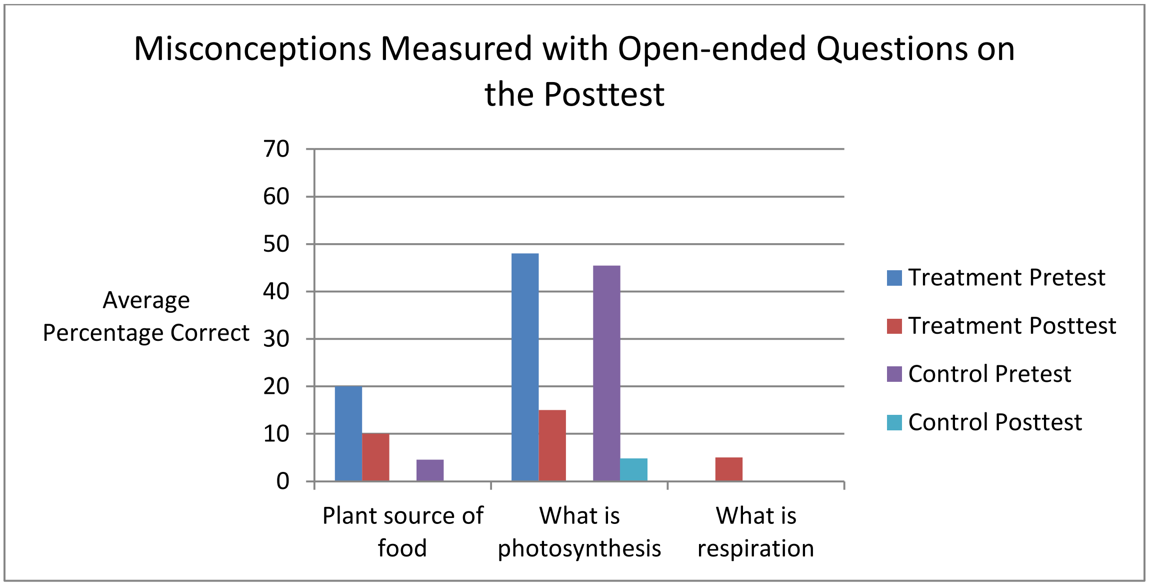
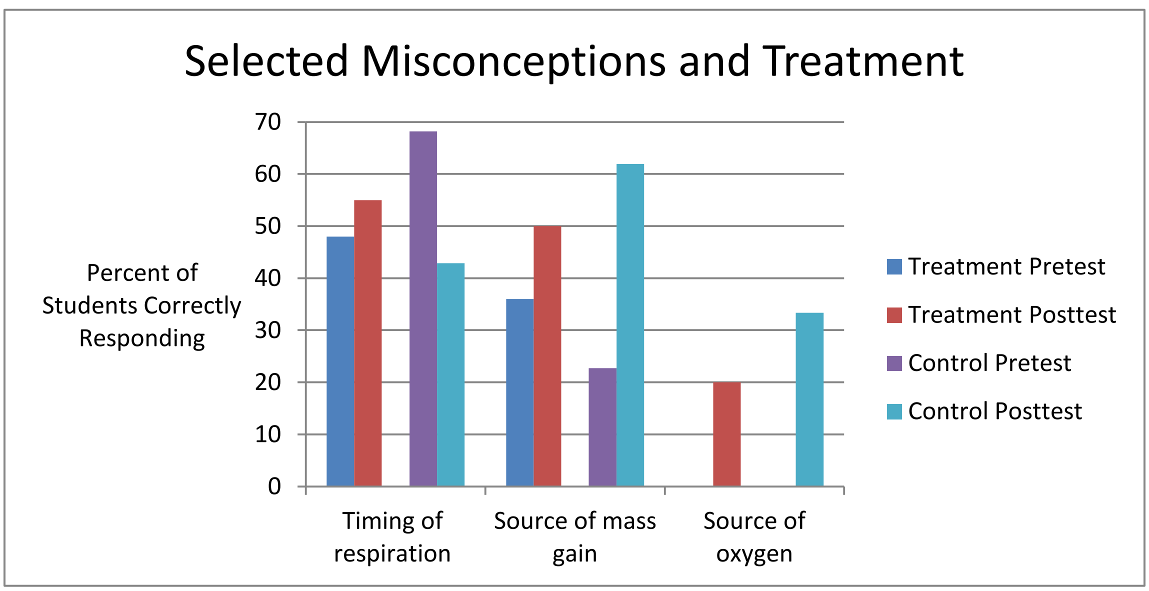


Figure 9. Change in Scores on Selected Misconceptions for Treatment and Control Groups



The pretest and the posttest had two questions that were repeated from the pretest to the posttest. One question was about the source of energy for plants (M2). Table 8 reports the data on individual misconceptions. In a two by two repeated measures ANOVA, the treatment group and the control group were not significantly different in their change of scores from the pretest to the posttest $F(1,39)=.668$, $p=.419$, however, the difference from the pretest to the posttest scores for all students combined on M2 in this analysis was significantly worse $F(1,39)=5.304$, $p=.027$. Misconceptions held about the source of energy for plants increased over time.

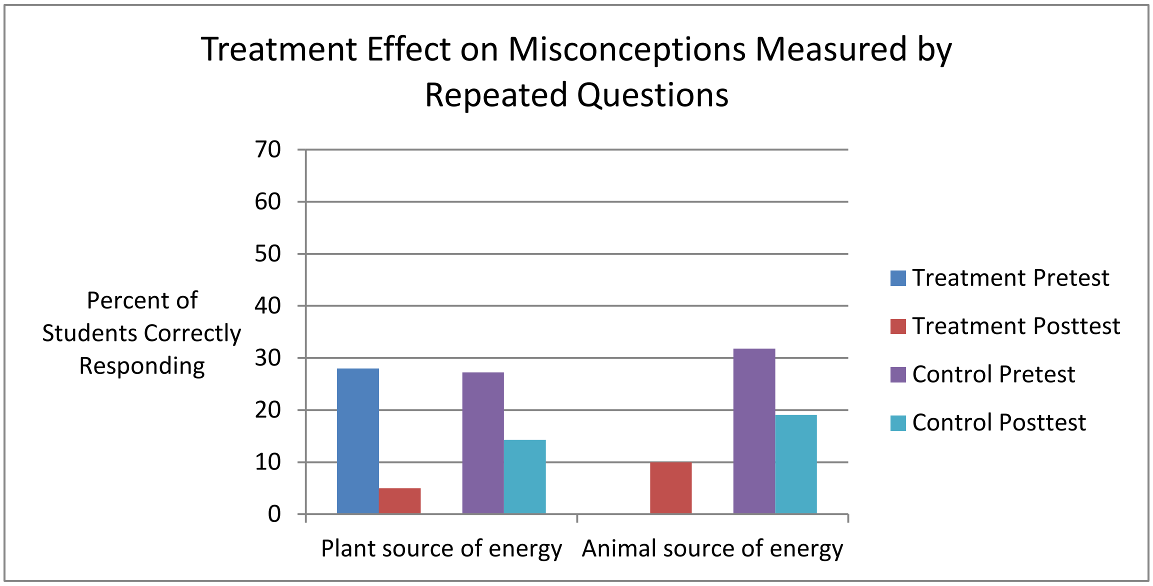
The other repeated question was about the source of energy for animals (M3). In a two by two repeated measures ANOVA, the treatment group and the control group were not significantly different in their change of scores from the pretest to the posttest $F(1,39)= 2.001$, $p=.165$. The difference between pretest to posttest was not significant for M3 $F(1,39)=.001$, $p=.973$. See Figure 10 for a comparison of M2 and M3 misconception scores from pretest to posttest.

Table 8. Mean Scores on Questions that are Repeated from the Pretest to the Posttest for Treatment and Control Groups

Measurement and Participants	Treatment M (SD) n=25	Control M (SD) n=22	All M (SD) n=47
Pretest Percentage of Correct Responses on M2	28.0 (45.8)	27.3 (45.6)	27.7 (45.2)
Posttest Percentage of Correct Responses on M2 [a]	5.0 (22.4)	13.6 (35.1)	9.5 (29.7)
Pretest Percentage of Correct Responses on M3	0.0 (0.0)	31.8 (47.7)	14.9 (36.0)
Posttest Percentage of Correct Responses on M3 [a]	10.0 (30.8)	18.2 (39.5)	14.3 (35.4)

[a] N=42, treatment n=20, control n=22

Figure 10. Change in Scores on Repeated Questions for Treatment and Control Group



Misconceptions on Concept Maps and Treatment

The number of misconceptions out of the four that could be seen on the concept maps varied from zero to four. The average number of misconceptions detected in the treatment group was 1.83 (N=12), and the average number of misconceptions detected in the control group was 2.2 (N=10). The concept map data on misconceptions present is incomplete at best since some concepts did not get connected or used on some student's maps and thus the misconceptions associated with that term would not be detected. The misconceptions that were detected were based on the data available, such as connecting carbon dioxide to oxygen with "becomes" which would be a misconception about where the oxygen produced in photosynthesis comes from. The individual misconceptions detected on the concept maps, when concept maps where all 4 misconceptions could not be determined were removed from the analysis, agreed with the individual misconceptions detected on the posttest 51% of the time (N=20).

Effect of Treatment on Attitude

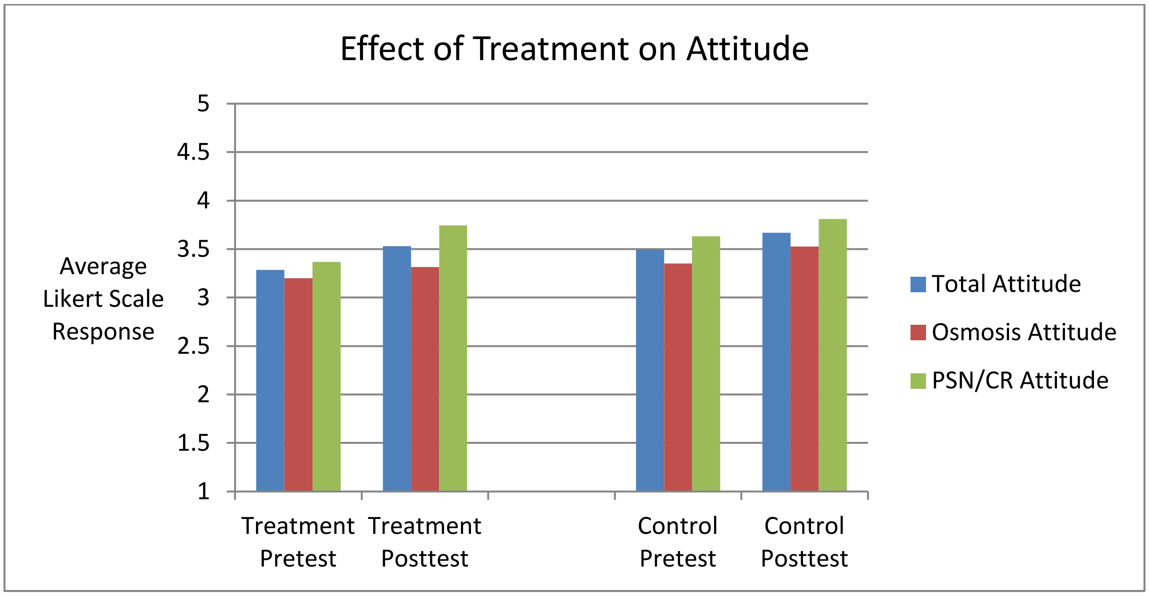
The difference between the mean change in attitude toward osmosis, diffusion, photosynthesis, and cellular respiration between the treatment and control group was not significant in a 2X2 ANOVA with repeated measures $F(1,39)= .304$, $p= .585$. The difference between the mean change in attitude toward osmosis and diffusion between the treatment and control group was not significant in a 2X2 ANOVA with repeated measures $F(1,39)= .349$, $p= .558$. The difference between the mean change in attitude to photosynthesis and cellular respiration between the treatment and control group was also not significant in a 2X2 ANOVA with repeated measures $F(1,39)= .636$, $p=.430$. See Figure 11 and Table 9.

Table 9. Attitude Ratings for Treatment and Control Groups on a Scale of 1-5

Measurement and Participants	Treatment M (SD) n=26	Control M (SD) n=25
Pre-Instruction Overall Attitude	3.35 (.64)	3.49 (.50)
Pre-Instruction Attitude Toward Photosynthesis and Cellular Respiration	3.37 (.64)	3.63 (.48)
Pre-Instruction Attitude Toward Osmosis and Diffusion	3.2 (.67)	3.35 (.61)
Post-Instruction Overall Attitude [a]	3.53 (.73)	3.67 (.67)
Post-Instruction Attitude Toward Photosynthesis and Cellular Respiration [a]	3.74 (.71)	3.81 (.79)
Post-Instruction Attitude Toward Osmosis and Diffusion [a]	3.31 (.89)	3.53 (.64)

[a] Treatment n=21, control n=22

Figure 11. Change in Attitude for Treatment and Control Groups



Effect of Instructor

Academic Achievement

Although the researcher did not plan to study the effect of the instructor on academic achievement and attitude toward photosynthesis and cellular respiration, it became apparent that the instructor might have an effect as the two instructors had very different teaching styles. Table 10 compares pretest data, data on the questions about photosynthesis and cellular respiration on the pretest, and posttest data for each instructor. Again, pretest performance was not directly comparable to the posttest as it also had questions about topics other than photosynthesis and cellular respiration. An ANOVA revealed that the instructor had no significant effect on the mean pretest score, mean photosynthesis and cellular respiration composite score, or mean posttest score. See Figure 12.

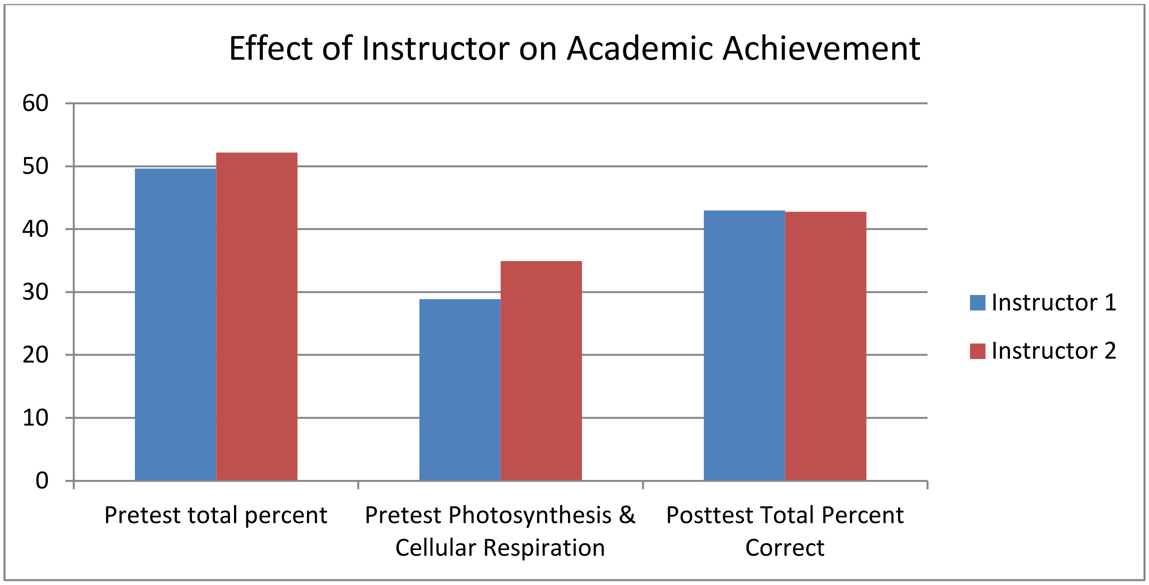
Table 10. Pretest and Posttest Scores for Students with Instructor 1 and with Instructor 2

Measurement and Participants	Instructor 1 M (SD) n=26	Instructor 2 M (SD) n=21
Pretest	49.6 (8.8)	52.1 (12.6)

Pretest Photosynthesis and Cellular Respiration	28.9 (18.0)	34.9 (18.9)
Posttest [a]	43.1 (14.1)	42.8 (10.0)

[a] Instructor 1 n=26, Instructor 2 n=16

Figure 12. Academic Achievement and Instructor



Concept maps and Instructor

The concept maps also revealed mixed results for the effect of instructor on academic achievement. No clear pattern of better understanding was revealed in comparing concept maps from students in Instructor 1's class to concept maps from students in Instructor 2's class. Table 11 displays the concept map data comparison between Instructor 1 and Instructor 2.

Table 11. Concept Map Data for Instructor 1 and Instructor 2

	Instructor 1	Instructor 2
N of maps that were not copied	18	7
Incorrect Conceptions		
Errors in connecting food to other terms	6.67%	0%
Confusing energy and matter	13%	42.86%
Confusing the light dependent reactions with the light-independent reactions	40.00%	0.00%
Incorrectly labeling a pathway, such as ATP	33%	42.86%

	Instructor 1	Instructor 2
making NADPH		
Confusing cellular respiration and photosynthesis	20%	0.00%
Labeling photosynthesis as gas exchange	13%	0.00%
N of maps with connections made between cellular respiration and photosynthesis	13	6
Correct Conceptions		
Correctly connecting cellular respiration to photosynthesis in energy use	36.36%	33.33%
Correctly connecting cellular respiration to photosynthesis in food's (glucose) use	63.63%	33.33%
Correctly connecting cellular respiration to photosynthesis in water's role	27.27%	33.33%
Correctly connecting cellular respiration to photosynthesis in the role of oxygen	27.27%	16.67%
Correctly connecting cellular respiration to photosynthesis in the role of carbon dioxide	18.18%	33.33%

Effect of Instructor on Misconceptions

Table 12 displays the data on misconceptions scores between the two instructors. The effect of instructor on the misconceptions removed was not significant. See Figure 13. The effect of the instructor on correct conceptions held at the posttest was not significant. See Figure 14. However, there was a significant difference between students with Instructor 1 and students with Instructor 2 on the misconceptions gained score in a two-way ANOVA $F(1,37)= 6.799$, $p= .013$, with no interaction between treatment and instructor. See Figure 15 which shows that students gained more misconceptions with Instructor 2.

Table 12. Measures of Misconceptions Removed, Held, and Gained for Students with Instructor 1 and with Instructor 2

Measurement and Participants	Instructor 1 M (SD) n=26	Instructor 2 M (SD) n=16
Percentage of Misconceptions Removed	18.1 (15.5)	10.5 (14.8)
Percentage of Correct Conceptions	28.9 (17.3)	24.4 (10.9)

Measurement and Participants	Instructor 1 M (SD) n=26	Instructor 2 M (SD) n=16
Percentage of Misconceptions Gained	19.0 (16.2)	33.0 (14.9)

Figure 13. Misconceptions Removed Score and Instructor

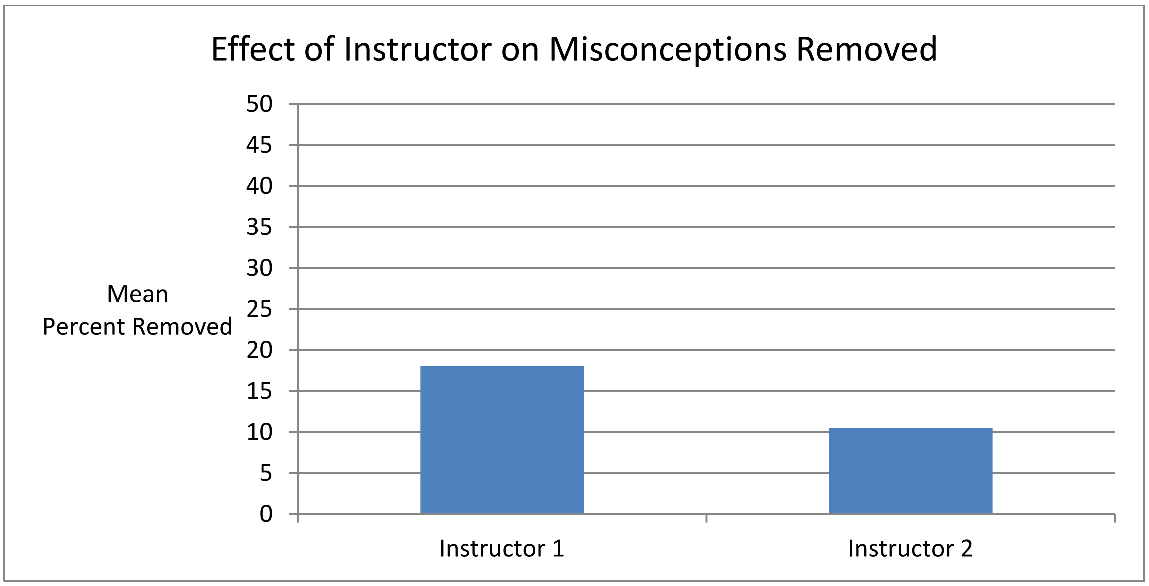


Figure 14. Correct Conceptions Held on the Posttest for Students with Instructor 1 and Students with Instructor 2

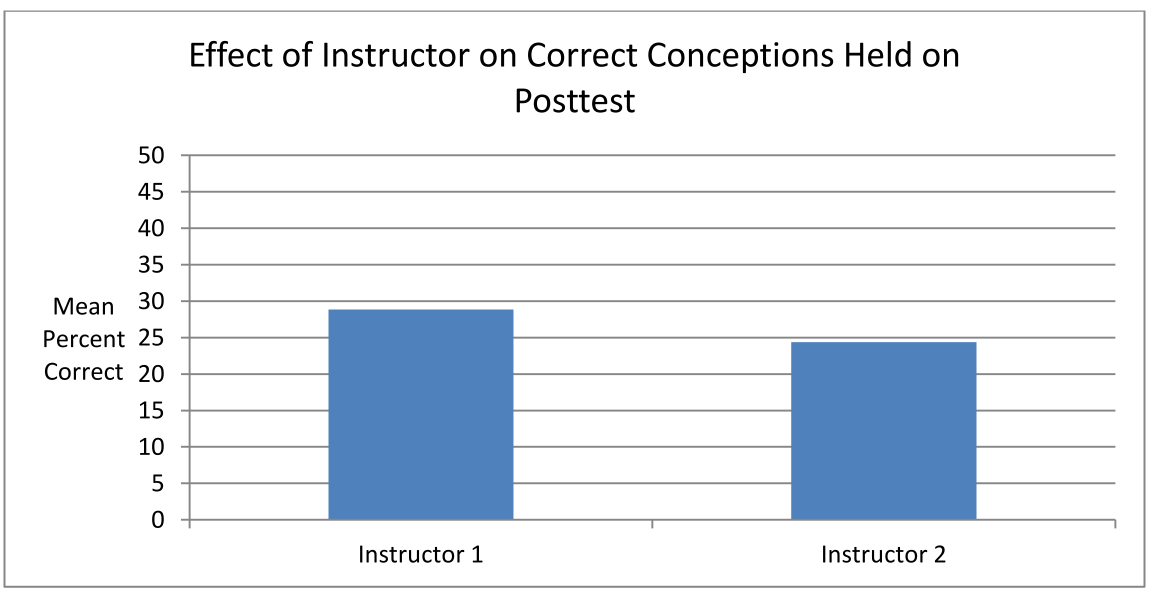
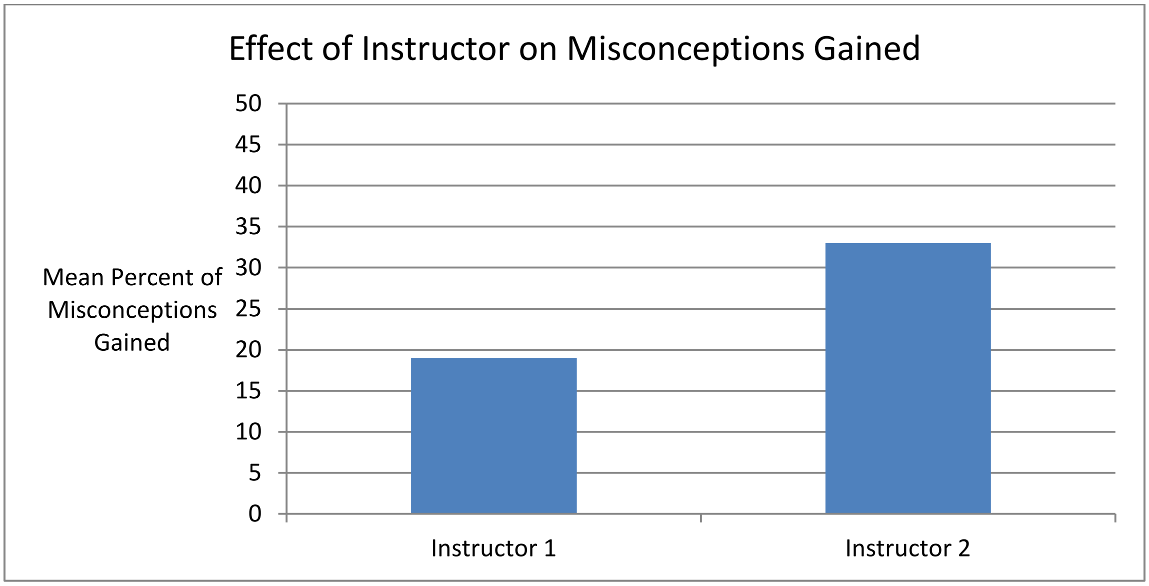


Figure 15. Misconceptions "Gained" Score for Students with Instructor 1 and Students with Instructor 2

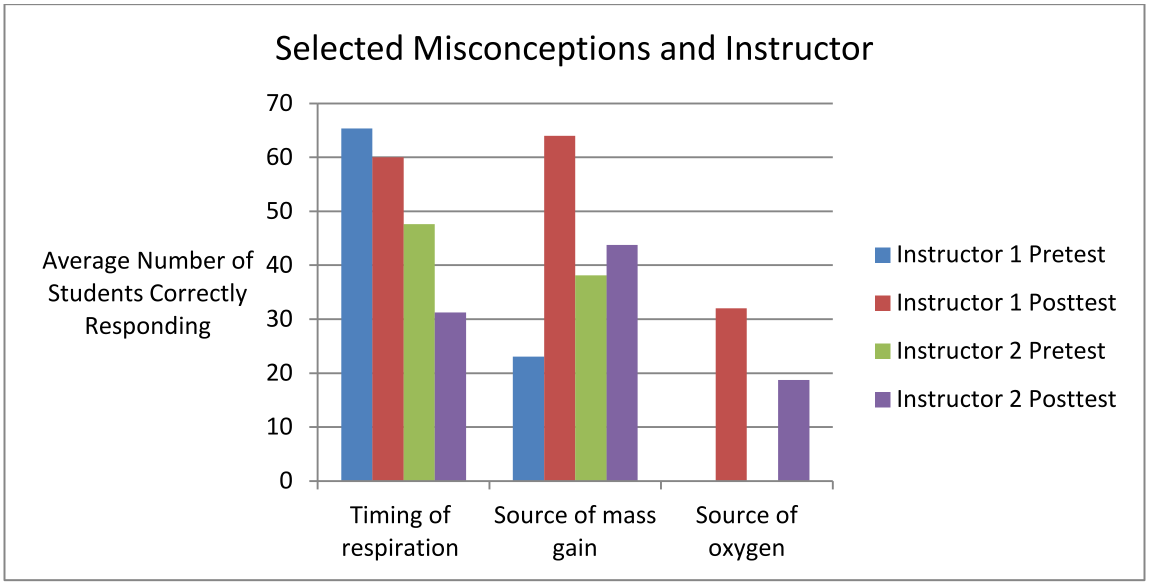


An inspection of the means of individual misconceptions scores between the two instructors revealed no differences between the two instructors. See Table 13 and Figure 16.

Table 13. Average Scores for Individual Misconceptions for Students with Instructor 1 and for Students with Instructor 2

Topic	Instructor 1 Pretest	Instructor 1 Posttest	Instructor 2 Pretest	Instructor 2 Posttest
Plant source of food	7.7	8.0	19.1	0.0
Plant source of energy	26.9	12.0	28.6	6.3
Animal source of energy	15.4	16.0	14.3	12.5
Timing of respiration	65.4	60.0	47.6	31.3
Plants have respiration	N/A	40.0	N/A	68.8
What is respiration	N/A	4.0	N/A	0.0
Source of mass gain	23.1	64.0	38.1	43.8
Function of light	N/A	40.0	N/A	56.3
Source of oxygen	N/A	32.0	N/A	18.8
What is photosynthesis	34.6	12.0	61.9	6.3

Figure 16. Number of Students Correctly Answering Questions on Selected Misconceptions with Instructor 1 or Instructor 2



In a two by two repeated measures ANOVA, the two instructor's classes were not significantly different in their change of scores from the pretest to the posttest on the repeated question about the source of energy for plants (M2) $F(1,39)=.598$, $p=.444$, however, the drop from the pretest to the posttest score for all students combined on the question about the source of energy for plants in this analysis was significant $F(1,39)= 5.741$, $p=.021$. Student responses to the question about the source of energy for animals (M3), when analyzed in a two by two repeated measures ANOVA, showed that the two instructors were not significantly different in their change of scores from the pretest to the posttest $F(1,39)= 0.00$, $p= 1.0$. See Table 14 and Figure 16 for the data on the repeated questions on the pretest and posttest.

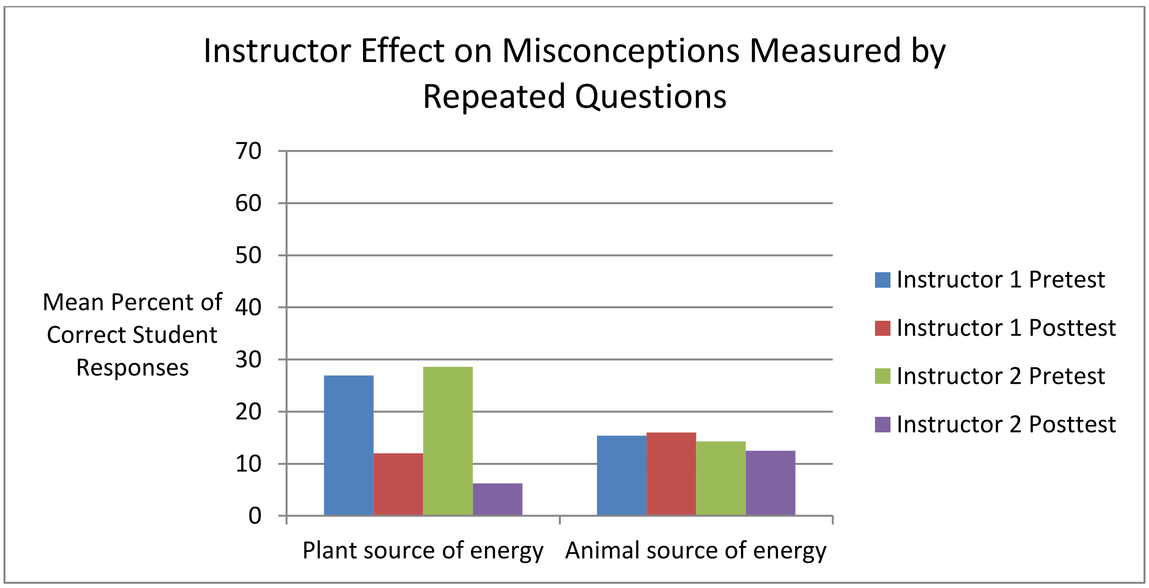
Table 14. Percentages of Correct Scores on Questions that were Repeated from the Pretest to the Posttest for Students with Instructor 1 and for Students with Instructor 2

Measurement and Participants	Instructor 1 M (SD) n=26	Instructor 2 M (SD) n= 21
Pretest Percentage of Correct Responses on M2	26.9 (45.2)	28.6 (46.3)

Measurement and Participants	Instructor 1 M (SD) n=26	Instructor 2 M (SD) n= 21
Posttest Percentage of Correct Responses on M2 [a]	11.5 (32.6)	6.3 (25.0)
Pretest Percentage of Correct Responses on M3	15.4 (36.8)	14.3 (35.9)
Posttest Percentage of Correct Responses on M3 [a]	15.4 (36.8)	12.5 (34.2)

[a] Instructor 1 n=26, Instructor 2 n=16

Figure 17. Percentage of Correct Responses to Questions Repeated from the Pretest to the Posttest for Students with Instructor 1 and Students with Instructor 2



Misconceptions on Concept Maps and Instructor

On the concept maps, the average number of misconceptions detected with Instructor 1 (N=16) was 1.68 and the average number of misconception detected with Instructor 2 (N=6) was 2.14. The misconceptions held ranged from zero to four, from the four selected misconceptions that could be detected on the concept maps. The concept maps indicate that Instructor 1's students may have had fewer misconceptions than those with Instructor 2.

Effect of Instructor on Attitude

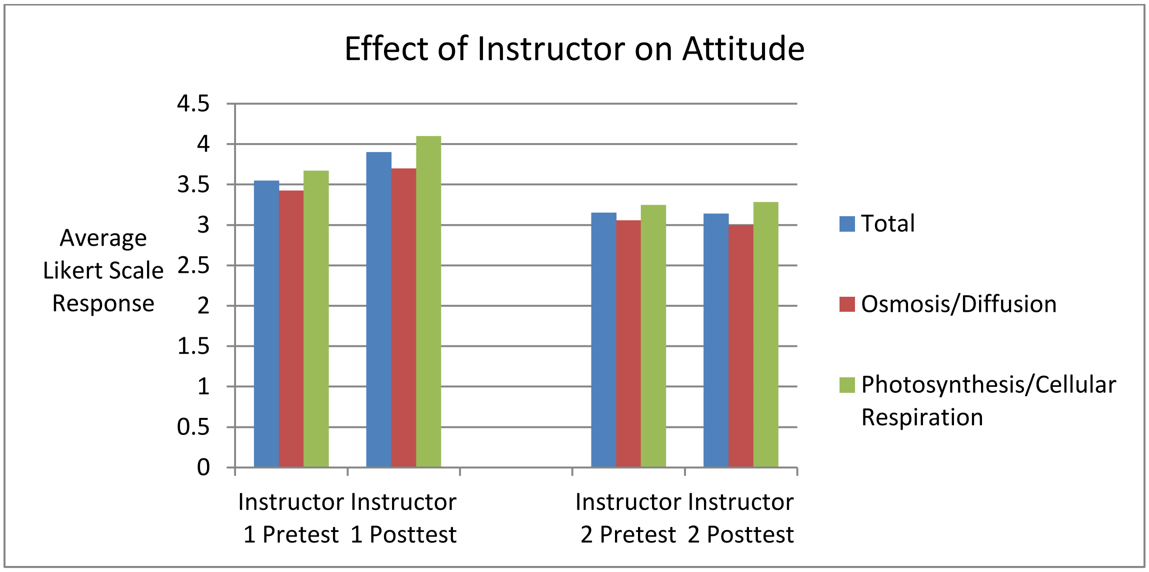
The difference between the mean change in attitude toward osmosis, diffusion, photosynthesis, and cellular respiration between the two instructors was significant in a 2X2 ANOVA with repeated measures F(1,39)= 7.098 , p= .011. The difference between the mean change in attitude toward osmosis and diffusion between the two instructors was not significant in a 2X2 ANOVA with repeated measures F(1,39)=2.49 , p= .123. The difference between the mean change in attitude to photosynthesis and cellular respiration between the two instructors was significant in a 2X2 ANOVA with repeated measures F(1,39)=1.453 , p= .02. This analysis indicated that the source of the difference in overall change in attitude between the two instructors was the change in attitude toward photosynthesis and cellular respiration. See Figure 18 and Table 15 which show that the students in Instructor 1's class gained a more positive attitude while for Instructor 2, students did not gain as much of a positive attitude.

Table 15. Attitude Ratings for Students with Instructor 1 and Students with Instructor 2

Measurement and Participants	Instructor 1 M (SD) n=30	Instructor 2 M (SD) n=21
Pre-Instruction Overall Attitude	3.55 (.55)	3.24 (.58)
Pre-Instruction Attitude Toward Photosynthesis and Cellular Respiration	3.67 (.56)	3.25 (.50)
Pre-Instruction Attitude Toward Osmosis and Diffusion	3.43 (.62)	3.06 (.60)
Post-Instruction Overall Attitude [a]	3.9 (.62)	3.14 (.54)
Post-Instruction Attitude Toward Photosynthesis and Cellular Respiration [a]	4.1 (.63)	3.28(.63)
Post-Instruction Attitude Toward Osmosis and Diffusion [a]	3.7 (.72)	3.0 (.66)

[a] Instructor 1 n=26, Instructor 2 n=17

Figure 18. Change in Attitude Ratings in Students with Instructor 1 and Students with Instructor 2



Summary

Overall the treatment did not have a significant effect on academic achievement or change in attitude. The instructors had no significant effect on overall academic achievement, but did have a significant effect on some of the misconceptions gained. These data show that new misconceptions showed up more frequently with Instructor 2 than with Instructor 1. The instructor also had a significant effect on the change in attitude toward photosynthesis and cellular respiration. This is indicated by the difference in attitude from the pre-instruction attitude survey to the attitude on the post-instruction attitude survey on attitude toward photosynthesis and cellular respiration. These data show that Instructor 1 influenced students' attitude toward photosynthesis and cellular respiration more positively than Instructor 2.

Individual profiles

To illuminate some individual patterns in all measures, the results from four students were compiled for comparison. These participants were selected for their attitude attributes. The participant with the highest pre-instruction overall attitude rating and the participant with the lowest pre-instruction overall attitude rating were selected to show a sample based on the range of pre-instruction scores for overall attitude toward osmosis, diffusion, photosynthesis, and cellular respiration. One of the participants with the greatest improvement in overall attitude rating and the participant with the greatest decline in overall attitude rating were selected to show a sample based on the range of change in attitude toward osmosis, diffusion, photosynthesis, and cellular respiration.

MV28, who will be given the pseudonym “Lisa”, had the greatest improvement in attitude toward photosynthesis and cellular respiration from the pre-instruction attitude survey to the post-instruction attitude survey. On the pretest she scored a 45%, and correctly answered four of the six questions on photosynthesis and cellular respiration. Lisa thought that the atoms in a candle were destroyed when a candle burned. She remembered the lab activity on the enzyme catalase and answered correctly that the catalase in a potato produces bubbles of oxygen when hydrogen peroxide was added on the pretest. Her response to the question on the source of energy for plants given a list of items was, “Water, promotes growth. The sun, the sun provides the energy and the soil is the blanket that brings it all together.” She correctly identified the sun as the source of energy, although her idea of the soil as a blanket could indicate a misconception about the role of soil. She answered the question on the source of energy for animals with, ”Water is the main component of all life. The air we breathe and the food we consume provide energy.” On the posttest, Lisa scored a 28%. She did not define cellular respiration. She defined photosynthesis as, “the creation of life.” Her definition of food for a bean plant was, “sun and water.” She circled water, sun, soil, worms & insects, fertilizer, and roots as sources of energy for a bean plant. She circled all of the choices, including exercise and sun as sources of energy for a human being. She correctly identified the timing of cellular respiration in plants and identified plants as performing cellular respiration. Lisa did not correctly label any of the four misconceptions that could be detected on the concept map. She confused the light dependent reactions with the light independent reactions, but she used all of the terms. Many of her propositions were not labeled, and some groupings appear to be random, such as red and blue wavelength connected to: NADP+, G3P, ATP, ADP, and starch by the proposition, "splits." Her concept map was incomplete in that she made no connections between cellular respiration and photosynthesis. She was placed in the control group with Instructor 1.

MV05, who will be given the pseudonym of "Jim", had the best attitude score toward photosynthesis and cellular respiration on the pre-instruction survey. He had an academic achievement pretest score of 50% and answered three out of six questions about photosynthesis and cellular respiration correctly. He correctly answered that atoms in a burning candle are not destroyed and identified oxygen bubbles as a product of the catalase reaction. His response to the source of energy for a bean plant was, "needs water and sun to grow." Water could be considered a source of energy by students as it is the source of replacement electrons for photosystem II, and electron transfer through redox reactions is how the light energy is converted into chemical energy. His response to the source of energy for a human being was, "In order to survive. A person needs sunlight for energy because Dr. Oz explained how it works in the human body. We need oxygen to breath in order for the red blood cells to work and water to keep us hydrated. Sunlight is kinetic energy." Jim's posttest score was 50%. His definition of cellular respiration was, "The mechanics of what it takes for cells to live." His definition of photosynthesis was, "The process by which plants live." His definition of food for a bean plant was, "Food, nutrition to process energy." He circled air, water, sun, soil, worms & insects, fertilizer, and roots as sources of energy for a bean plant. He circled water as the source of energy for a human being, which changed from sun, water, and oxygen in the pretest. On the concept map, Jim confused matter and energy by labeling sun as the source of oxygen, and mixed the light independent with the light dependent by connecting both the light dependent and the light independent reactions as sources of ATP. He held misconceptions about the source of food for plants, the source of mass gain for plants, and the source of oxygen on the concept map. He correctly answered that it is true that most of the dry weight of plants came from carbon dioxide on the posttest, so he either guessed right or did not understand how to properly label terms on the concept map. Jim was one of the few students to add color at different levels within the concept map and different shapes to his concept map; although, he did not make any connections between cellular respiration and photosynthesis. Almost all of his propositions were labeled, usually with short phrases such as, “source of”, “goes to”, and “requires.” Jim’s answers to the questions from the laboratory in the CELE program included a technical explanation copied and pasted from wiki.answers.com. Otherwise, they were mostly well-thought out answers that were researched, although he did not run any tests in the drag and drop laboratory. All of the questions were answered, which indicated that Jim put forth an earnest effort into the CELE lab questions. Jim was placed in the treatment group with Instructor 1.

MV68, who will be given the pseudonym, “Bill”, had the most negative change in attitude toward photosynthesis and cellular respiration. He scored 65% on the pretest, just below the highest score of 70%. Bill answered two out of six questions about photosynthesis and cellular respiration correctly on the pretest. He correctly answered that the atoms in a candle are not destroyed when it burns, and he correctly identified the oxygen bubbles from the activity of catalase in a potato. His response to the source of energy for plants was, “The bean plant uses energy from air, water, sun, soil, worms and insects, fertilizer, dead animals, and roots.” He selected all of the possible choices as sources of energy for plants. His response to the source of energy for a human being was, “A human being gets the energy they need from food like meats, vegetables, and fruit. These foods are converted into either energy for immediate use - glucose, starch energy storage or fat energy storage convert the food into one type of energy.” He correctly identified the source of energy for animals, and even identified some examples. The pretest was administered online, so it is likely that Bill was looking up some of his answers online. Bill's posttest score was 33%. His definition of cellular respiration was, "cellular respiration occurs all the time." His definition of photosynthesis was, "Photosynthesis occurs in the light." His definition of food for a bean plant was, "food is water, sun, soil, air, roots, fertilizer in order for bean plant to grow." His response to the source of energy for a bean plant was to circle air, water, sun, soil, fertilizer and roots. His response to the source of energy for a human being was to circle all of the choices including beans, air, water, meat, potatoes, sun, and exercise. This was very different from his response on the pretest to the same question. If he looked up the information on the pretest, but did not have access to the internet or book during the final exam, then this is a more accurate representation of his conception of where energy comes from for animals. Bill had some misconceptions about the source of food and the source of oxygen on the concept map. However, no other errors were detected in his concept map, other than he sometimes used general propositions that made it hard to determine how much he understood of how terms related to each other in specific ways. Bill connected cellular respiration to photosynthesis, completing the assignment. He also made connections that were not seen in other student maps, such as cellulose fibers strengthen roots. He does demonstrate understanding of the source of mass gain in plants and connects cellular respiration and photosynthesis correctly in the different ways they use or produce carbon dioxide, labeled with "reactant" and "product." Bill was placed in the control group with Instructor 2.

MV14, who will be given the pseudonym, "Gloria", indicated the lowest ratings on the pre-instruction attitude toward photosynthesis and cellular respiration survey. She had an academic achievement pretest score of 45%, and she answered one out of six questions about photosynthesis and cellular respiration correctly on the pretest. She correctly identified oxygen bubbles as a product of the activity of catalase, but she answered that atoms in a candle are destroyed when it is burned. She responded to the question about the source of energy for plants as, "water, soil, fertilizer, roots." She did not include the source of energy, light or sun in her response to this question. Her response to the question about the source of energy for a human being was, "water, beans, meat, potatoes." She included different types of food, which are correct, but also adds in water as a source of energy, which is incorrect. Her posttest score was 53%. Her definition of cellular respiration was, "using the product of photosynthesis to supply energy." This shows a complete correction of her misconception that was present on the pretest. Her definition of photosynthesis was, "The process of using solar energy, water, and carbon dioxide to produce glucose and oxygen." This is also a correction of her earlier misconception. Her definition of food for a bean plant was, "water, soil & sunlight." Carbon dioxide and its conversion into sugar was not mentioned. Her response to the question about the source of energy for a bean plant was to circle water, sun, soil, fertilizer, and roots. Even though water and sun would be correct, soil, fertilizer, and roots are closer to a source of food than a source of energy. Her response to the question about the source of energy for a human being was to circle beans, water, potatoes, sun, exercise, and meat. Her misconception about the source of energy for humans became worse. Gloria's concept maps showed misconceptions about the source of energy for plants and the source of oxygen in photosynthesis. She correctly labeled the source of mass gain for plants and the source of food for plants by connecting carbon dioxide to glucose with the proposition "to", and glucose is connected to starch with the proposition "stored as." She listed oxygen as a source of electrons for photosynthesis, and connected carbon dioxide to water with "food" in a three-way connection with Carbon dioxide, water, and ATP.   Although some terms were missing from the map of photosynthesis, her map did correctly connect photosynthesis and cellular respiration with the terms glucose and electrons. Gloria ran two tests in the drag and drop laboratory, so she probably used the CELE program some of the time. Gloria was placed in the treatment group with Instructor 1.

Chapter 5

Discussion

Effect of Treatment

Enacting Constructivism in the Treatment Group

The treatment group used the CELE program for laboratory instruction in photosynthesis and cellular respiration. The CELE program was designed using constructivist principles and was meant to engage students in making predictions and testing them to build their own knowledge as well as use the questions as a basis for a problem to solve using the resources in the CELE program. Most computer-aided instruction used for laboratory instruction in science simulates an experiment but does not provide the scaffolding to allow the students to build their understanding from using the simulation. Students were not accustomed to solving problems where the answers were not clearly spelled out. It was common in other laboratory activities for students to copy answers from a website or their textbook with no understanding of what they were writing down. The CELE program would have seemed different and perhaps more difficult to use for students who were not used to pulling resources together to solve a problem for themselves. The students were accustomed to finding the right answer and writing it down without necessarily understanding it.

Academic achievement

The results of this study indicate that there was no difference in academic achievement between the students using the CELE program and the students who participated in the regular laboratory activities. The large standard deviation on the pretest and the posttest appear to come from a wide range of scores on both of these assessments. There is some evidence from the second peak in the total pretest scores that there may have been a group of students with more prior knowledge of biology, but this peak does not appear when only the items on photosynthesis and cellular respiration are considered. This is evidence that very high or very low scores did not skew the results of the pretest questions on photosynthesis and cellular respiration. The posttest had a positive skew with a possible outlier on the high end of the scores, indicating that one student scored higher than the rest, but most scores followed a normal distribution with 91% of the scores falling between 25% and 65% correct. It does not appear that this one high scoring student, with a 73%, skewed the data significantly. The variability in pretest scores may be due to many factors, including the choice to use the internet to look answers up or not, skills in finding information, and varying backgrounds in prior schooling or in prior experiences with science. In my experience, students taking this class at this community college have little experience with growing plants, for example. Many community college students taking biology for non-science majors are still developing skills such as basic math and reading, and this may have affected the variability in scores on the posttest as well. Some variability may be due to some students using the CELE program and some students not using the CELE program. Students who were using the CELE program all started out by saving a copy of the questions that they were to answer using the program, and began using the program at the beginning of the lab period, but soon many of them turned to the internet to search for the question text or sections of the question text. Some students completed the lab halfway through the time period and left, or stated that they were going to complete it at home. Other students remained for the entire time, some diligently searching for correct answers on the internet or in the CELE program. Data were not collected on which students stayed longer or which students used the CELE program most; although the records from the drag and drop laboratory indicate that only seven students out of the twenty seven who worked on the CELE program in the treatment group actually used the drag and drop laboratory activities to answer their questions. As is fairly common in a science course for non-science majors, it appeared that many students wanted to get the right answers to the questions without spending much time on learning the concepts that were applied in the questions.

Although the posttest scores did not show any significant difference between the students using the CELE program and the students who did not use the program, the concept maps showed some differences. More students in the treatment group showed understanding of several concepts, such as how the light dependent reactions were distinct from the light-independent reactions and how photosynthesis is distinct from cellular respiration. Students in the treatment group also connected biochemical pathways correctly more often than students in the control group, while students in the control group more frequently labeled the role of water, oxygen, and carbon dioxide in photosynthesis. This may have resulted from how each group engaged in their laboratory activities. The control group observed demonstrations such as a *Coleus* leaf boiled and then tested for starch, light directed at a test tube of chlorophyll extract to demonstrate fluorescence, and took measurements from a chromatogram of photosynthetic pigments from spinach extract. The control group completed a packet as they did these activities, and there was a section of blanks to be filled in from the textbook that included the source of oxygen from photosynthesizing plants twice, which could explain why students in the control group demonstrated understanding of how water and oxygen are connected more often than students in the treatment group, who did not have a question that directly asked them where oxygen comes from. Students in the treatment group answered questions that were grouped by topic, such as questions about energy or questions about building materials. Students in the treatment group were meant to use the CELE program glossary, diagrams, video links, and drag and drop laboratory activities to answer their laboratory questions. The way these questions were categorized may have helped students in the treatment group to organize terms better than students in the control group and this could lead to a better conceptualization of separate energy pathways for processes such as the light dependent reactions and the light independent reactions as well as a better conceptualization of other biochemical pathways, such as ADP forming ATP.

Another --and perhaps key-- difference in the laboratory experience for the two different groups is that some students in the control group received feedback on whether their answers were correct or not before they submitted their work, while only some of the students in the treatment group got this feedback, and it was after they submitted their work. Students in the treatment group also only received their feedback online where they would have to go view it, meaning that not all of them would see it since they would not all remember to look or be motivated to look unless they had questions about their grade. Without feedback on their responses to the questions, students in the treatment group who answered some questions incorrectly might not have known that their understanding was incorrect. Without feedback, their experience of answering the questions using the CELE program would not lead to reliable gains in understanding. Only seven students actually used the drag and drop laboratory, but it was designed to give students feedback on their hypotheses about the patterns of movement in matter and energy. Vygotsky theorized that social interaction is very important to learning, so the feedback from the drag and drop laboratory would not be enough to foster genuine learning but it would help the students to see where their misconceptions were. Once a misconception was identified, the correct explanation could be sought out and also tested. This feedback, combined with supporting discussion with a more knowledgeable other such as an instructor or other students, could have increased understanding and corrected conceptions as they would add other experiences and information to help weed out incorrect conceptions. This more knowledgeable other could also help the learner in reconstructing their ideas around the new conception by giving examples or analogies that provide scaffolding to build new knowledge.

The concept maps also indicated that students using the traditional laboratory activities confused matter and energy less frequently than students who used the CELE program. An example of this confusion would be connecting light to oxygen as the source of the oxygen. It is possible that although the CELE program questions divided the questions up into categories of building, energy, gases, light, and overview that the students did not make the distinction between energy and matter. Past observations as well as observations during the experiment when students were explaining photosynthesis and cellular respiration to each other indicate that students see the material as having a lot of terms with corresponding definitions that the student memorizes or writes word for word. It is common for college students to answer questions about processes with types of matter or about energy with types of matter. It appears that students do not understand how the terms in photosynthesis and cellular respiration are categorized with respect to energy, locations, processes, and matter. This may be attributed to the high cognitive load of too many terms coming in at once with no schema to place them in, and this would lead to terms being placed somewhat randomly in relationship to each other rather than in a way that makes sense.

Effect of Treatment on Misconceptions

The correct conceptions held on the posttest did not differ significantly between students using the CELE program and students using traditional laboratory activities. This indicates that treatment did not have a significant effect on academic achievement after instruction. Students' underutilization of the CELE program itself may help explain this lack of an effect.

The change in misconceptions was measured by misconceptions "removed" and by misconceptions "gained". The questions on the pretest were not the same as the questions on the posttest although there were questions about some of the same material to assess students' understanding of a selected six misconceptions. This was done due to the short time in a summer course in order to avoid the effect of remembering a test question from the last assessment.

Initially, the posttest was to be administered one week after the pretest, which had a high likelihood of students' remembering test items from the first test, so most questions about photosynthesis and cellular respiration were not repeated from the pretest to the posttest. Instead, the posttest was administered with the final exam after it was inadvertently left out of the exam following instruction on photosynthesis and cellular respiration by the instructors and the effect of pre-exposure to the questions did not appear to have any effect since there was no significant correlation between students' answers to the same questions on the pretest and posttest for the two repeated questions. Since most of the questions on the pretest and posttest were not repeated measures, the misconceptions removed score may not accurately report the same exact misconception on the pretest as it does on the posttest. The fact that many students had misconceptions on the posttest that were not there on the pretest may be due in part to the posttest actually assessing a different misconception. For example, following the assessment in Anderson, the question about the source of food for plants has four parts to it on the posttest, while only one question is used on the pretest. If a student understood that only one choice could be correct on the pretest, they may have chosen the correct answer (i.e. plants make food inside the cells) more often than on a partitioned question with more than one possible answer (i.e. some food is made in the cells but some is also absorbed through the leaves).

The misconceptions gained score was not significantly different between students using the CELE program and students who used the traditional laboratory activities. Two possible explanations are offered here: The misconceptions gained score could indicate that students actually gained a new misconception though their experiences with photosynthesis and cellular respiration, or it could indicate that the posttest elicited the misconception in a different way than the pretest did. The pretest and posttest addressed the same six misconceptions and two questions were repeated from the pretest to the posttest. The repeated questions were about energy; one on the source of energy for a plant and one on the source of energy for a human being. The treatment and control groups were not significantly different in their change in understanding of energy for a plant or energy for a human being. However, students' misconceptions about energy for a plant decreased in the treatment group and increased in the control group from the pretest to the posttest. In addition, the number of students holding this misconception about the source of energy for plants significantly increased from pretest to posttest for all students combined. For the misconception about the source of energy for a human being, both the treatment and the control increased in their misconceptions. These results are surprising, as the source of energy was certainly addressed both by the CELE program and the traditional laboratory activities. These two misconceptions may be more persistent than other misconceptions that were tested in this study.

An example of a misconception that was assessed differently on the pretest than it was on the posttest was about the source of food for plants. The pretest forced students to choose where the plant's food came from while the posttest allowed students to select more than one answer as correct, as well as gave an open-ended short answer question on what the student thought would be food for a bean plant. Many students apparently picked up on another question in the posttest about the source of energy for a bean plant, and were able to go back to the short answer question with the information from this later question. This resulted in some students listing items from the source of energy question on the source of food question, or using the items in the list with a brief explanation. Students were not able to go back to prior questions while taking the pretest (no backtracking), although they were able to take the pretest twice, with the same questions in a random order. This may also have affected their responses on the pretest as opposed to their responses on the posttest, which was on paper at the final exam. However, only six students out of the 41 to complete the study took the pretest twice and there were several instances of a student getting a question correct on the first attempt and then getting the same question wrong on the second attempt. This indicates that on the pretest there was some level of random guessing, while on the posttest there was misguided use of an item in an attempt to answer a different item.

The individual misconceptions that could be detected on the concept maps showed some differences between students using the CELE program and students using the traditional laboratory activities. In particular, more students using the CELE program had correct conceptions of the source of food for plants (62.5% to 27.27%). The number of misconceptions about the source of energy for plants was the same for treatment and control, and the source of mass gain and the source of oxygen were fairly close as well, although the treatment group had a slightly higher percentage of correct connections than the control group. The CELE program did have a definition of food and referenced food in the glossary section, but it is unclear whether that could have caused the higher percentage of correct conceptions of the source of food for plants.

Effect of Treatment on Attitude

This study showed a significant difference in the change in students' attitudes toward photosynthesis and cellular respiration between the attitude survey given before instruction and the attitude survey given at the end of the semester, with some students having a significantly more positive change in attitude than others. However, there was no significant difference in the attitudes of students who used the CELE program compared to the students who used the traditional laboratory activities. Several factors may have influenced the attitudes toward photosynthesis and cellular respiration. Two students who were randomly assigned to the CELE program group mentioned that they felt anxious about using the program and they wanted to do the traditional laboratory activities. One of these students had already completed the CELE program, but stated that he learned better with hands on activities and wanted to do the traditional laboratory activities. The traditional laboratory activities for photosynthesis and cellular respiration that summer did not offer many opportunities for hands-on activities since most activities involved drawing a picture, looking up information in the textbook, or observing demonstrations. This student decided to remain in the treatment group since he had already used the CELE program, but he did additional work in the laboratory to satisfy his concern that he wasn't getting the hands on experience. Another student stated that he was not very smart and didn't feel like he could take on the challenge of using the computer to learn science. This student notified the researcher at the beginning of the photosynthesis laboratory activities and was switched over to the control group where he could feel more comfortable. Many students expressed anxiety about the lack of time to complete activities such as the concept maps. A test was scheduled on the day after the students worked on the concept maps, and many students felt they needed to study for the test rather than work on the concept maps. It was apparent that many of them did not consider making concept maps a valid way to study for the test. A few students really engaged the CELE program and commented that the questions were good and made them think. One student went back into the CELE program to find terms and how they were related, which would indicate that at least a few students found the program useful. Many factors played a role in shaping the students' attitudes, but time pressure and unfamiliarity are the most likely factors that decreased the attitude of finding photosynthesis and cellular respiration interesting and understandable as well as not scary. Like the academic achievement scores, the attitude ratings also had a large standard deviation, both before instruction and after instruction. A wide variation in prior experiences with science was likely to have contributed to the variation in attitude toward instruction in science, as well as variation in prior experiences with photosynthesis and cellular respiration. Different levels of perceived ability to succeed at science may have also contributed to the variation in attitude ratings. The researcher has seen this variation via comments made by students taking the same class in prior semesters who indicated that they did not believe they could pass the class whereas other students who came in excited about what they would learn and achieve.

The change in attitude toward osmosis and diffusion, in which all students participated in hands on laboratory activities, did not differ significantly between students using the CELE program and student who used traditional laboratory instruction. This would indicate that the two groups were not significantly different in their attitude toward a common experience with activities on osmosis and diffusion.

Effect of Instructor

Enacting Constructivism with the Instructor

The two instructors for this course were very different in their approach to teaching. Instructor 1 was enthusiastic about teaching and about photosynthesis and cellular respiration as important topics. Instructor 2 showed less enthusiasm and did not emphasize the importance of photosynthesis and cellular respiration, but was more task-oriented and interested in helping students complete the work. Instructor 1 was open to new methods of teaching and was very excited about the CELE program. Instructor 2 was indifferent to the program and seemed content to teach in the same way as had been done before, making minimal accommodations for using the CELE program and not doing anything extra to facilitate student's use of the CELE program. Instructor 1 clearly believed that students need to be actively involved in learning and that students need feedback, which would support learning in a constructivist style. Instructor 2 gave minimal feedback to students; usually waiting for students to come and ask questions before giving feedback, and then the feedback consisted mostly of indicating whether the answer was correct or not. This did not support constructivist learning. From prior learning experiences, students may have been more familiar with instructors who supported learning the right answers without understanding the concepts. To use new methods of learning such as the concept map and the CELE program was foreign to most of them, and it was apparent that many students were not comfortable with trying them out with a tight summer schedule. Instructor 2 may not have been comfortable with the new learning strategies either, preferring to stick with what had "worked" in the past.

Academic Achievement

While observing the participants during the study, the researcher noted that each of the instructors had a very different approach to teaching, yet results did not indicate any significant difference in overall academic achievement between the students of the two different instructors. Instructor 1 gave a full explanation of both photosynthesis and cellular respiration at the beginning of each lab period. Instructor 1's explanation included diagrams on the white board, visual aids, audience participation, manipulatives, and time for the students to explain the concepts to each other while Instructor 1 circulated around the room, listening for correct conceptions and missing information. After the introduction to the material, students split into their groups and Instructor 1 stayed with the control group in the lab while the researcher stayed in the computer lab with the group working with the CELE program as a technical assistant. The researcher did not assist students with finding answers, but with technical problems or difficulty navigating in the CELE program. Instructor 2 gave a very brief introduction to the lab activities, describing what the students would do for each activity, and then stayed in the lab with the control group. Instructor 2 was not as interactive as Instructor 1 and tended to sit at a computer or on a chair while students were working and wait for students to come ask for help when they got stuck. It is possible that students in Instructor 2's classes were forced to go to the book and the internet for help when they got stuck and this caused them to put more effort into finding the right answers, which developed their conceptions of photosynthesis and cellular respiration more strongly than students in Instructor 1's class, where the students were given better background information and did not have to work very hard for it. However, this did not increase performance in students with Instructor 2. This did result in frustration in Instructor 2's classes and students in the control group came to the researcher to ask for help with their labs when they came into the computer lab to look up information.

The concept maps also showed some differences between Instructor 1 and Instructor 2 in their students' understanding. Fewer students in Instructor 1's classes confused matter and energy, and slightly fewer students in Instructor 1's classes incorrectly labeled biochemical pathways. However, fewer students in Instructor 1's classes correctly labeled how carbon dioxide and water play a role in photosynthesis and cellular respiration, as well as confused the light dependent reactions with the light independent reactions. Given the extensive introduction given by Instructor 1 for both photosynthesis and cellular respiration, especially the manipulatives involved, it makes sense for these students to be able to visualize the categories of location, matter, energy, and processes. This may have contributed to their better understanding of the difference between matter and energy. However, Instructor 1's students still had more trouble with the role of some of the important molecules aside from oxygen, and a large percentage of them confused the light dependent reactions with the light independent reactions that should have been clearly separated in the interactive lecture they participated in. This might be due to students' not visualizing the whole process of photosynthesis, but rather getting pieces of the process and getting lost on some parts. This was apparent in the session with Instructor 1 where the students explained photosynthesis right after the interactive lecture and cellular respiration right after the interactive lecture on cellular respiration. Many students attempted to explain to each other, but most were missing parts of the process in one place or another. Rather than ask for help, they would puzzle amongst themselves and some groups would state that they understood when their overheard conversations would indicate otherwise. Others would state where they got lost to the researcher or the instructor and those students were able to fill in the gap and move on to explain more of the process. The reluctance to ask for clarification may have been due to time pressure and a desire to get the laboratory activities done, or it may have been due to not wanting to appear less intelligent to their peers, or even to themselves as this might affect their self-esteem.

Effect of Instructor on Misconceptions

The misconceptions removed were not significantly different between the students in Instructor 1's class and the students in Instructor 2's class. The correct conceptions held at the posttest were also not significantly different between the students of the two instructors. However, the misconceptions gained score was significantly different between the students with Instructor 1 and the students with Instructor 2, and more misconceptions were gained with Instructor 2. This could indicate that the students with Instructor 2 added more new misconceptions than students with Instructor 1. This may be the case with the misconception about the source of energy for plants but less change was seen for the misconception about the source of energy for animals. Both of these misconceptions were measured with the same question on the pretest and on the posttest. But for the other four misconceptions, it is possible that the misconceptions were present at the pretest, but not detected with the question on the pretest while this same misconception was detected on the posttest with a different question. The trend in the two repeated questions was an increase in misconceptions from the pretest to the posttest. Therefore, it is likely that new misconceptions had actually arisen and more of them came about with Instructor 2's classes. This could be explained by the level of feedback given to the class by Instructor 1 compared to the level of feedback given to Instructor 2's class. Most of Instructor 1's students who used the traditional laboratory activities left the laboratory having not only learned whether their answers were correct, but also having heard an explanation of the phenomena being demonstrated in the activities. Most of Instructor 2's students that used the traditional laboratory activities left the laboratory having no feedback as to whether their answers were correct or not and had no verbal explanations of the phenomena that the activities were demonstrating.

The change in the individual misconception about the source of energy for plants (M2) was also not significantly different between the two instructors, although the number of misconceptions increased for both instructors and this change in M2 for all of the students was significant. The change in the individual misconception about the source of energy for human beings (M3) was also not significantly different between the instructors, and the change for each instructor was minimal. This would suggest that the misconception about the source of energy for plants is even more difficult to correct, as it only increased after instruction, while the source of energy for human beings misconception stayed relatively level rather than increasing. Students tended to include other items as sources of energy besides the sun or light energy. While water could be considered a distal source of energy by the electrons it donates to photosystem II, soil, fertilizer, dead animals, and roots are not sources of energy for plants. Photosystem II is the cluster of molecules that capture light energy and pass it along using electrons, but the electron that is passed on must be replaced by taking it from water. The misconception of soil or fertilizer as a source of energy for plants may arise from students associating plant food (fertilizer) with food that we eat as a source of energy. Air might be included by some students as a source of energy for plants if they associate energy with breathing and consider gas exchange to be a source of energy for both animals and plants. Even though oxygen is required as the molecule to deposit electrons that were collected from food molecules in aerobic cellular respiration, it is not a source of energy in the form of potential energy in the bonds of food molecules. Perhaps if the question on the pretest specified that the energy was taken into the plant or animal to make chemical energy in the form of ATP (the usable form of energy that the cell is making from food energy), the results might show a clearer picture of what the students understand about how energy is gathered for plants and for animals.

The concept maps showed some differences between the two Instructors for the four misconceptions that could be detected on the concept maps. For the misconception on the source of energy for plants, Instructor 1's students' correctly labeled light or sunlight 79% on average, while Instructor 2's students labeled it correctly 67% on average. Despite this trend on the concept maps, the average score on the same question from the pretest to the posttest greatly decreased for both Instructor 1's students and Instructor 2's students. This may be due to the type of question used to assess the students' conceptions of the source of energy for plants. The question asks students to circle their answer(s) and explain as needed. Students could then choose more than one answer as correct, unlike a traditional multiple choice test. The concept map may also have multiple ways in which to connect light energy to photosynthesis, but students may be treating light energy as a material that is not necessarily energy, but connects in very specific ways to photosynthesis. Students' confusion of energy and matter may be contributing to these disparate results. Instructor 1's students also had more correct labeling of the source of mass gain for plants, with some connection between carbon dioxide and a carbohydrate such as cellulose, glucose, or starch. Instructor 1's students labeled the source of mass gain correctly 71% on average while Instructor 2's students labeled it correctly 40% of the time. Yet Instructor 1's students also had more errors in correctly labeling the role of carbon dioxide. Again, students may have been able to make the concept map conform to diagrams and descriptions that they have in the book or from their notes while the questions on the pretest and posttest would not have been in a familiar format and would have forced them to apply their understanding to the question. Students reported that they wanted to study for the upcoming test rather than create their concept maps, indicating that they did not consider concept mapping to be a valid form of studying and may have had trouble making the transfer of learning from one format to another. A closed book and notes concept map assessment might give a more equivalent result.

Effect of Instructor on Attitude

The change in attitude toward photosynthesis and cellular respiration was significantly different between students in Instructor 1's class and students in Instructor 2's class. Students in Instructor 1's classes had a significantly greater improvement in their attitude toward photosynthesis and cellular respiration than students in Instructor 2's classes. Not only were the methods of instruction very different between these two instructors, but also their attitude toward the material. Instructor 1 was very energetic and sought engagement with the students. Instructor 1 made the interactive lesson fun for the students and had students come up to the front of the class to play the role of electron acceptors and ATP synthase with sticky notes to represent protons. Instructor 1 showed a passion for how important and interesting photosynthesis and cellular respiration are, and how they apply to the students' lives. Instructor 1 became so interested in the research project that Instructor 1 had the students do extra activities with these topics for a little bit of extra credit on the test grade. Instructor 1's energetic interest in teaching and in science was infectious and could be felt in the responses of the students to instruction. Instructor 2 had a very low energy personality and Instructor 2 did not seek out engagement with the students. Instructor 2 played the role of help desk and waited for students to come for help when they needed it. Given the great difference between these two instructor's display of interest in the science and energy invested toward teaching, it is not surprising that there was a significant positive change in attitude in students with Instructor 1 than with Instructor 2.

The change in student's attitude toward osmosis and diffusion was not significant between the two instructors. This makes it apparent that the extra energy spent and the extra focus on photosynthesis and cellular respiration from Instructor 1 made a difference in how students perceived these topics, which many students find difficult and scary because they are not easy to understand.

There was no lecture for this summer course, as the course was transitioning from self-paced to traditional lecture and lab. Instead, students reviewed flash cards online and answered the questions on the flash cards (connect activities). The CELE program was piloted with these classes to determine whether it could give students interactive resources to help them learn the material even when no traditional lecture is available. Students have expressed a desire to have a traditional lecture with more direct input from the instructor in the past, stating that it helps them learn and helps keep them motivated to get the work done. Although the CELE program was designed to let students explore the reactions and the practical applications of photosynthesis and cellular respiration, it was not meant to stand alone as the source of instruction. A good instructor was still needed to give feedback to the students on how well they understood science; furthermore, to help show the students that the material was not incomprehensible or scary and that the student can succeed with moderate effort.

Individual profiles

Although significant differences were not detected in academic achievement outside of the misconceptions gained, something can be learned from the work that each student did. Here is a qualitative look at students with different attitude responses to photosynthesis and cellular respiration, and some commentary on a sample of students.

Lisa's great improvement in attitude toward photosynthesis and cellular respiration did not correlate with an improvement in academic achievement. It may be that misconceptions that were undiagnosed by the pretest came to light on the posttest for Lisa. Diagnosis of misconceptions and feedback to make these misconceptions apparent to the student are critical parts of learning. This feedback would have allowed Lisa to see where she had misconceptions and would have enabled her to rebuild her understanding of photosynthesis and cellular respiration with new conceptions that explain her experiences and observations more correctly. Lisa was placed in the control group with Instructor 1, who was enthusiastic about photosynthesis and cellular respiration, placing great emphasis on its importance by spending extra time on it and describing how energy is necessary for life. Although Lisa's interaction with Instructor 1 helped her attitude toward instruction in photosynthesis and cellular respiration to improve, she did not get the feedback to help her correct her misconceptions. She had the desire and the motivation to learn, but not the tools through feedback to overcome her misconceptions.

Jim's positive attitude toward photosynthesis and cellular respiration before instruction showed in his extensive effort to understand the material but his academic achievement stayed at the same level from pretest to posttest. He did gain a misconception on the source of energy for plants from the pretest to the posttest, on a repeated question. This could have been due to his over-thinking the question, or due to randomly selected answers. With the highest score on the posttest being a 75%, Jim with a 50% was above the class average on academic achievement. Yet he showed no improvement in academic achievement from the pretest to the posttest. It is apparent that the feedback needed to allow Jim to see where his misconceptions were was not given to him. Like Lisa, Jim needed feedback to improve his understanding – his positive attitude before the study was not enough to help him correct his misconceptions.

Bill had a very high pretest score, yet a very low posttest score. His negative attitude change correlated with his change in academic achievement. Photosynthesis and cellular respiration became less interesting and more scary and incomprehensible to Bill after instruction. His use of very general terms for propositions on the concept map may indicate that he was making up for lack of understanding by making it look like he might understand without actually giving details. Unlike Jim and Lisa, his attitude toward instruction in photosynthesis and cellular respiration became more negative after instruction. Having Instructor 2 may have influenced his attitude with the lack of enthusiasm and the lack of positive interaction from his instructor. The lack of feedback from Instructor 2 also allowed Bill to proceed with his misconceptions and low academic achievement on the posttest. Like Lisa, Bill did not get corrective feedback for his misconceptions, but he additionally got feedback about the importance and interest of photosynthesis and cellular respiration from Instructor 2 that this topic is not interesting or important in the instructor showing little enthusiasm for the topic or for the students' learning.

Gloria had a very negative attitude toward photosynthesis and cellular respiration before instruction, but her academic achievement increased and she was able to correct some misconceptions about photosynthesis and cellular respiration. Unlike most of her classmates, Gloria used the drag and drop laboratory. She may have done this out of curiosity, seeking feedback on her ideas. The drag and drop laboratory did not hold her interest for long as she only ran two tests, so it is likely that she did not get much useful feedback. She was also able to improve her overall attitude toward instruction from 2.0 to 2.8. Her instructor may have been able to help her overcome her attitude and improve her understanding. As her attitude improved, Gloria may have become more receptive to information that challenged her ideas about photosynthesis and cellular respiration, which would allow her to re-construct her ideas to explain how the new information related to her pre-existing ideas.

Conclusion

The CELE program, as it was used in this study, had no significant effect on overall academic achievement, misconceptions, or attitude toward photosynthesis and cellular respiration when compared to a traditional lab. The instructor had no significant effect on overall academic achievement, but it did significantly affect the number of misconceptions gained as well as the students' attitude toward photosynthesis and cellular respiration. This research indicated that although computer instruction can be helpful, it cannot replace a good instructor. Programs like the CELE program should be used alongside other forms of instruction and timely feedback is likely to be critical to the success of the computer program. The constructivist design of the computer program is not enough to ensure student learning; the instructor must also enact constructivist practices in his or her use of the program to further learning.

In order for any form of instruction to be effective, the feedback from that instruction must be utilized. It is likely that because the CELE program was not used to its full potential by most students who used it in this study, this form of computer instruction did not show improvement over traditional instruction in academic achievement. Clearly, students must be directed in how to use the computer program to ensure that they get the feedback that will help them learn. Adult learners will take the shortest route to learning that they perceive as viable to arrive at having the correct answers, so careful design of the students' interactions with the instruction is important.

The misconceptions that contributed to reduced academic achievement were not changed by this technology. Technology is a tool for learning among other tools, and technology alone is not always effective at removing misconceptions (Kuech et al., 2003). Unless the correct feedback that directly challenges to misconception is received, the misconception will remain. This is due to the misconception appearing to explain all experiences and information better than the correct conception. Until the misconception is directly challenged, it will be regarded as the best possible explanation. Although technology can bring useful tools to help challenge misconceptions, such as animations and simulations, unless they are directly impacting the misconception they will fall short of their target and be ineffectual.

The pretest and posttest for this study used some questions from Anderson in 1990, and their research also found that misconceptions were persistent even after extensive experience with photosynthesis and cellular respiration (Anderson, C. W. et al., 1990). Misconceptions are tenacious, partly because they are the current best explanation for observations and experiences, and other ideas are often built upon them. To change a misconception is to cause all associated ideas to also have to be re-constructed, which would be more difficult than to keep an imperfect explanation.

This study found that the instructor had a significant impact on students' attitude toward photosynthesis and cellular respiration. Instruction methods that are more familiar may also affect attitude (Nwagbo, 2006). Technology may improve attitude toward instruction simply by being new and different (Kara & Yesilyurt, 2008). The instructor's attitude toward the subject material can influence students' attitude toward instruction in that subject as students are not likely to consider a topic important if the instructor does not appear to value the topic themselves. The attitude of the instructor is an important factor in the attitude of the students, which will also impact students' academic achievement.

The CELE program needs some improvement although it did not perform worse than traditional laboratory activities in this study. It could be used with other instructional settings and with different levels of students with some modification. The instruments used for measuring change in attitude were effective and could be used to measure the change in attitude toward photosynthesis and cellular respiration and osmosis and diffusion for other forms of instruction in these topics. The instruments for measuring academic achievement need some improvement to more accurately pinpoint specific misconceptions, but it appears that they have both research and instructional potential and could be used at the high school or college level to assess changes in understanding of photosynthesis and cellular respiration.

Limitations

There were a number of factors that limited the validity of the results of this study; most of them limited the internal validity of this study. One factor that limited the internal validity of this study was the process of collecting enough data so that each student in the study would have a complete set of measures. Absences, students who dropped the class, and students who did not submit work, such as the concept maps, all affected the data set. The lack of concept maps completed and submitted led to the concept maps not being rated by experts in science like the posttest open-ended questions were. This made it so that the concept maps could not be analyzed quantitatively. Due to the research being conducted in a summer session, time constraints affected how much effort students were able to put into the work as well as the anxiety levels of the students trying to get all of their work completed.

Technical problems with installing Adobe Flash player on the computers threatened the internal validity of this study because the computers were wiped of all newly installed programs each night and Flash player was not installed. Before students could fully use the CELE program, Adobe Flash had to be installed on each computer through Firefox as Internet Explorer was not working properly. The IMHC Cmap Tools software also had to be installed by the first class of the day on all of the computers each day that the program was to be used. Since students created a login and the computers were shared, some students in later classes were able to use previous students' concept maps. This was a problem since the concept map of photosynthesis should have been completed on their own. There was some learning curve for the students and the researcher in using CmapTools; consequently, the proposition connector lines did not all have arrowheads.

The students' engagement with the CELE program was not as intended, which also threatened the internal validity of the study. The information needed for the questions was built into the program, and some of the questions were designed to be answered from the drag and drop laboratory, but 35 out of 42 (83%) students chose to use Google instead. This strategy sometimes worked, but sometimes it may have actually taken longer than searching within the program. Since this was to be a pilot of the program in a real world situation, the researcher did not interfere with students who decided to use Google instead as this would probably happen in fully online class or when the students worked from home on it. Students did not find the question set to answer using the CELE program enough incentive for genuine learning and thus chose not to invest in it; instead, they chose to seek out the right answers. If the students had engaged the CELE program in a constructivist manner, they would have invested the effort to make sense of what they were learning and would have been able to apply it to their own lives and their own understanding. To enhance student engagement with the CELE program, students could be directed to use a specified detector in the drag and drop laboratory and record their results in their lab write up. The material could also be broken up into modules to narrow the area that the student needs to look through for a particular activity.

Due to the research design, the researcher was not able to give feedback to students as they completed the questions in the CELE program other than to clarify questions, help them find features in the program, or troubleshoot Flash player. This threatened internal validity and meant that the students in Instructor 1's classes in the control group would have had more feedback than students in the treatment groups. Without any feedback on their laboratory work until after the test, students were not able to see whether they were on the right track or not. They still received feedback from their online lecture activities through McGraw Hill's Connect, but they did not get feedback on their laboratory work. Students in the treatment group with Instructor 2 probably had an equivalent amount of feedback as the control group on their laboratory activities.

The timing of the work on the concept maps was not optimal in this study, threatening internal validity. The concept maps should be introduced before cellular respiration and photosynthesis. This was originally in the research plan, but time constraints and the preparation of materials for the traditional laboratory activities caused the omission of a concept map of cellular organelle functions. If it had been done, it would have allowed students to either become familiar with a tool such as CmapTools or to manually draw a concept map on paper or on the computer. If the concept map of cellular respiration was made as a pre-lab activity, then students could get feedback on their map of cellular respiration and then add their individually made maps of photosynthesis to it. Concept mapping activities should not be scheduled when the students are under extreme time pressure to perform on an upcoming test.

Finally, the internal validity was threatened by problems with the assessments. The assessments are critical to the researcher being able to interpret the findings in a study; thus, revisions and fine-tuning of the assessments are recommended for future studies. The pretest and posttest did not have a repeat of all the questions to assess misconceptions in photosynthesis and cellular respiration because there was some concern that prior exposure might influence the results of the posttest. Even in the summer session, where the pretest and posttest were only separated by three weeks, the effect of prior exposure was not noticeable in the two repeated questions, as students' answers to these questions did not correlate from pretest to posttest scores. The pretest and posttest should be edited for clarity and all six questions about cellular respiration and photosynthesis should be repeated from the pretest to the posttest. The posttest should also be integrated into the final exam as part of the exam rather than as a separate piece of paper so that it would be perceived as something to put effort into, rather than as an additional piece of work that might not count for anything. The pretest might also be moved to a regular paper test to get better effort and eliminate access to the internet for answering the questions.

The external validity of this study was threatened by the type of student that was enrolled in a summer session. The students who attend a community college in the summer are often university students who may not be equivalent to the more "typical" community college student. University students tend to have fewer commitments outside of school, and more experience in a college environment than community college students. Thus the results of this study may not be truly descriptive of community college students' learning.

The external validity of this study was also threatened by the artificial separation of the students from their instructor in the treatment group. In regular instruction, the instructor would be checking on students at the computers to see if they had questions and to help guide them as well as encourage discussion among the students. Students rarely collaborated on the lab work with the CELE program even though they were encouraged to do so and given suggestions on strategies to team up and get the questions answered faster. The computer lab was quiet for most of the class period except for the sound of occasional typing on the first day of instruction. Some students may have felt that they would be seen as less intelligent by their peers if they asked for help. This can be seen in the common expression by students that they have a "stupid question", or students not wishing to be called upon to answer a question because they feel stupid when they answer incorrectly. Students may have also felt that others would simply slow them down if they tried to socially interact while completing the activities from the CELE program. Students express this when they complain that they don't want to work in groups or they work better on their own. The second day had much more interaction as students worked with their instructor and the researcher to complete their concept maps. Some students worked together as well, forming pairs or triplets who looked at each other's work and asked the other students where they put individual terms as well as asked the instructor or researcher if what they had looked right. The students received much more feedback on their first concept map, but not as much on their second concept map as it was meant to be individual work. Students still asked the researcher if what they had looked right and the researcher minimized feedback by stating that it looked right and commenting that perhaps more connections could be made to a particular term to help students gauge how complete their map was. Although they were not analyzed in this study, the first concept maps on cellular respiration would be expected to be better in quality and correct conceptions than the second maps on photosynthesis since the feedback was much more for the first concept map. The researcher did not formally observe the students in the control group as they completed the traditional laboratory activities, but past experience with these activities has shown that some students do collaborate on them. This has taken the form of helping other students in finding the material in the textbook, in making drawings in the right place on the worksheet, sharing answers directly from their worksheet, and occasionally in discussion of a topic (usually with some prompting from the instructor). This higher level of social interaction in the control group may have also contributed to differences in academic achievement or in attitude toward instruction, as social construction of knowledge is important to learning. It is possible that the work on the concept map helped fulfill the need for social interaction in learning for the treatment group.

Future Research

This study brought up many possibilities for future research. A more thorough pilot of the CELE program should be made with improvements to the program. Some of these improvements might include feedback in the drag and drop laboratory for every possible combination that can be made, making basic and advanced sections of the glossary to make it applicable both to non-science majors and science majors, changing the student engagement with the program to be one activity in the lab and having it replace the laboratory activities of looking up answers in the textbook, incorporating results from the drag and drop laboratory into the activity to engage students, and include a social activity for students to collaborate on and build ideas together, while also encouraging them to acknowledge and deal with the needs for clarification. These changes would help the students to not feel like they were missing out on the hands on activities in the traditional laboratory activities, and the CELE program would feel more like another online activity that is sometimes used in the laboratory to illustrate a concept. To accomplish these changes, the number of questions should be reduced and grouped into modules. Each module could focus on a topic with one or two central problems to solve, with encouragement to collaborate in the process of solving the problem.

Research on the effect of instruction and of instructor on misconceptions in photosynthesis and cellular respiration, as well as other difficult areas such as osmosis and diffusion and genetics could be done with different populations, such as other community colleges, four-year colleges, and high schools. Different forms of class delivery could also be studied, such as courses which are completely online, courses that have a traditional laboratory and a traditional lecture, and hybrid courses.

Students using the CELE program should get feedback on their laboratory work while they are working on it and before they submit it, equivalent to the feedback that the students who are not using the CELE program get. A post-use survey should also be administered to students who either used the program or did the traditional laboratory activities to determine how well students liked their form of laboratory instruction, how useful they found it, and any improvements they would make to it. This could be useful for improving both the CELE program and the traditional laboratory activities. In addition, the attitude survey that was administered before and after instruction should have some items about attitude toward using a computer for learning as opposed to traditional instruction.

The number of concept maps that were submitted limited the interpretation of the data from the maps, but the maps themselves also only offered a snapshot of the students' understanding. Post-mapping interviews would add valuable data to tease out what the student understood when he or she connected items in a particular way.

This research shows that the instructor is critical to student learning, both in terms of students' attitude and in their academic achievement. A tool such as the CELE program can only be effective if it is supported by instruction with constructivist principles. This research lays the groundwork for future studies on how to engage students and instructors in constructivist learning with a computer program. It has been valuable in learning how students interact with this pilot version on the CELE program and in learning what is most useful in assessing academic achievement.

Table 16. Misconceptions about Photosynthesis and Cellular Respiration

Author	Misconception
Akpinar	Plants take in food from outside/eating
Akpinar, Tamir	Soil, water and/or minerals are plant food
Anderson	Soil, water or fertilizer are sources of energy for plants
da Luz	Glucose is the only fuel for respiration in mitochondria
Haslam	Photosynthesis can occur when there is no light energy
Haslam	Oxygen is used in respiration which only occurs in green plants when there is no light energy to photosynthesis
Ozay	Sunlight keeps plants warm and healthy rather than giving them energy
Tamir	Minerals are used in the products of photosynthesis
Tamir	Dry weight of leaves will increase when transpiration rates are high
Yenilmez, Anderson, Haslam	Respiration in green plants is taking in carbon dioxide and giving off oxygen
Yenilmez, Haslam	Plants only use carbon dioxide in respiration when light is not available
Akpinar	Photosynthesis is the reverse of respiration
Anderson	Carbon dioxide is changed into oxygen in photosynthesis
Balci	Respiration and photosynthesis never occur at the same time
Haslam	Carbon dioxide is given off in large quantities in the presence of light
Haslam	Plants make their food from oxygen and light energy
Haslam	Non-green plants can photosynthesize
Haslam, Balci	Photosynthesis happens all the time
Ozay, Stavy, Akpinar, Balci	Photosynthesis is a form of gas exchange rather than a form of energy conversion
Tamir	Energy for activities comes from oxidizing food in animals and from photosynthesis in plants
Tamir	Plants give off more oxygen than carbon dioxide because they do not need oxygen for photosynthesis
Anderson	Water, air, exercise or sunlight are sources of energy for people
Balci	Photosynthesis provides energy for the plant
Balci, Haslam	Glucose and oxygen are released as waste products when plants produce energy from carbon dioxide and water

Author	Misconception
Barker	Photosynthesis does not produce a carbohydrate product
Haslam	Chlorophyll combines with carbon dioxide in the presence of light energy and produces glucose and water
Ozay	Plants are called producers because they produce oxygen rather than food
Ozay	Plants gain mass from the soil rather than from carbon dioxide
Ozay	Animals depend upon plants for survival only because plants are food for animals, not because plants produce oxygen
Tamir	Oxygen is given off during the day and carbon dioxide is given off at night
Balci	Respiration in plants happens only in the roots because the roots have small pores to breathe
Balci, Haslam	Respiration in green plants does not occur in the presence of light
Haslam	Respiration takes place only during the day in green plants
Haslam	Plants stop photosynthesis and continue to respire when there is no light energy and give off oxygen
Haslam	Respiration is a chemical process to obtain energy which occurs only in plant cells and not in animal cells
Haslam	Respiration provides energy and is a process in which plants manufacture food from water and carbon dioxide
Ozay, Yenilmez, Balci, Haslam	Plants only respire at night
Stavy	Respiration is simply breathing rather than converting food into readily available chemical energy
Stavy, Yenilmez, Tamir	Plants do not respire
Tamir	Respiration breaks food down into elements that are the raw materials to make ATP
Tamir	Photosynthesis is the respiration of plants
Yenilmez	Plants only respire when they can't get enough energy from photosynthesis
Yenilmez, Akpinar	Respiration in green plants is gas exchange through the stomata
Yenilmez, Haslam	Respiration only takes place in the leaves of green plants
Yenilmez, Haslam	Photosynthesis provides energy for plant growth only

Appendix A: Design of the computer program

In the computer program, students started on the start page. See Figure 19 for a map of the computer program. This page had the directions for the final products for the program, a welcome screen with ideas on how to use the tools, and a navigation bar that was shared by all sections of the program. The first step in this program was to complete the pretest in order to receive a code that granted students access to the rest of the screens. This helped to ensure that students took the pretest. The pretest included some of the questions from the multiple-choice and short answer instrument that was used after the students completed this unit. The final products were a concept map made with CMap tools of photosynthesis and cellular respiration, a test with multiple-choice and short answer questions, and problems that the students solved and posted their answers in essay form. The test was used in place of the lecture test for the topics of photosynthesis and cellular respiration and the concept map and problem solving questions were presented as the lab that the students turned in. Students used the resources in the program to construct their understanding of photosynthesis and cellular respiration and to represent their knowledge in these final products. From the start screen, the student chose to go to any of the following sections, using the suggested strategies listed on the start page.

One of these sections was the practice area, called the laboratory preparation area. This section gave students a place to practice making hypotheses, designing experiments, and analyzing results with some guided experiments and descriptions of how the detectors work. Scaffolding for hypothesis generation and experiment design are especially important as it will impact students' ability to generate meaningful results from their experiments. The notepad tool allowed for students to record a hypothesis and design an experiment, as well as note what results they would expect if the hypothesis was supported. In this section of the program, a hypothesis generating tool was used to scaffold this process. It included prompts on what they want to learn from their test and whether the variables they considered using aligned with this information; also, it had an idea menu of variables, verbs, connectors for the hypothesis, prompts for the student to enter how they chose to test their hypothesis, and what they predicted the results of the test would be that supported their hypothesis. Experimentation hints were also provided along with sample hypotheses, tests, results, and interpretations. The above ideas for supporting hypothesis making were taken from De Jong & Jooligan (1998). It was important that students worked through the hypothesis making process in order that they could make use of the results from their experiments. There also were problem solving activities to help students conceptualize a problem in a particular way; priming them to solve the problems presented in the storyboard. Using problems with similar solutions to help students learn a problem solving strategy was also used in the Animation Tutor Project (Reed, 2005). Expert modeling is another way to help students conceptualize how to approach problems. Videos of "experts" describing how they would approach a problem similar to the ones that the students would have to solve were used as another way to generate ideas and organize thoughts into a problem solving strategy. For more information on the use of expert modeling see Liu, 2006 and Mayer et al., 2002.

Another section of the program was the laboratory. In this section, the notebook tool was again available for students to record their results and their thoughts on how they interpreted their results. Prompts were used in this area to help the student interpret their results, such as prompting the student to answer how they decided that they have enough data to draw conclusions or how they decided what to do next. This prompted students to consider their own learning process (Lin, X. & Lehman, 1999). Information from the notebook could then have been used in a discussion board post about what the student was thinking and discovering in the laboratory if the student desired feedback on the direction they were going with their investigation. This is similar to a learning log, which is a dialogue between the teacher and the student, where the student gets feedback on their thinking process (Hurwitz & Abegg, 1999). However, students were not forced to post their findings on the discussion board if they did not want feedback from the instructor or other students. The notebook tool was capable of storing images and screenshots as well as text, and could have been used to organize different topics with tabs so that students could use a different tab for each problem they are working to solve. It functioned as an organization scaffold and reduced the cognitive load of trying to keep all this information in memory by making it easy to retrieve from the notepad.

The laboratory section of the program also had digital apparatuses to do experiments with. The apparatuses were similar to each other in that certain materials were added to them, and they processed the materials and gave a result. Each apparatus had a manual that told students what it did and how to interpret the results. I will call these apparatuses detectors in this paper. There was a detector for each of the following: starch, protein, glucose, fat, glycogen, electrons (electron transfer), oxygen, carbon dioxide, pH, ATP, calories (quantifying calories), and life functions (for self contained ecosystems such as a plant with a mouse). The materials that could have been added to these detectors were diverse and were represented with a picture and a name. They included items such as rocks, leaves exposed to light, leaves left in the dark, non-photosynthetic plants, algae, roots, potatoes, a mouse, an insect, live yeast, live anaerobic bacteria, water, flowers, chlorophyll, intact chloroplasts, mitochondria, ATP, oxygen, bubbles on an aquatic plant stem, mushrooms, and so on. The items included facilitated a study of a broad range of organisms with different forms of metabolism, nonliving items, cells and cell components, and components of metabolism such as ATP. The simulations of laboratory experiments were simplified by removing the steps between students getting the starting materials and students getting their results. The simulations were integrated into this program with a goal of solving the problems on the start page and scaffolding to help the students design effective experiments. This alleviated the problem of having isolated simulations that may not be effective in instruction (Smetana & Bell, 2006). Allowing students to place multiple items together allowed them to test hypotheses about how items interact. An example would be how a mouse with food and a plant, sealed in a jar, would interact in the presence of light or in the absence of light over time. Being able to set up these combinations gave the student one more ways to challenge their misconceptions about photosynthesis and cellular respiration (Akpinar, 2007); this may have helped to create dissatisfaction with their previous model for how photosynthesis and cellular respiration work and lead to the formation of new models that incorporate the new information they were learning (Bishop et al., 1986). In order to help confront student misconceptions, I also listed the known possible misconceptions from the literature and suggest a way to test the misconception. This helped students who are looking for direction to choose what they wish to test in the lab.

Another section of this program was the information database, where multiple representations of concepts were present. Multiple representations of a concept are more effective for learning than single representations (Reed, 2005). The Lifelab program also makes use of a variety of information formats, including videos of laboratory work, encyclopedia excerpts, and three dimensional animations (Zumbach, Schmitt, Reimann, & Starkloff, 2006). Not only should there be multiple representations of concepts, but the information should also be presented in context and different aspects of photosynthesis and cellular respiration should be purposefully linked together to create context. Representing concepts at multiple levels of organization is one way to contextualize information. This has been done in another program by representing processes at the level of DNA molecules all the way up to populations (Horwitz & Christie, 2000). In my program, molecular events in photosynthesis, for example, could be tied to what is happening to the leaf and what is happening to the whole plant. Images of the ecosystem or the whole plant can also be used to give context to the information. Students with more positivist leanings in their theory of how they learn may find this section more familiar and prefer to attempt to solve the problems using the information found here. Students' beliefs about their own learning process do impact how well constructivist or positivist instruction works for them (Wallace et al., 2003; Windschitl & Andre, 1998).

Within the information database section, several different types of information were presented. These were linked together so that a student could move from watching the animation of a process to the images and to the text about that same process. One type of information would be animations. Animations are very popular for modeling processes in science, but they are not always the best choice for learning. An animation can be so full of information that it distracts the student and leads to confusion rather than clarity. Animations also hinder the formation of mental models of how a process works in some cases; leaving the learner dependent upon viewing the animation to describe how a process works. In understanding mechanical systems, students who viewed an animation of a toilet flushing mechanism did do as well as students who studied a diagram and were forced to make a mental animation of how it worked (Hegarty, Kriz, & Cate, 2003). Students' spatial ability may impact the effectiveness of learning from an animation since high spatial ability students benefitted more from static diagrams and low spatial ability students benefitted more from animations (Koroghlanian & Klein, 2004). Nonetheless, animations do produce superior results compared to static images in learning many processes in science. Students viewing an animation with no narration of the processes of cholesterol uptake, apoptosis, and infection by the influenza virus retained information better than students viewing diagrams, with or without text , after a twenty one day period (O'Day, 2007). For animations used in teaching cell biology, Stith (2004) encourages use of animations for processes with sequential steps, motion, or specific locations in the cell (Stith, 2004).

Static images were also presented in the information database. Again, these were represented at several levels of organization to give them context. Images included static images with name labels, static images with function labels, images of ecosystems and whole plants to show how the functions and structures of smaller components play a role in their overall functioning. The images without labels were also available in the concept mapping tool. Some images were interactive and could be “dissected” to show how the parts fit together and how their functions interact. Another part of the information database was the text definitions. Rather than have students look to other resources that may have very complex definitions with much scientific terminology, I wrote definitions in commonsense terms as much as possible. Where scientific terms are necessary, I also defined all of those scientific terms in commonsense terms. Putting the scientific terms in commonsense language could have helped scaffold the language for a non-science major and help remove the barrier of confusing terminology (Driver et al., 1994).

Analogies were another form of information included in the information database. Analogies for functions and processes are powerful tools for explanation although they are a type of model and do have limitations. They relate prior knowledge to new information (Zydney, 2005). Stavrianeas reports an analogy between electrical power generation and the activity of three key regulatory enzymes in glycolysis (Stavrianeas & Silverstein, 2005). The citric acid cycle may be visualized as a water wheel or a computer game and separated into four quadrants (Schultz, 2005). These analogies are related to respiration, but would be too detailed for non-science majors. A simpler analogy would be between a water tower and its potential energy and the proton gradient that drives ATP synthase (S. Bell, personal communication, March 29, 2007). Other analogies could be explored such as chlorophyll is like a solar panel used to generate electricity.

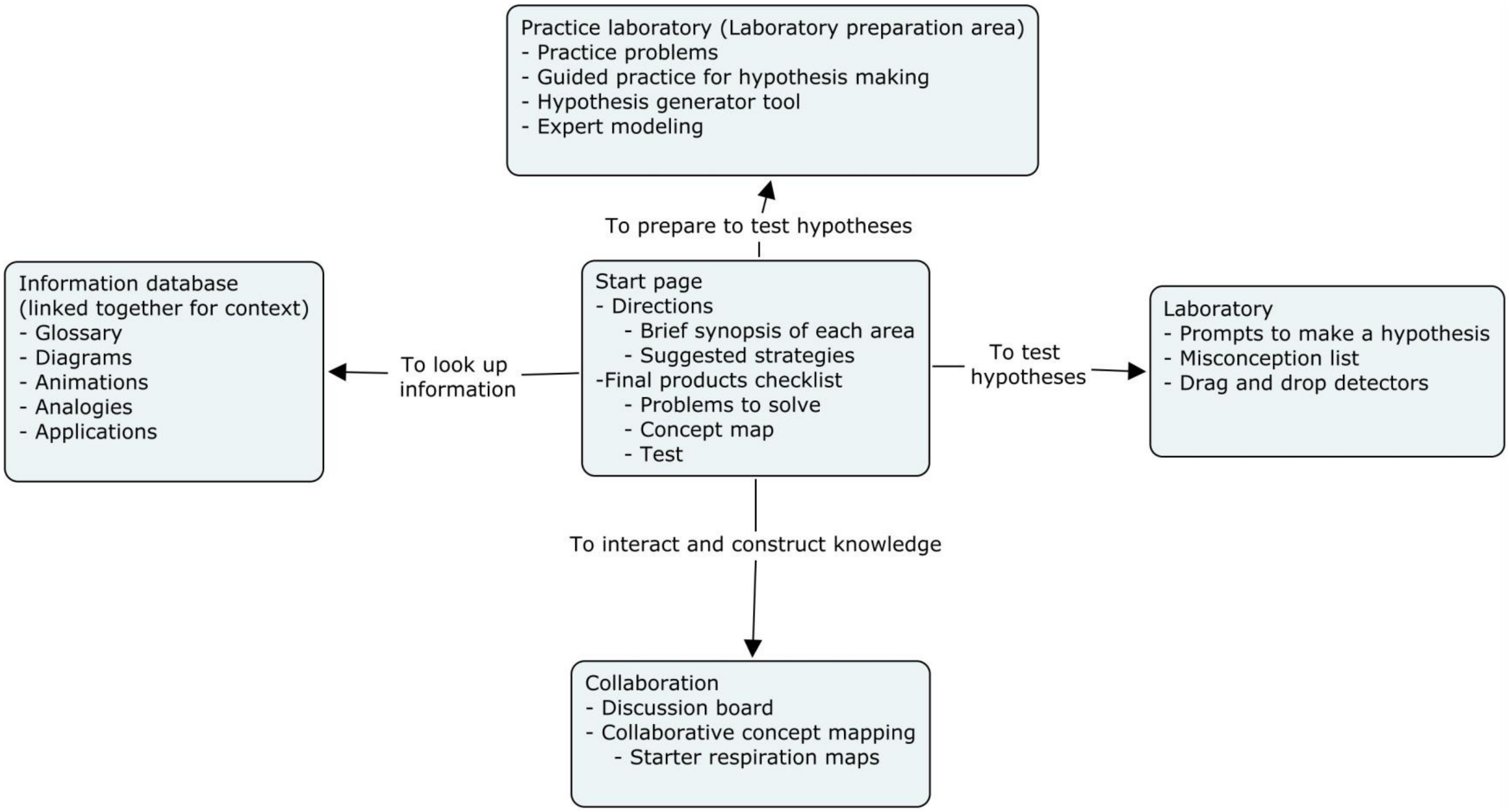
The last section of the program was the collaboration section. This section allowed interaction among students and instructor(s). This section was composed of two parts: the discussion board and the collaborative concept map. The collaborative concept map made use of CMap tools' ability to be used collaboratively. Directions for making a concept map and some sample concept maps were provided in this section. This section also served to give students practice in making concept maps in preparation for one of their final products. It did this by giving students starter concept maps for cellular respiration without photosynthesis for the students to build on and label connections on. The students were able to comment on each other's work to help improve the concept map over time. When the students made their final concept map for the laboratory activities, they could have taken their collaborative map of cellular respiration and created a concept map of photosynthesis to connect to it. The final concept map included both photosynthesis and cellular respiration as well as how the two are related to each other.

The second component of the collaboration section was the discussion board. A discussion board uses threaded discussions to organize user posts by topic. The discussion board was another tool for students to use in the process of solving the problems presented on the start page. It had the potential to form a limited online community for giving and receiving feedback on the problem solving process. In the computer program, it was designed to be a place where students can get feedback from instructors and fellow students on their work, thoughts, and findings in the form of questions that check for understanding or clarification of the student's objectives. Students could ask questions about what they were doing and planning and get feedback from the instructor on what other things they might try or help in framing a new plan. Other students may have had the same questions and could benefit from this feedback or also have given their own feedback to students asking questions. It was anticipated that students who needed help would come to the discussion board and students who were more independent learners would have only used it minimally if at all.

This computer program gave students cognitive tools to help prevent overload and frustration in their interaction with the program. Students constructed their own understanding of photosynthesis and cellular respiration in a way that helped them create their final products by choosing how and when to use the tools in the computer program. The investigative lab component and a social knowledge construction component helped students engage in the material in a meaningful way. The combination of different ways to interact with the material helped students to overcome some of their misconceptions.

The computer program was created in Adobe Flash for the user interface and PHP to work with a MySQL database to store information, as well as HTML to create different screens. The computer program was uploaded to a server so that students could access it online. Students in the sections that were selected to use the computer program were given access to the online computer program when the unit of photosynthesis and cellular respiration began. Students were given access to the computer program until the end of the course, but they were required to submit their final products from this program at the end of the week. Students who did not have access to a computer at home were able to use computers in the computer laboratory at their college. The multiple-choice and short answer instrument, pretest, and attitude survey were administered through Blackboard's ecampus system as online assessments. The concept map was submitted by the students using CMap and placing their finished concept map in a Microsoft Word document and submitting it to SafeAssign, Blackboard's version of a digital dropbox.

Figure 19. Design Overview of the CELE Program



Appendix B

Pretest

Question Topic	Question Numbers	Number of Questions
Osmosis and Diffusion	2-4, 9-12	7
Genetics	13, 16-19	5
Photosynthesis and Cellular Respiration	5-8, 14, 15	6
Enzyme/Lab Application	1	1
Conservation of Matter	20	1

1. What happened when hydrogen peroxide (H_2O_2) was placed on a slice of potato?

   *a. Oxygen (O_2) bubbles were produced
   b. The potato turned blue-black in color
   c. The potato increased in mass
   d. Carbon dioxide (CO_2) bubbles were produced

2. What happens if a red blood cell is placed in a hypertonic solution?

   a. no net change
   *b. cell will shrink
   c. cell will swell and burst

3. A bag made of dialysis tubing was filled with a starch solution. This bag was placed in a beaker filled with an iodine solution. What happened?

   *a. iodine moved into the bag
   b. nothing
   c. starch moved out of the bag
   d. iodine moved into the bag and starch moved out of the bag

4. In lab, how did you determine if osmosis occurred across the membrane of the potato?

   a. Bubbles were produced
   *b. the mass of the potato changed
   c. The potato turned color
   d. It was impossible to determine

5. A bean plant needs energy to survive and grow. Where does the energy that a bean plant uses to make its own food come from? (write all correct answers & explain if necessary)
Write your answers from this list: air, water, sun, soil, worms & insects, fertilizer, dead animals, roots
Misconception: Plants get their energy from something other than food/glucose/starch/light

(1 point for sun – may also have soil, worms & insects, dead animals, water, roots). Zero for not having sun or adding air.

6. A human being also needs energy to grow and survive. Where do you think a person directly (not the ultimate/original source of energy, but what the human being directly interacts with) gets the energy he or she needs to power cell activities, and therefore growth and survival? (write all correct answers & explain if necessary)
Write your answers from this list: air, water, beans, sun, exercise, meat, potatoes
Misconception: An animal's energy comes from something other than food/nutrients
(1 point for meat, potatoes, beans – any of these) Zero points if air, water, sun, or exercise are included.

7. Which of the following statements about the processes of photosynthesis and respiration in green plants is correct? To respire in this question means to perform cellular respiration. Photosynthesis refers to "regular" C3 or C4 photosynthesis, not CAM photosynthesis.

a. Green plants only photosynthesize during the day (or when there is light) and respire at night (when there is no light energy at all).
*b. Green plants only photosynthesize during the day (or when there is light) and respire all the time.
c. Green plants only respire when they cannot obtain enough energy from photosynthesis (e.g. at night or in a dark closet).
d. Green plants only photosynthesize at night and only respire during the day.

Misconception: Respiration only occurs in the dark in plants

8. Where does a plant's food that is used to make energy for activities other than photosynthesis come from? Select all answers which apply.

*a. From absorption through its roots
b. From absorption through its leaves and stems
*c. From making it inside its cells
d. From ingesting it with its cells

Either A or C were scored as correct, if B or D were selected, this question was scored as incorrect.
Misconception: Plants get their food from something other than carbon dioxide, usable compounds or compounds that may be used as a source of energy. Minerals from the soil are also used to build cell components, and so may have been considered food.

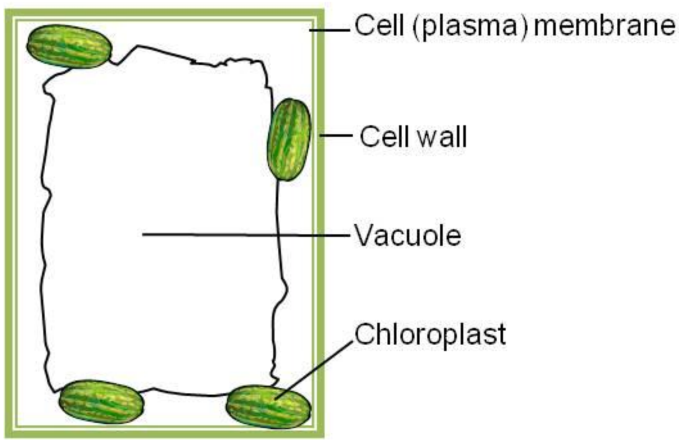
9. Suppose there is a large beaker full of clear water and a drop of blue dye is added to the beaker of water. Eventually the water will turn a light blue color. How does this happen?

a. The lack of a membrane means that osmosis cannot occur and diffusion cannot occur.
*b. The dye particles move between regions in the water that have different concentrations of the dye.
c. The dye breaks down into smaller and smaller particles so that it will look lighter in the water.

d. The water moves from one region of dye concentration to a region of different concentration of dye.

10. Figure 1 is a picture of a plant cell that lives in freshwater. If this cell were placed in a beaker of 25% saltwater solution, what would happen?

Figure 1.



a. The salt will leave the vacuole to enter the saltwater solution.
*b. Water will move from the vacuole to the saltwater solution.
c. The salt will enter the vacuole from the saltwater solution.
d. Water will move from the saltwater solution into the vacuole.

11. Suppose there are two large beakers with equal amounts of clear water at two different temperatures. Next a drop of green dye is added to each beaker of water. The water turns light green in the warmer beaker first, and then it eventually turns light green in the colder beaker. Why does this happen?

a. The lower temperature breaks down the dye, so that the smaller particles will be lighter colored.
*b. The heat causes the molecules to gain kinetic energy and move faster.
c. The cold temperature speeds up the molecules by giving them more kinetic energy.
d. Heat helps the molecules to expand so that they will be lighter colored.

12. Assuming that there are no electrical charge interactions, which of these describes how diffusion happens?

a. There are too many particles crowded into one area; therefore, they move to an area with more room.
b. There is a greater chance of the particles repelling each other than of the particles being repelled by the solvent.

c. The particles tend to move until the two areas are isotonic, then the particles completely stop moving.
*d. Particles in areas of greater concentration are more likely to bounce off other particles toward other areas.

13. Background information: In a large population of mice, all possible combinations of dominant and recessive genes (alleles) happen in every generation, meaning that the offspring could receive 2 dominant genes, 1 dominant gene and 1 recessive gene, or 2 recessive genes. The combination that the offspring receive does not affect their survival or reproductive rate.

True/False: When a mutation occurs in this population, if it is recessive, it will disappear in one or two generations, while a dominant trait will continue to appear in future generations.

a. True
*b. False

14. True or False: Photosynthesis is the respiration of plants.

a. True
*b. False

Misconception: Oxygen is produced from something other than photosynthesis/comes from something other than water.

15. Growth of a plant comes from adding molecules from the air to the plant.

*a. True
b. False

Misconception: Mass in plants comes from something other than carbon dioxide

16. Pea seeds were planted in the garden. The plants that grew from these seeds had flowers of different colors. What are the differences between the seeds that produced the different flower colors?

a. The seeds include different types of pigments.
b. The seeds include DNA that consists of different kinds of nucleotides.
*c. The seeds include DNA that consists of different nucleotide sequences.
d. The seeds include different types of ribosomes.

17. What is a gene?

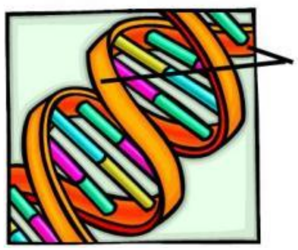
a. A gene is a characteristic, like straight hair, in the organism.
b. A gene is a characteristic, like straight hair, that transfers from one generation to the next.
*c. A gene is a segment of the DNA that codes for protein.
d. A gene is a sequence of amino acids that is responsible for the transmission of a trait from one generation to the next.

18. What is the relationship between gene and protein?

*a. The gene carries the instructions for making a nucleic acid sequence, which carries the instructions for the sequence in building protein.
b. The gene carries the instructions for the sequence in building a protein, which carries the instructions for making a sequence of nucleic acids.
c. The gene and the protein are both made of nucleic acids.
d. The gene is made of amino acids, which produce proteins.

19. When a skin cell divides, what happens to the DNA? Refer to figure 2.

Figure 2.



A chain or strand of a DNA molecule, pictured here with its 2 chains lined up in parallel.

a. Each daughter cell gets half of the original chromosome set, meaning that one daughter cell might get chromosomes 1-11 while the other daughter cell might get chromosomes 12-23 in a random split of the chromosomes.
b. The DNA in the mother cell divides into two chains of molecules, and each daughter cell gets one of the chains, meaning that DNA is not copied.
c. A new DNA molecule is created, according to the sequence in the original DNA. One daughter cell contains only the original DNA, and one contains only the new DNA molecule that was copied.
*d. Two new chains of DNA are built according to the sequence of the original DNA, and each daughter cell gets one DNA molecule, consisting of one of the original chains and one new one.

20. True or False: When a candle burns, the atoms in the wax and wick that are burned are destroyed.

a. True
*b. False

Appendix C

Posttest

1. What would be a biologist's definition of the term, "cellular respiration"?
Misconception: Cellular respiration in animals is unrelated to the breakdown of nutrients to produce ATP in cells
2 points: Full understanding: Cellular respiration is the process by which organisms obtain energy from food or make ATP energy.
1 point: Partial understanding: Using oxygen, giving off carbon dioxide.
0 points: Breathing. Plants exhale oxygen.

2. What would be a biologist's definition of the term, "photosynthesis"?
Misconception: Photosynthesis is something other than capturing light energy to build compounds such as G3P, glucose, or starch for energy storage or compounds for building new cell components. For example, that photosynthesis is simply the reverse of respiration.
2 points: Full understanding: Photosynthesis is the process by which plants use light energy to make their own food from carbon dioxide.
1 point: Partial understanding: Light is used. Carbon dioxide is changed to oxygen. Keeps plants green. Light is used to make food.
0 points: No understanding: The formula (with no explanation). Plants give off oxygen. It makes chlorophyll.

3. What would be your definition of "food" for a bean plant?
Misconception: Plants get their food from something other than light energy and carbon dioxide
2 points: Full understanding: A substance that may be used as a source of energy or for materials for growth.
1 point: Partial understanding: Minerals/fertilizer. Soil. Dead animals/plants.
0 points: No understanding: Light. Water.

4. A bean plant needs energy to survive and grow. Where does the energy that a bean plant uses come from? (circle all correct answers & explain if necessary)
air water sun soil worms & insects fertilizer
Misconception: Plants get their energy from something other than food/glucose/starch/light

In questions 5-7, circle the response you feel is most accurate. Use (?) only if you have no idea. If necessary, explain your answers in the space following the question.
5. What portion of their food do bean plants get by making it inside their cells?
ALL SOME NONE ?
Misconception: Plants get their food from something other than light energy and carbon dioxide

6. What portion of their food to bean plants absorb through their roots?
ALL SOME NONE ?
Misconception: Plants get their food from something other than light energy and carbon dioxide

7. What portion of their food do bean plants absorb through their leaves and stem?
ALL SOME NONE ?

Misconception: Plants get their food from something other than light energy and carbon dioxide

8. A human being also needs energy to grow and survive. Where do you think a person gets the energy he or she needs? (circle all correct answers & explain if necessary)
air water sun exercise meat potatoes
Misconception:

9. Which of the following statements about the processes of photosynthesis and respiration in green plants is correct?
a. Green plants only photosynthesize during the day and respire at night (when there is no light energy at all).
b. Green plants only photosynthesize during the day (when there is light) and respire all the time.
c. Green plants only respire when they cannot obtain enough energy from photosynthesis (e.g. at night or in a dark closet).
d. Green plants only photosynthesize at night and only respire during the day.
Misconception: Cellular respiration only happens in animals and not in plants

10. True or False: At 4:00 p.m., it is very hot, hence much water will be lost by transpiration and consequently the dry weight (which is the weight of the leaves with no water in them) of the leaves will increase.
Misconception: Mass in plants comes from something other than carbon dioxide

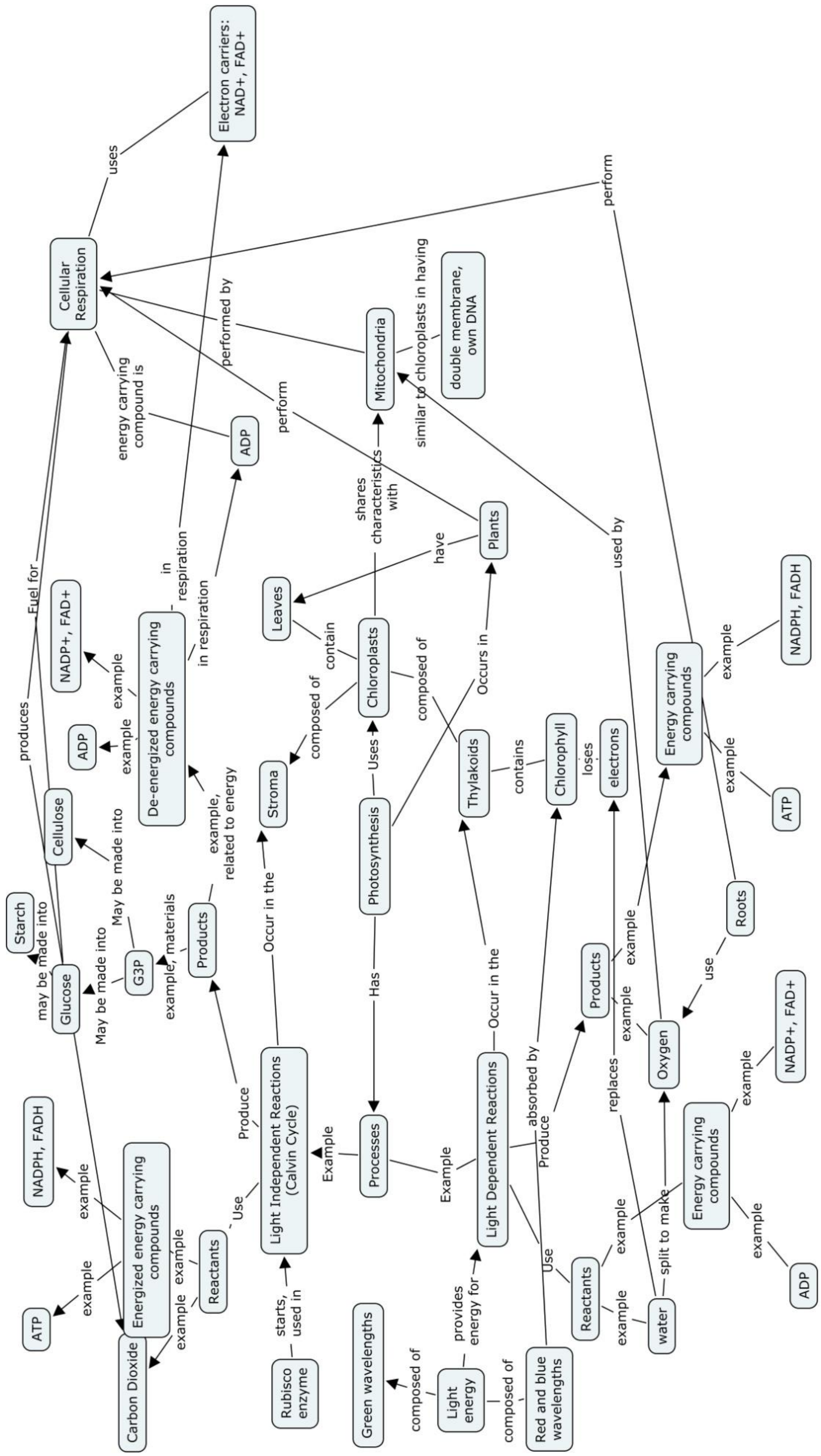
11. Do green plants need light to be healthy? ______ Why or why not?
Misconception: Plants do not need light for photosynthesis/light is used for something else like keeping plants warm and healthy
2 points: Full understanding: Yes – light provides energy for photosynthesis.
1 point: Partial understanding: Yes – light makes plants green.
0 points: No understanding: Yes –light keeps plants warm. No.

12. Which of the following statements is true for the process of photosynthesis?

a. Photosynthesis can take place with no light energy.
b. Non-green plants like fungi which do not contain chlorophyll or similar pigments can also photosynthesize.
c. Photosynthesis cannot take place without carbon dioxide.
d. Oxygen is not required for photosynthesis, it is a by-product of photosynthesis.
Misconception: Photosynthesis is something other than capturing light energy to build compounds such as G3P, glucose, or starch for energy storage or compounds for building new cell components. For example, that photosynthesis is simply the reverse of respiration.

Appendix D

Master Concept Map



Appendix E

Attitude Instrument

Using the Likert scale below, place a check mark below the answer that best represents your belief about each statement.

		Strongly disagree	Disagree	Undecided	Agree	Strongly agree
1	Osmosis and diffusion are very interesting to me.					
2	I don't like the topic of osmosis and diffusion, and it scares me to have to study it.					
3	It makes me nervous to even think about doing an experiment with photosynthesis and cellular respiration.					
4	I feel at ease in studying photosynthesis and cellular respiration and like it very much.					
5	Osmosis and diffusion are fascinating and fun.					
6	It makes me nervous to even think about doing an experiment with osmosis and diffusion.					
7	Photosynthesis and cellular respiration are very interesting to me.					
8	I feel at ease in studying osmosis and diffusion and like it very much.					
9	Photosynthesis and cellular respiration are fascinating and fun.					
10	I don't like the topic of photosynthesis and cellular respiration, and it scares me to have to study it.					

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ABSTRACT

THE EFFECT OF A COMPUTER PROGRAM DESIGNED WITH CONSTRUCTIVIST PRINCIPLES FOR COLLEGE NON-SCIENCE MAJORS ON UNDERSTANDING OF PHOTOSYNTHESIS AND CELLULAR RESPIRATION

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The primary objective of this project was to learn what effect a computer program would have on academic achievement and attitude toward science of college students enrolled in a biology class for non-science majors. It became apparent that the instructor also had an effect on attitudes toward science. The researcher designed a computer program, the CELE program, for use in instruction on photosynthesis and cellular respiration. The researcher modified existing instruments to assess academic achievement in understanding photosynthesis and cellular respiration and to assess student attitudes toward these topics. The researcher also used concept maps to assess student understanding of the material. The CELE program had no significant effect on academic achievement or student attitudes, which was possibly due to students' not engaging with the program as anticipated. The instructor had a significant effect on student attitudes toward photosynthesis and cellular respiration as well as on misconceptions that were not detected on the pretest but were detected on the posttest.