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THE EFFECT OF LABORATORY EXPERIMENTATION ALONG WITH GRAPHICAL AND DATA ANALYSIS ON THE LEARNING OF PHOTOSYNTHESIS AND CELLULAR RESPIRATION IN A HIGH SCHOOL BIOLOGY CLASSROOM

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Marie Lynn Jasper

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THE EFFECT OF LABORATORY EXPERIMENTATION ALONG WITH GRAPHICAL AND DATA ANALYSIS ON THE LEARNING OF PHOTOSYNTHESIS AND CELLULAR RESPIRATION IN A HIGH SCHOOL BIOLOGY CLASSROOM

By

Marie Lynn Jasper

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Submitted to
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ABSTRACT

THE EFFECT OF LABORATORY EXPERIMENTATION ALONG WITH GRAPHICAL AND DATA ANALYSIS ON THE LEARNING OF PHOTOSYNTHESIS AND CELLULAR RESPIRATION IN A HIGH SCHOOL BIOLOGY CLASSROOM

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This research project studied the effectiveness of using laboratory experimentation along with graphical and data analysis on the learning of photosynthesis and cellular respiration in a high school biology classroom. The goals were to address students' misconceptions and increase their retention and understanding of the concepts. Graphical and data analysis skills were emphasized to promote student achievement in other academic areas, personal situations, and the work force. The data collected and graphed during the laboratory experiments were also used to reinforce key concepts. The associated lecture material, demos, laboratory activities, assignments, quizzes, and tests were developed to complement the goals stated above. The effectiveness of this unit was determined using embedded assignments, lab write-ups, surveys, quizzes, subjective data, and pre/post test comparative analysis. The results from these assessments signify the unit was effective. This document also examines and critiques the day-to-day flow of the unit and the related lesson materials.

To my students past, present, and future, who have instilled in me a desire to always work towards becoming a better teacher.

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- Dr. Merle Heidemann for her content knowledge, insight and guidance.
- Dr. Ken Nadler for his content knowledge and advice on lab development.
- Dr. Chuck Elzinga and Dr. Jerry Urquhart for their content knowledge and ability to instill in me a greater appreciation for the outdoors.
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INTRODUCTION

Statement of Problem and Rationale for the Study

Multiple classroom observations over my first five years as a high school biology teacher pointed me in the direction of this investigation on photosynthesis and cellular respiration. Certain problems surfaced over time in regards to the content of these two complex topics. Additional problems related to the nature of science as a method of inquiry also emerged throughout my high school biology curriculum. These observations, in conjunction with my students' need to capture the quantitative nature of science, directed my research.

My high school biology students lack a complete understanding of how energy is transferred through an ecosystem. Their misconceptions center on the role of plants in food production for themselves, as well as for all heterotrophs within the community. During assessments, most students can describe a typical food chain, identifying producers and consumers. They can also state that producers "make" food for consumers through photosynthesis. Problems arise when students are asked where the plants get their food. The most common answer is the soil. Students fail to realize that producers make glucose for themselves and that the carbon to produce this glucose comes from the atmosphere and not the soil. Many students also claim that only plants perform photosynthesis and only animals perform cellular respiration. They lack an understanding of the connection between these two processes. They miss the relationship piece of the puzzle connecting the energy from the sun used to power photosynthesis to the energy stored in a molecule of glucose later released through cellular respiration to do cellular work. Lastly, students think that matter is created and destroyed rather than converted into different forms as it is transferred through an ecosystem.

The amount of scientific detail taught in my classroom in regards to these two complex processes was also overwhelming to students. From my first year teaching at Thornapple-Kellogg to the present, our philosophy as a science department has been to teach fewer concepts with more detail and better understanding rather then more concepts with little detail and moderate understanding. With the introduction of this unit, my goal was to incorporate the best of both philosophies while still covering all the Michigan Benchmarks. I wanted students to gain an appreciation for the complex nature of these processes without memorizing every step. I also wanted students to come away with a deeper understanding of the big ideas and how they set the foundation for so many other biological concepts. Sheldon Anderson once wrote in the Journal of Research in Science Teaching (1990),

> "We chose to focus on the related processes of respiration and photosynthesis because of their curricular significance. For example, our digestive systems, circulatory systems, and respiratory systems all function as they do largely because of the needs of our body cells to engage in respiration. Similarly, the demands of photosynthesis dictate many characteristics of plant structure and function. Even more important an understanding of photosynthesis and cellular respiration is a prerequisite for any systematic understanding of ecology."

Another concern was my students' ability to learn through inquiry and investigation. A good science education program provides all students with the opportunity to construct the important ideas involved in biology. Although I have spent amble class time teaching students how to design and conduct a good scientific investigation, I have fallen short of incorporating the scientific method into every unit I teach. Students need to practice science.

My goals for this unit on photosynthesis and cellular respiration are threefold. First, I would like to instill within my students a more accurate understanding of how energy flows through the ecosystem as a result of these two processes. I also want my students to develop an appreciation for the complexity of photosynthesis and cellular respiration and realize they set the stage for so many other biological concepts. Second, I want to provide opportunities for my students to construct the important ideas involved with these concepts through inquiry and investigation. Third, I want my students to recapture the quantitative approach to science by becoming proficient at designing, constructing, and analyzing data tables and graphs.

While conducting my research at MSU during the summer of 2006, I had five goals in mind as I developed new labs to foster student understanding of photosynthesis and cellular respiration. The five goals were, 1) to involve students in the process of scientific investigations, 2) implement a quantitative approach to most activities, and 3) keep the cost of supplies and preparation time to a minimum. By implementing new labs, I also allowed students to 4) critically evaluate and reflect on their conclusions. Also, biologists at all levels use mathematical tools to further their understanding of the natural world. Thus, my students need a 5) basic skill set that includes how to organize and analyze sets of numerical data. These are skills that students must master in order to facilitate their success at the next level of education and in their work, leisure, and fulfilling their responsibilities within the global community.

Cellular Respiration and Photosynthesis Education in the Literature

Plants are a vital component to life on earth. They are the link between the sun and the energy that flows through all ecosystems. Because of these facts, students interact with plants on a daily basis and should know a great deal about them from what they learn in school and experience in their everyday lives. However, misconceptions about them seem to arise early and understanding these misconceptions is the key to addressing them in the classroom.

A number of researchers (Batzli & Heidemann 2002; Weise 2006; Barman, Stein, & McNair 2006) have found that students' understandings of photosynthesis and cellular respiration are often limited. For example, Batzli and Heidemann (2002) found that when asked about photosynthesis students could tell them something about the capture of light and transformation to biochemical energy during the light reactions, but they were very unclear about the gain of biomass via the dark reactions. Similarly, Barman, Stein & McNair (2006) found that students understood that plants have basic needs that include water, nutrients and light, but had a harder time with the idea that plants need air to grow. Students who did consider air important for plant growth indicated that oxygen was the substance most utilized and showed no apparent link between carbon dioxide in the atmosphere and photosynthesis. Another common student misconception is that the "dark reactions" of photosynthesis only happen in the dark and therefore plants only fix carbon at night (Hershey 2004).

Batzli & Heidemann (2002) also found that many students do not readily accept the idea that plants undergo the process of cellular respiration at all. Or, they believe that plants photosynthesize during the day and conduct cellular respiration only at night.

(Hershey 2004) Many students also attributed anthropomorphic characteristics to plants, such as breathing, drinking, and eating based on their own experiences (Osborne & Freyberg 1985). These students failed to recognize the difference between cellular respiration at the cellular level and the process of taking in and releasing atmospheric gases at the organism level.

Weise (2006) observed that at the end of a unit on photosynthesis and cellular respiration students who could easily define glycolysis and fermentation many times had trouble describing the overall purpose of cellular respiration. Other students who memorized numerous facts about the Kreb's cycle and electron transport chain insisted all together that plants do not need cellular respiration.

These same researchers had many useful ideas on how to counteract the numerous misconceptions held by high school biology students. Batzli and Heidemann (2002) recommended showing that CO_2 gas is "real", has mass, and is measurable. This led me to develop the lab entitled *Anaerobic Respiration in Yeast* (Appendix D-3) and integrate the Van Helmont story into my lecture and assessment tools. Weise (2006) suggested helping students develop a working knowledge that all living things, including plants, transform food into usable energy during cellular respiration by performing multiple labs in the classroom that make use of only plants to observe the process. This moved me to create a lab that utilized the fruits of many different plants to study cellular respiration (Appendix D-2). Nelson (2001) recommended that instead of bombarding students with the details of the reactions of photosynthesis and cellular respiration, students should learn the bigger picture. Weise (2006) echoed this statement by reiterating how important it is to concentrate on the big ideas. She suggested providing lab opportunities so students are able to trace the transformations of matter and energy as they cycle through the ecosystem without memorizing every detail of each process. This was the motivation behind the lab entitled *Observing the Relationship between Photosynthesis and Cellular Respiration* (Appendix D-6) and the writing pieces (Appendix B-2 & B-4) that required students to explain the two processes using a given set of vocabulary terms in their own words.

Ultimately, one of the major obstacles facing educators is getting students to see photosynthesis and cellular respiration as dynamic, "not static", processes. Instead of passively presenting the material, it is imperative that students have opportunities to actively discover it (Clements & Jackson 1998). This practice of actively learning photosynthesis and cellular respiration has been encouraged by the National Science Foundation as an improvement of pedagogy over standard didactic lecture (NSF 96-139). The activities, labs, and objectives for this unit have therefore been designed to enable all students to master these two processes.

Review of Pedagogical Literature

Piaget's theory of cognitive development emphasizes the development of conceptual knowledge as a result of self-regulation, physical interaction, and social dialogue. During the process of self-regulation, the learner is actively involved in mentally forming concepts through assimilation and accommodation. This process is intensified through physical manipulation of materials and objects involving the concept and through social interaction that occurs between individuals discussing the concept (Piaget, 1970). Therefore, it is believed that appropriate hands-on labs can lead to increased student achievement in science because they occur in an authentic context, involve a deeper processing of ideas, and confront misconceptions (Wilke & Straits 2005). Pedagogical research also implies that active learning in science greatly enhances a students' ability to conceptualize abstract ideas and increases the students' level of retention (Rehorek 2004). The same applies to laboratory activities that are relevant to students' everyday lives and link real-world experiences with the classroom (Rutledge 2005).

An understanding of the nature of science as a method of inquiry is a fundamental component of scientific literacy (Rutledge 2005). According to Wilke & Straits (2005) many students who enter college lack any of the skills necessary to conduct scientific inquiry. These students are only as strong as their weakest link. For instance, even if a student has mastered the skills necessary to analyze data, if his/her experimental design is flawed, the data gathered will also be flawed and yield inaccurate results. Therefore, the development of science process skills is important at the high school level. The National Research Council (1996) recommends providing ample opportunities for students to manipulate and analyze data and to question those that are anomalous. By doing this, they can understand that science is a process of discovery (Chan 1996). This means that students need numerous opportunities to observe, classify, design, predict, infer, analyze, summarize, communicate, evaluate, and problem-solve. They also need practice asking questions, proposing hypotheses, making predictions, designing experiments with appropriate variables, collecting/analyzing data, drawing conclusions, and identifying sources of error. Involving students this deeply in the scientific process allows them to experience the joys and disappointments common to scientists as they conduct experimental work (Crandall 1997). Only after these skills are mastered has scientific literacy been achieved.

The hands-on laboratory approach to science education is a wonderful way for students to collect data and "do" science. But what good is this experience, if students cannot successfully interpret their data and correlate it to the science standards being taught? Developing methods to help students organize and analyze sets of numerical data is therefore of the utmost importance in science education (Christensen & Christian 1997). The national standards for science state that as part of the laboratory experience it is crucial that students learn to use data analysis tools to organize data and formulate hypothesizes for further testing (NRC, 1996). Similarly, the Science Education and Quantitative Literacy (SEAQL) project is a curriculum initiative that stresses the importance of having students' laboratory experience enhanced by allowing them to cooperatively develop data collection protocols, apply data analysis techniques, and critically evaluate results (Christensen & Christian 1997). These skills are especially important because they prepare students for a data focused future and are the cornerstone for success on standardized tests such as the ACT and SAT and MEAP (Michigan Educational Assessment Program).

According to Drummond (1999), high school teachers who incorporate quantitative reasoning skills into their science classes provide students with a toolkit that will facilitate their success at the secondary and collegiate levels. This ability to be successful at the next level is critical in today's changing world because most jobs now require advanced schooling and many require competence in technology and information systems. Drummond suggests four primary areas of focus. First, students should be able to manipulate and comprehend mathematical relationships between variables. Second, they should know how to use appropriate units of measure in the metric system so they can appreciate the magnitudes of numbers preceding them. Third, they should develop strong mathematical skills. Fourth, students must be comfortable in plotting graphical expressions. Graphing is important because it allows students the ability to assimilate and communicate large amounts of information. In addition, the ability to take a set of data, lay out the axes, and plot the points correctly represents a major advance in student understanding (Drummond, 1999). Unfortunately, many college students lack the ability to design and construct graphs especially utilizing computer programs such as Microsoft and Excel. In conclusion, these objectives should be integrated into the classroom and laboratory experiences.

Review of the Scientific Principles

The following summary of relative science objectives are categorized into two main sections: Photosynthesis and Cellular Respiration. These objectives were derived from the Kent Intermediate School District's Kent County Collaborative Core Curriculum (KC4). The KC4 is tightly aligned to the standards and benchmarks of the Michigan Curriculum Framework for Science and was developed by local teachers in Kent and Barry counties along with the Kent Intermediate School District's staff. The KC4 curriculum also meets all of Michigan's grade level content expectations. These summaries describe outcomes that all students should be able to obtain by the end of the unit.

Photosynthesis is a chemical process that takes place in green plants. These plants are capable of absorbing CO_2 and releasing O_2 to the atmosphere in the presence of light. Photosynthesis allows plants to use the carbon found in carbon dioxide, along with water and light, to grow and create food for itself, which directly or indirectly supplies energy to most living things. The process of photosynthesis can be broken down into two reactions that take place in the chloroplasts of green plants. The first, known as the light reactions, utilizes chlorophyll to absorb solar energy and convert it to chemical energy. During this process water is split into oxygen and hydrogen and NADPH and ATP are produced. The second reaction, known as the dark reactions, or Calvin cycle, convert carbon dioxide plus the hydrogen ions and high-energy electrons carried by NADPH into glucose. Overall, photosynthesis transfers solar energy into chemical energy in plants by converting energy-poor molecules like carbon dioxide and water into energy-rich molecules like glucose and oxygen. This is the only way most plants get food.

Cellular respiration is a chemical process that takes place in many living things. The energy generated during this process is ATP, which is used by living cells to perform their many life sustaining tasks. Most of the energy that enters the ecosystem is as solar energy and most of it leaves as heat when ATP is utilized by cells to do work. During cellular respiration energy is transferred from the bonds in simple food molecules utilizing oxygen. This takes place in the mitochondria of all living cells and the outputs are carbon dioxide and water. The process of aerobic respiration can be broken down into three sets of reactions. The first set, known as glycolysis, takes a six carbon sugar molecule and breaks it down into two-three carbon molecules known as pyruvic acid. The energy management molecules ATP and NADH are produced. The second set pf reactions, known as the Kreb's cycle or citric acid cycle, finishes the breakdown of pyruvic acid molecules to carbon dioxide, energy is transferred to ATP, NADH, and $FADH_2$. The final series of reactions is known as the electron transport chain, which utilizes the reducing power of NADH and $FADH_2$ to drive the production of additional ATP molecules via ATP synthase.

Fermentation is the process of creating ATP without using oxygen in an anaerobic environment. All types of fermentation make ATP entirely from glycolysis, the same process that is the first reaction of aerobic respiration. Some cells go through a process known as lactic acid fermentation where lactic acid is the waste product. Other cells undergo alcoholic fermentation were carbon dioxide and alcohol are released as waste products. The purpose of fermentation is to create ATP, albeit small amounts, to sustain life in oxygen deprived environments.

Demographics of the Classroom

Thornapple-Kellogg High School is a rural school serving approximately 1,000 students located in Middleville, Michigan. This village suburb lies on the southern most edge of Grand Rapids and is the largest district in terms of land mass in Kent and Barry counties. The average household income is approximately $53,000 and 14% of students qualify for either free or reduced lunch. Thornapple-Kellogg lacks diversity within its student population with 96% white, 2% Hispanic, 1% Asian, and 1% Black. The graduation rate is 96% with 66% of those students being college bound.

Thornapple-Kellogg High School runs a trimester schedule with Biology spanning two of the three trimesters. Students must currently complete four trimesters of science in order to meet graduation requirements. The Biology curriculum is taught at a level appropriate for students seeking further education after high school and is divided into Tri A and Tri B. Students have the option of taking the consecutive trimesters back-to-back or taking a trimester off in between. Each class period is 70 minutes in duration and meets everyday for 12 weeks.

I chose my 5^{th} block Biology class as subjects for this thesis research project. From a class of thirty-one, nineteen freshman and seven sophomores consented to the study, for a total of twenty-six student participants. Every student who returned a consent form said they planned to pursue some form of higher education after high school.

IMPLEMENTATION

This unit on cellular respiration and photosynthesis fits into my high school biology curriculum after units on the scientific method, ecology, and cells. Table 1 is a summary of the unit. The table is followed by a day-by-day description and analysis of each activity. The entire unit required four weeks.

Table 1: Cellular Respiration and Photosynthesis Unit Outline

Week 1:	10-23-06	Pre Unit Survey and Test Administered Lab Group Roles Identified
	10-24-06	Balloon Demo with Worksheet Cellular Respiration Notes
	10-25-06	Potassium Chlorate Demo ATP Notes Lab #1 ATP vs. ADP Lab
	10-26-06	Lab #1 Presentations and Wrap-up Continuation of Cellular Respiration Notes Cellular Respiration Role Play
	10-27-06	No School
Week 2:	10-30-06	Lab #2 Cellular Respiration Measuring CO_2 Production
	10-31-06	Lab #2 Classroom Calculations and Wrap-up Worksheet on Cellular Respiration
	11-1-06	Notes on Fermentation Collin's Type II Writing Assignment on CR
	11-2-06	Lab #3 Cellular Respiration Anaerobic Respiration in Yeast
	11-3-06	Cellular Respiration Quiz Lab #3 Computer Lab Data and Graphical Analysis
Week 3:	11-6-06	Lab #3 Wrap-up Photosynthesis Notes
	11-7-06	Continuation of Photosynthesis Notes Lab #4 Photosynthesis Part 2: The Absorption Spectrum Computer Work and Wrap-up Absorption Spectrum Worksheet
	11-8-06	Lab #5 Photosynthesis A Study of the Rate of Photosynthesis

Table 1 (cont'd).

	11-9-06	Lab #5 Computer Lab Data and Graphical Analysis Worksheet on Photosynthesis
	11-10-06	Lab #5 Wrap-up Photosynthesis Quiz Collin's Type II Writing Assignment on Photosynthesis
Week 4:	11-13-06	Cellular Respiration/Photosynthesis Notes Lab #6 Observing the Relationship Between Photosynthesis and Cellular Respiration Set-up Worksheet on Cellular Respiration and Photosynthesis
	11-14-06	Lab #6 Wrap-up Comparison Drawing of Cellular Respiration and Photosynthesis
	11-15-06	Cellular Respiration and Photosynthesis Test Review
	11-16-06	Cellular Respiration and Photosynthesis TEST

Week 1:

The first week of the unit began by getting the students excited about what would be happening in class over the next several weeks. Time was spent discussing lab groups and individual roles within those groups (facilitator, communicator, materials manager, recorder, etc). We discussed how the format of this unit would be hands-on, with multiple labs and activities (role plays, demos, etc.) incorporated. We also talked about the quantitative theme of the unit and the focus on data collection, graph development, and analysis of results. Afterwards, students were excited to spend time in both the science and computer labs.

During this week, the pre-unit survey (Appendix G-1) and pre-test (Appendix F-1) were also administered. These instruments were used as benchmarks to assess student achievement at the end of the unit. Students were asked to only place their names on the pre-test and not the survey. This was to permit truthful responses and gave the students a sense of autonomy in answering how they learn best and their plans for the future.

The first demo required students to observe a 20oz. soda bottle filled with 10% sugar solution and 3% yeast solution (Appendix C-1). A balloon was placed over the apparatus and 40 minutes were allowed to expire. Every five minutes a student volunteer made their way to the front of the room to take a circumference measurement. In the meantime, lecture notes were taken reviewing the following topics: conservation of matter, chemical equations, and coefficients/subscripts. After 40 minutes, each student calculated the radius and volume of the balloon at each five minute interval. Students were also required to answer thought provoking questions identifying the gas content of the newly inflated balloon, the process that produced this gas, and the reasons behind adding the sugar and yeast solutions. When finished, we briefly discussed the students' responses. Common hypothesis as to the content of the balloon included, CO_2, O_2 and water vapor. Most students were not familiar with the process that created the gas and they we only able to say that they thought the yeast was in some way "eating" the sugar.

To help students identify the true identity of the gas, I dropped the CO_2 produced into to a small flask and had it extinguish a lit match that was placed inside. I also asked a student volunteer to demonstrate to the class how a flask of Bromthymol Blue (BB) could be turned green as the student exhaled CO_2 through a straw. Then I did the same by inverting another balloon filled with CO_2 and a flask of BB. By this point students unanimously agreed that the content of the balloon was indeed carbon dioxide. The demo ended with a trip to the computer lab to graph the balloon's volume over time (Figure 1). Students were asked to identify the independent and dependent variables and place each on the appropriate axis with units.

Figure 1: Students Plotting the Balloon's Volume over Time in the Computer Lab

Next, I introduced the role of ATP and ADP in metabolism. Students did not know exactly how the stored energy of ATP was put to use in an organism. To show how much energy can be released from glucose, I began with a demo. Four grams of potassium chlorate were heated up in a test tube supported by a clamp and stand. A gummy bear was then added to the boiling mixture and a raging inferno was produced. Students were awed by the power and energy stored in such a small sample of food.

The class then discussed and recorded the structure and function of the ATP and ADP molecules. Then, students completed *Lab #1: ATP vs. ADP* (Appendix D-1).

Overall, this lab was successful and drove home the big ideas of stored up and released energy in the forms of ATP and ADP. The students had no problems constructing the models of ATP and ADP and answering questions about the molecules as a form of embedded assessment. Students successfully developed analogies after given an example. For instance, one group wrote that ATP is like a stretched out rubber band because it is full of potential energy and that ADP is like a stretched rubber band that has been released because it lost its energy in the form of kinetic motion.

Some possible improvements for next year include finding more diverse objects to use during the analogy portion of the lab. Students suggested a yo-yo, jack-in-the-box, and wind up airplane. Informal interviews revealed that students enjoyed the lab and felt it was easier to connect with an abstract idea after listening to each group's presentation.

The week ended with the big ideas surrounding cellular respiration and the few details that were essential to student understanding. In previous years a large percentage of time was spent getting students to memorize details involved with this process. Unfortunately, this came at the expense of students being able to grasp the overall importance. This year the instructional goals were changed to focus more on the why and less on the how (Appendix A). With this in mind, a simple role play utilizing rubber balls, colored balloons, and name tags was introduced to help students visualize the basic processes of glycolysis, Kreb's Cycle, and the Electron Transport Chain. This role play required multiple volunteers and left students less overwhelmed and more confident in their knowledge of the topic.

Week 2:

Week two started off with a lab designed to quantify the amount of CO_2 produced via cellular respiration by different types of fruit during a set period of time (Appendix D-2), (Figures 2-3). This was to help show that cellular respiration is a process that is occurring in all living things not just consumers.

Figure 2: Titration of Remaining 0.25M $Ba(OH)_2$ with 0.01 M HCl

Each lab group was responsible for a different type of fruit and a control. Results were compiled on the board. Averages were calculated for each type of fruit and the milliliters of HCl used to titrate per gram of tissue was determined. Using the inverse relationship between the amount of HCl used and the amount of CO_2 produced, students ranked the various fruits from the fastest to slowest in terms of respiration rate.

Figure 3: Measuring CO_2 Production in the Lab

Students were able to observe the process of cellular respiration first hand and use basic math and data analysis skills. Students were able to observe how numerous sets of data can lead to more accurate results and how rates can be calculated without the use of a graph. Most biology students have not had the opportunity to titrate and it was a nice preface for what they will be asked to do in the chemistry lab someday. One of the most useful conclusion questions asked students to draw a piece of fruit on the back of their lab and show what goes into and out of the fruit during the process of cellular respiration. I checked this portion of the lab before anyone was allowed to turn in their report and it gave me a quick and effective way to address misconceptions and make sure students' were grasping the big idea. Again, students were also asked to identify the independent,

dependent, and standardized variables to stress the importance of a good experimental design.

The biggest drawback to the lab was students being able to understand the inverse relationship between the amount of HCl used in the titration and the amount of CO_2 given off by the fruit. The data collected were also in very small numbers (to the hundredths and thousandths positions). In the future it will be helpful to talk about what an inverse relationship reveals and how small numbers can be compared. More thought also needs to be given on how to run the experiment for longer than 30 minutes so the values are larger and more recognizable. Overall, the lab went very well and students enjoyed the hands-on approach to data collection and examination. An additional review assignment (Appendix B-1) was given at the conclusion of the lab to help reinforce the overall process of cellular respiration.

Now the process of fermentation was introduced. Most students seemed very interested in the topic because of the relevance to their personal lives. To help students compare and contrast fermentation with aerobic respiration a writing assignment (Appendix B-2) was used. This assignment allowed me to assess student understanding by having them explain the concepts in the form of a letter written to a classmate who had just entered the class and knew nothing of cellular respiration.

The objective of *Lab #3: Fermentation in Yeast* (Appendix F-3) was to measure the amount of CO_2 produced by yeast during fermentation. Students were then to use this data to determine if there was a statistical difference in the production of CO_2 by yeast in warm water compared to cold water. This lab was very effective in a 70 minutes time slot. Students were genuinely interested in what was going to happen once the idea of

CO_2 production in warm water vs. cold water was introduced. Most students agreed that the rate of cellular respiration would be faster in the warm water. One student hypothesized that the warm water environment will allow the yeast to produce more CO_2 bubbles because bread rises faster on a warm, humid day. Another student hypothesized that the glucose molecules would be moving faster in the warm water and thus the yeast would come into contact with them more often and be able to conduct more fermentation. Both ideas were very insightful.

Plastic pipettes filled with a sugar and yeast solution were inverted into a warm water bottle and a cold water bottle. Thirty minutes were allowed to expire and the number of bubbles released by each pipette was recorded (Figures 4). As expected, the warm bottles were especially efficient at releasing CO_2. Students then compiled and graphed, using Excel, a classroom set of data. The students utilized their math skills to calculate the average number of bubbles released in the warm water bottle and cold water bottle per minute and converted the bubble totals into milliliters of gas released. They also identified on their graphs the time intervals where the rate of CO_2 production was the greatest for both temperatures. The scientific method was highlighted in this lab by requiring students to identify the independent, dependent and standardized variables along with an appropriate control. They also selected a new variable and designed an experiment that would test it as a factor in yeast fermentation. Most students chose to increase or decrease either the sugar content or yeast content of the pipette. All students did a nice job of describing what they would do to carry out the new experiment.

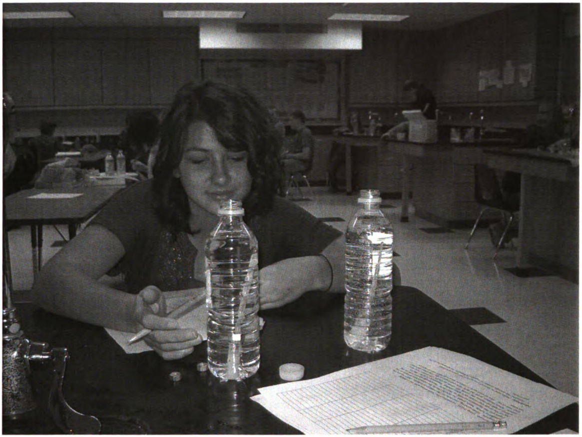


Figure 4: Studying Fermentation in Yeast

The students then took a quiz on the basic details of the respiration/fermentation. (Appendix E-1). Students performed well with a class average of 78%.

Week 3:

Week three began with notes on photosynthesis and a review of the carbon dioxide/oxygen cycle and its' importance to the survival of living things on earth. *Lab #4: The Absorption Spectrum of Spinach* (Appendix D-4) was then performed. Each student hypothesized about wavelengths of light spinach leaves used the most and least by drawing an absorption spectrum. The graph plotted percent absorption on the y-axis and wavelength on the x-axis. Many students plotted a very high percent absorbance for the color green compared to the other colors. This was one of the misconceptions to be corrected by the end of the lab. Once students finished their preliminary graphs, we proceeded to the computer lab to plot the data I obtained through my work during the summer of 2006 at MSU (Figure 5). The lab worked extremely well with students excitedly anticipating what their final graph would look like after completion on Excel. As with all the labs, students were required to reconstruct a data table along with their graph as further practice in data organization. They compared and contrasted their expected results with the actual results as seen on their final graph. From this they were able to deduce the required information regarding wavelengths of light. They could also accurately determine why the most photosynthetic parts of the plant are green. Additional practice on graph reading was given as homework in preparation for *Lab #5* (Appendix D-5).

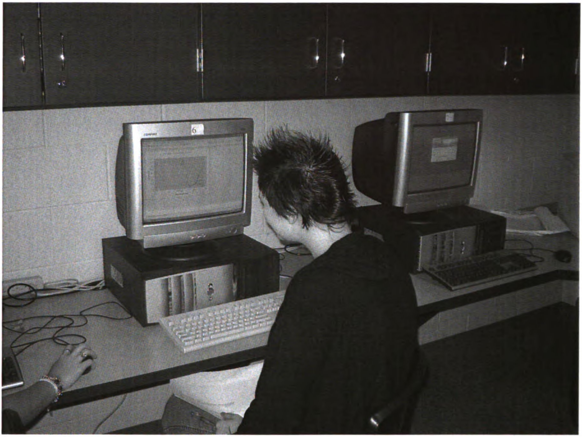


Figure 5: Plotting the Absorption Spectrum of Spinach Leaves

Lab #5: A Study of the Rate of Photosynthesis (Appendix D-5) was a student favorite (Table 7). The objective was to measure and compare the rates of photosynthesis in spinach leaf disks that were subjected to different colors of light (red, green, and white). This was accomplished by placing different colored pieces of cellophane (to act as filters) around three separate 60cc syringes. A bicarbonate/detergent solution was then placed in each syringe along with 15 spinach leaf disks. The suspended leaf disks were subjected to a vacuum and slowly sunk to the bottom of the inverted syringes as air was removed from their air spaces. Once the lab began, the syringes were exposed to a light source for a total of 30 minutes. Students were then required to measure how quickly the leaf disks floated upward (Figure 6). Generated oxygen sticks to the surface of the leaf disks and forces liquid out of their air spaces, thus making them buoyant.

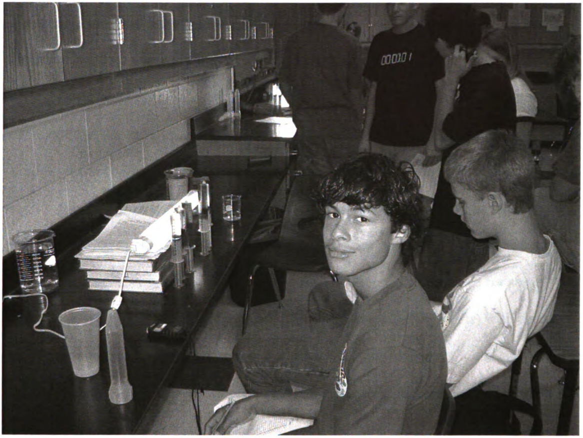


Figure 6: Measuring Photosynthetic Rates in the Lab

Before the lab began, students ranked the colored syringes from the fastest to the slowest in terms of photosynthetic rate and record their answers in the pre-lab. The majority of students responded with white, then red, then green. I also asked my students to explain what was meant by the term "rate". Students struggled with an appropriate definition and example. Therefore, we spent several minutes at the beginning of the lab discussing what rate reveals in a scientific experiment and how it can be measured. Overall, this time of pre-lab questioning worked well for getting students curious, quiet, and on-task.

A couple of challenges emerged as the lab was being performed. First, the lamps used to illuminate the syringes differed among groups because I did not have access to ten or more identical lamps. Students brought them in for extra credit. The second challenge had to do with the water-filled beakers used as heat sinks in front of the syringes. Because 1,000 mL beakers were the largest I had on hand, the two syringes on the outside of the experimental set-up were receiving bent light whereas the syringe in the middle was not (Figure 7).

Students calculated the cumulative classroom totals for each color, finding that the greatest rate of photosynthesis took place in the color white, followed by red, then green. Students also graphed class results in Excel. This was a challenge for some students as it required a multi-lined graph (three separate colors/symbols) with time on the x-axis and the number of disks that floated upward on the y-axis. In the end, students were excited by the results and impressed that they could quantitatively support their original hypotheses with "hard" data.

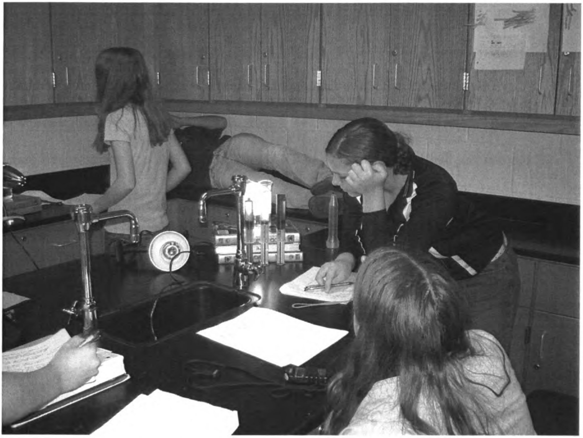


Figure 7: Oxygen Production Due to Different Colors of Light

This lab was also beneficial because the follow-up required students to analyze sources of error, identify the parts of the scientific method, and apply their knowledge of light and photosynthesis to hypothetical situations involving blue and yellow cellophane. The lab also incorporated numerous mathematical calculations and the determination of rate into a quantitative study of photosynthetic activity.

In the future, I plan on supplying each lamp brought in by a student with a new incandescent light bulb of the same wattage. I may also purchase a class set of inexpensive chicken lamps (these seemed to work very well) to have on hand for this lab. I would also require my students to rotate the syringes every two or three minutes so they receive equal time at each position on the table.

The week ended with a review assignment (Appendix B-3) and the photosynthesis quiz (Appendix E-2). Students performed well on this quiz with a class average of 79%. After the quiz, students demonstrated their understanding of photosynthesis by completing a writing assignment (Appendix B-4) that required them to explain the big ideas back to me in the form of a letter written to a classmate who had just entered the class and knew nothing of photosynthesis

Week 4:

Week four focused on the relationship between photosynthesis and cellular respiration. Visual illustrations were drawn by each student to show the flow of matter and energy through an ecosystem. Labels and arrows were included to facilitate understanding. Justification as to the rate of each reaction in terms of sustaining life on earth was also discussed.

Lab #6: Observing the Relationship between Photosynthesis and Cellular Respiration (Appendix D-6) began with students filling two large test tubes three-fourths of the way full with bromthymol blue solution. They then turned the solution in the tubes green by blowing in CO_2 gas. Each test tube received a sprig of Elodea and was corked. One flask was placed in a dark cupboard and the other in a sunny windowsill for the same amount of time.

Each student recorded the color of the BB solution in each test tube after 24 hours. The test tube in the light turned back to blue and the test tube in the dark turned a lighter shade of greenish/yellow (Figure 8). Because a plant was used for this experiment it really helped address the misconception that plants do not go through cellular respiration. It also revealed the extent of each reaction and whether it can proceed in the light, dark, or both. The conclusion questions challenged students to apply their knowledge of photosynthesis and cellular respiration to additional scenarios. Student responses to these questions were superb and revealed a deep understanding of the two processes. As always, the different parts of the scientific method were also addressed and explained in terms of their relevance to the experiment.

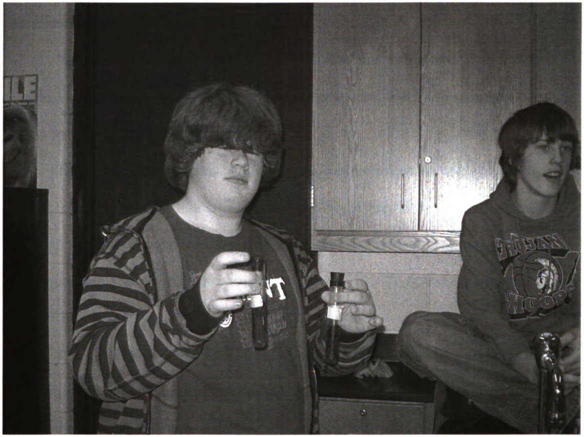


Figure 8: Observing the Relationship between Photosynthesis and Cellular Respiration in the Lab

The unit concluded with the unit test (Appendix F-2). Students were given 70 minutes and many had to rush toward the end of the period. In the future, the test will need to be given in two parts.

Assessments:

Numerous assessment tools were utilized throughout this unit. They included writing tools, quizzes, pre/post surveys, and pre/post tests. Each was customized to assess specific objectives of the unit.

The writing tools required students to explain the important concepts of the unit in a manner that made sense to them and was hopefully scientifically accurate. They had the opportunity to respond to both short answer type questions and essays. Therefore, some questions asked about one particular idea, while other required the synthesis of many different ideas.

The quizzes covered basic scientific principles along with incorporating critical thinking skills. For the cellular respiration quiz, students were required to apply their knowledge to a hypothetical scenario involving a mouse, phenolphthalein indicator, and an experimental apparatus that was open to the surrounding environment. For the photosynthesis quiz, students were required to apply their knowledge of photosynthesis to explain the classic Van Helmont experiment and describe what would happen to a geranium plant placed in two different experimental set-ups.

The pre-unit and post-unit surveys were used to gain insight into the likes and dislikes of each student. Students were asked to reveal information regarding future educational plans and what type of teaching techniques they find most useful. They were also asked to rate each laboratory exercise in terms of effectiveness in teaching the principles of cellular respiration and photosynthesis.

Finally, the pre-test and post-test were used to gauge student improvement over the course of the unit. The pre-test consisted of ten multiple choice questions, three short answer questions, and two essays, each relating to a key concept of the unit. The post-test consisted of 51 multiple choice questions and 11 critical thinking short/answer essay questions (some with numerous parts). Statistical analysis was done comparing the ten identical multiple choice questions and the two identical essay questions from the pre/post tests. The overall percentages earned on both the pre-test and post-test were also analyzed. Throughout both assessments, students were repeatedly asked to apply their knowledge of cellular respiration and photosynthesis to new experimental designs by explaining what was happening or what would happen and why. On the post-test they were also asked to analyze large sets of data and explain what it revealed and how it related to the key concepts of the unit. Finally, students were required to develop a graph based on a given set of data and determine the independent, dependent, and standardized variables.

RESULTS AND EVALUATION

Subjective Assessment Pre-Unit Survey

The pre-unit survey (Appendix G-1) included fifteen statements that the students were asked to answer truthfully and anonymously. These self-response data revealed student goals, skills, and learning styles and helped frame the unit. The results are presented in Table 3 and Figures 9 and 10.

Table 2: Students Future Academic Plans

	Yes	No	Not Sure
1. Do you plan to continue your education after graduating from TK?	24	0	2
2. Will you take another life science course either in high school or beyond?	9	5	12
3. Do you plan to have a career that is related to science?	8	7	11

Students who answered "yes" to question one (Table 3) indicated that they would like to continue their education at a college or university, cosmetology school, or trade school. Students who answered "yes" to question two (Table 3) indicated that they would like to pursue the following careers: veterinarian, marine biologist, DNR park ranger, zoologist, chiropractor, or pediatrician. According to the survey, 62% of all students listed math or science as their favorite class at Thornapple-Kellogg, while only 19% listed math and science as their least favorite classes. This information showed that the majority of students involved with this research were academically motivated and planned to continue their education after high school. It also revealed that most students were at least moderately interested in the content of the unit, but less than half planned to pursue a career related to the field. This information was therefore used to meet the needs, knowledge, and experience of the students and maintain their interest and curiosity.

Figure 9 shows that the majority of the students involved with this project are academically successful in the areas of math and science. These students are not representative of all biology students at Thornapple-Kellogg in that they are above average in the areas of math and science. This was encouraging considering the complexity of a unit on cellular respiration and photosynthesis. Figure 10 depicts what aspects of science class students find the most helpful. More than 50% responded with labs, which fit in nicely with the goals of this unit.

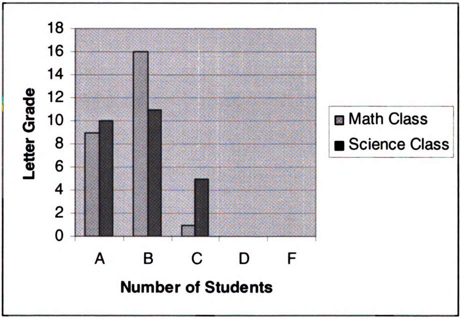


Figure 9: Students Letter Grade in Math and Science Class during the 2005-06 School Year

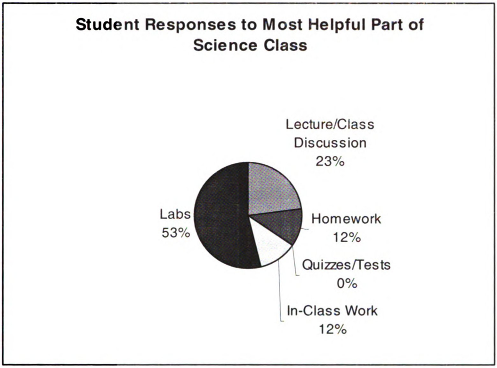


Figure 10: Student Responses to Most Helpful Part of Science Class

Objective Assessment Analysis of Pre/Post Writing Assignments

Figure 11 displays the results for the cellular respiration writing piece (Appendix B-2). The class average for the number of vocabulary words used correctly on the pre-test was 2.1 words. The class average for the number of vocabulary words used correctly on the final writing assignment was 19.5 words. The number of students using all 21 words correctly on the final writing assignment was 15 out of 26 students.

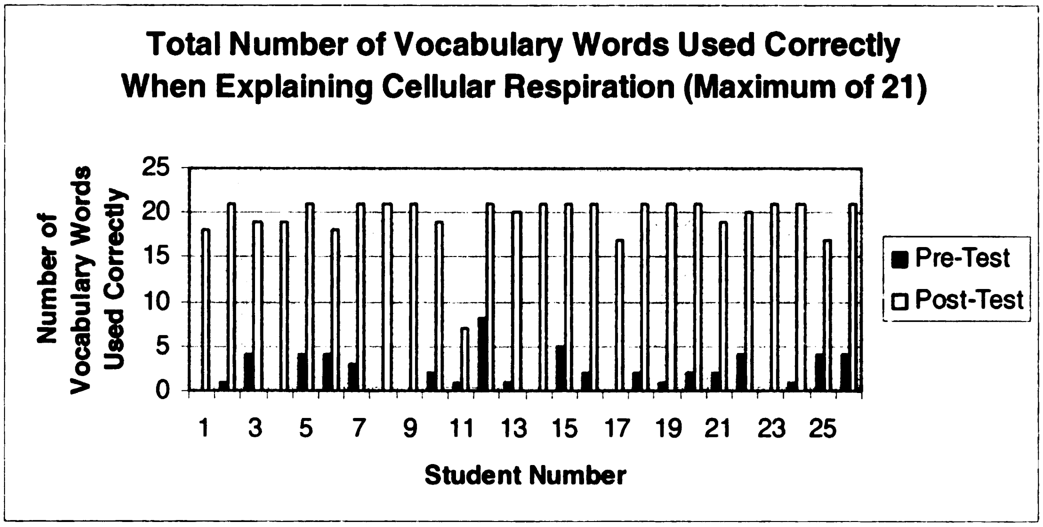


Figure 11: Writing Results on Cellular Respiration

A paired student's t-test was used to determine if the results of this assessment were statistically significant. The null hypothesis is that the cellular respiration portion of this unit will have no effect on student understanding. The T value for this test is 24.7. When matched with the degrees of freedom (23) the probability of this result, assuming the null hypothesis, is 0.000. Thus, the results are highly statistically significant and allow rejection of the null hypothesis.

Based on these results, most students achieved a strong understanding of cellular respiration by the end of the unit. The following is just an example of an excellent student response from the final writing assignment.

> "One form of cellular respiration is entitled aerobic respiration because it requires oxygen. The first step is glycolysis. It splits a molecule of glucose in half and releases carbon dioxide and 2 ATP. It happens in the cytoplasm. The second step is the Kreb's Cycle. It continues to break down the glucose. As this happens the energy is captured in NADH and $FADH_2$. Carbon dioxide and 2 ATP are released. It takes place in the mitochondria."

Most students who struggled to use all 21 vocabulary words correctly at the end of the unit misunderstood fermentation. This was an area that we covered in less than a day and as a result students were confusing lactic acid fermentation and alcoholic fermentation. Many students were able to state that this process happened in the absence of oxygen, but struggled with the inputs and outputs of each individual type.

Figure 12 shows the results for the photosynthesis writing piece (Appendix B-4). In general, the data shows that students entered Biology with more background knowledge on photosynthesis than on cellular respiration (Figure 11-12). The class average for the number of vocabulary words used correctly on the pre-test was 6.7 words. The class average for the number of vocabulary words used correctly on the final writing assignment was 19.4 words. The number of students using all 21 words correctly on the final writing assignment was 8 out of 26 students.

A paired student's t-test was used to determine if the results of this assessment were statistically significant. The null hypothesis is that the photosynthesis portion of this unit will have no effect on student understanding. The T value for this test is 23.8. When matched with the degrees of freedom (23) the probability of this result, assuming the null hypothesis, is 0.000. Thus, the results are highly statistically significant and allow rejection of the null hypothesis.

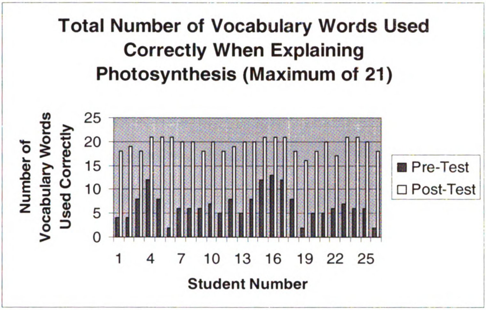


Figure 12: Writing Results on Photosynthesis

Based on these results, more students entered this unit with a more advanced understanding of photosynthesis compared to cellular respiration. At the beginning, many students were able to write knowledgably about sunlight, water, carbon dioxide, oxygen, and glucose as they loosely related them to the process of photosynthesis. For example, one student wrote the following, "Photosynthesis is a process that happens in plants where they use the suns energy, along with water and carbon dioxide, to make food. We use the oxygen that is given off to breath." However, by the end of the unit, fewer students were able to use all 21 photosynthesis vocabulary words correctly compared to the cellular respiration vocabulary words.

For most students, the problematic areas of photosynthesis were the basic details of the light reactions and Calvin Cycle. For example, one student wrote the following explanation. "During the light reactions water is split by light energy and oxygen is released. ATP and NADPH are made. The dark reactions happen in the dark. Energy from ATP and NADPH is used to split CO_2." This is unfortunately the end of this student's explanation and it already yields two misconceptions. The dark reactions can happen in light or dark conditions and CO_2 is split. I believe my students' limited experience retaining detail oriented information is responsible for this type of result. Although I cut back tremendously on the amount of information my students were required to memorize this year, I still think perfecting this skill is essential to their success at the next level.

Objective Assessment Analysis of Pre-test and Post-test Scores

Figure 13 shows the student's pre-test and post-test scores on ten specific multiple choice questions. A paired student's t-test was used to determine if the results of this assessment were statistically significant. The null hypothesis is that the cellular respiration and photosynthesis unit will have no effect on student understanding. The T value for this test is 3.9. When matched with the degrees of freedom (9) the probability of this result, assuming the null hypothesis, is 0.004. Thus, the results are statistically significant and allow rejection of the null hypothesis.

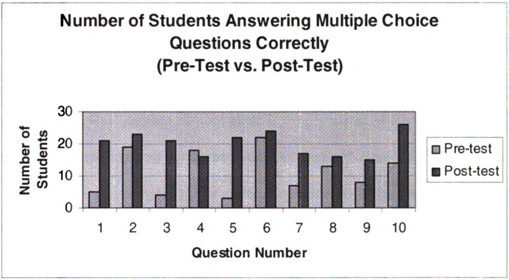


Figure 13: Students' Pre-Test and Post-Test Scores

These ten questions were chosen for analysis because they represented ten different concepts related to cellular respiration and photosynthesis. In nine out of ten questions, more students answered correctly on the post-test compared to the pre-test.

Four of the selected multiple choice questions struck me as interesting in their outcomes. First, number four is the only question that showed students performing worse on the post-test compared to the pre-test and specifically asked students to relate the processes of cellular respiration and photosynthesis. The outcome of this question was especially disappointing because grasping the relationship between these two processes was a major objective. The majority of students who answered this question incorrectly did so by answering "all of the above". This leads me to conclude that many students may have been overwhelmed by the amount of information in the question and therefore probably selected what they hoped was an all inclusive answer.

The second question of interest was question number six. It asked students to identify the misleading portion of the following statement, "producers carry out photosynthesis and consumers carry out cellular respiration". All but two students selected the correct answer in that both producers and consumers carry out cellular respiration. This question showed that the misconception that only consumers carry out cellular respiration was no longer widely accepted among the participants in this study.

Third, was question number nine. It simply asked which of the following molecules is not involved in fermentation. Although 15 out of 26 chose the correct answer, which was oxygen, 11 out of 26 chose ethanol. This, along with the errors made on the writing assignment, showed that fermentation was not well understood by my students. The most likely explanation for this outcome was the limited time devoted to the topic.

The last question of interest was question number ten which all students answered correctly. It required them to identify transformations of energy as they relate to cellular respiration and photosynthesis. This question demonstrated that the unit successfully addressed my students' lack of complete understanding of how energy is transferred through a community.

Figure 14 shows the 26 students percent scores on both the pre-test and post-test. The average pre-test grade was 23.7% and average post-test grade was 79.9%. Each of the 26 participants showed improvement from pre-test to post-test.

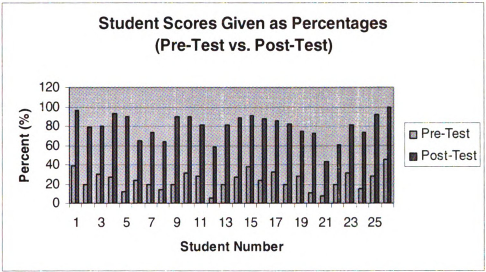


Figure 14: Percent Achievement for each Student on Multiple Choice Questions

A paired student's t-test was used to determine if the results of this assessment were statistically significant. The null hypothesis is that the cellular respiration and photosynthesis unit will have no effect on student understanding. Table 3 displays the results.

Table 3: Paired t-Test Results

T= 30.8	**Group A Data**	**Group B Data**
Degrees of Freedom = 25	Pre-Test Scores	Post-Test Scores
Number of items	26	26
Mean	23.7	79.7
95% Confidence Interval for Mean	19.78-27.60	74.29-85.02
Standard Deviation	9.67	13.3
Hi Score	45	100
Low Score	5	43
Median	24	81.2
Average Absolute Deviation from Median	7.69	10

The T value for this test is 30.8. When matched with the degrees of freedom (25) and the p value of .01 (for highly statistically significant) on the student's t-distribution table, the t-value of 2.48511. This allows rejection of the null hypothesis.

Subjective Assessment Post-Unit Survey

The post-unit survey, used as a subjective assessment following the implementation of the unit (Appendix G-2), included three sections. The first required students to evaluate their confidence in responding to sixteen objectives directly related to cellular respiration and photosynthesis (Table 4). For clarity, the answer receiving the highest percentage of votes is bolded. Of the 16 categories, only one received the highest percentage in the "Sometimes" column. This objective asked if students felt comfortable explaining what chemical energy is and how cells release it from food through cellular respiration. All others received the highest percentage in the "Always" column or "Usually" column. This indicated that students felt very comfortable with the information presented in this unit.

Table 4: Student Confidence Regarding Unit Objectives

	Always	Usually	Sometimes	Never
I can describe the functions (jobs) of the chloroplast and mitochondria	27%	**50%**	23%	0%
I can explain the relationship between photosynthesis and cellular respiration	**58%**	35%	8%	0%
I can distinguish between kinetic and potential energy	**42%**	38%	19%	0%
I can explain what chemical energy is and how cells release it from food through cellular respiration	23%	31%	**42%**	4%
I can describe the structure of ATP and how it stores energy	38%	**46%**	15%	0%
I can give examples of work that cells perform	**46%**	38%	15%	0%
I can relate breathing and cellular respiration	**54%**	35%	12%	0%
I can identify the overall reactants and products of cellular respiration	**54%**	42%	4%	0%
I can summarize glycolysis, the Kreb's Cycle and the Electron Transport Chain and identify where ATP is made	**50%**	38%	12%	0%

Table 4 (cont'd).

I can explain how fermentation in muscle cells is different from fermentation in yeast cells	**54%**	42%	4%	0%
I can summarize the overall reactants and products of photosynthesis	**58%**	38%	4%	0%
I can explain how white light is captured in plant cells	**54%**	35%	12%	0%
I can identify the chemical reactants and products of the light reactions	31%	**46%**	23%	0%
I can explain how the Calvin Cycle makes a simple sugar	31%	**54%**	15%	0%
I can summarize the light reactions and the Calvin Cycle	**42%**	38%	19%	0%
I can describe the types of organisms that carry out photosynthesis and cellular respiration	**73%**	23%	4%	0%

The second section of the post-unit survey required students to evaluate their ability to organize, display, and analysis data (Table 5). Again, for clarity, the answer receiving the highest percentage of votes is bolded. All seven categories received ratings of "Always" or "Usually", indicating that the unit was successful in increasing student confidence in working with numerous types of data.

Table 5: Student Confidence Regarding Data Manipulation

	Always	**Usually**	**Sometimes**	**Never**
If given a graph I can identify the dependent and independent variables in an experiment.	**54%**	35%	12%	0%
I can organize data into a data table.	**77%**	23%	0%	0%
If given a data set, I can make a graph using paper and pencil.	**77%**	19%	4%	0%
If given a data set, I can make a graph using Excel.	**77%**	23%	0%	0%
I can draw conclusions about an experiment by analyzing the data table	38%	**54%**	8%	0%
I can analyze a graph and determining what it is trying to tell me.	**54%**	38%	8%	0%

Table 5 (cont'd).

I can apply previously learned knowledge to help me understand new labs, diagrams and story problems, even if I may never have seen them before.	**50%**	27%	23%	0%

The third section asked students to reveal how well they thought the labs reinforced the unit objectives (Table 6). The answer receiving the highest percentage of votes is bolded. Students ranked four out of six labs as "very helpful" and two out of six labs as "somewhat helpful". The lab receiving the lowest rating was the one that was not completed fully. Students only performed *Lab #4: Part 2: Graphing the Absorption Spectrum of Spinach Chloroplast* (Appendix D-4) Overall, the data reveals that students thought the labs were extremely helpful in reinforcing the unit objectives.

Table 6: How Well Students Thought Labs Reinforced Unit Objectives

	Very Helpful	**Somewhat Helpful**	**Not Helpful**
Lab 1: ATP	**54%**	42%	4%
Lab 2: CO2 Production	**54%**	42%	4%
Lab 3: Yeast Fermentation	**65%**	31%	4%
Lab 4: Part 2: Absorption Spectrum	35%	**58%**	4%
Lab 5: Rates of Photosynthesis	**62%**	35%	4%
Lab 6: Photosynthesis vs. Cellular Respiration	46%	**50%**	4%

DISCUSSION AND CONCLUSION

Goals Were Met

This unit, laboratory experimentation along with graphical and data analysis on the learning of photosynthesis and cellular respiration in a high school biology classroom, met the goals I had, the goals of my district, and the Michigan Benchmarks. It successfully incorporate laboratory activities of a quantitative nature and was a pleasure to teach and reflect upon.

To begin, I wanted my students to be able to describe how energy flows through the ecosystem and gain an appreciation for the complexity of photosynthesis and cellular respiration. This was successfully accomplished as shown in Figure 13. Questions six and ten from the multiple choice section of the pre/post test specifically address energy flow through an ecosystem and students performed remarkably well on both during the post-test. Similarly, the students overall understanding of photosynthesis and cellular respiration as complex processes was evident as shown in their writing samples. Looking at the significant differences in the pre-test and post-test scores in Figures 11-12 validates this finding.

I also wanted to provide opportunities for my students to construct the important ideas involved with these concepts through inquiry and investigation. This was accomplished by implementing six newly developed labs, all of which utilized the scientific method. These labs required students to be scientists and they enjoyed the challenge. In fact, 53% of students stated in the pre-survey that labs were the most useful part of science class (Figure 10) and they echoed this statistic in the post-survey. When asked "what was your favorite part of this unit", 18 of 26 students replied "labs".

According to the students, the implementation of numerous labs helped make the information presented more meaningful. They also said it helped with their comprehension of the concepts and their ability to retain the information.

Throughout the unit, students had opportunities to experience the quantitative approach to science by becoming proficient at designing, constructing, and analyzing data tables and graphs. Four of the six labs developed and implemented required students to practice these skills. This type of proficiency will be needed as they try and make sense of the vast amounts of information that will confront them in years to come.

Students also walked away with a more complete understanding of cellular respiration and photosynthesis. This goal was met as indicated by the comparison of pre-test scores and post-test scores in Figures 11-14 and the statistical significance of the student's paired t-tests.

By accomplishing the goals mentioned above, I successful met the goals of my district in teaching cellular respiration and photosynthesis and practicing data analysis skills. As a result of implementing this unit, I also successfully met many of the Michigan Benchmarks. By the end of the unit, students were able to compare and contrast ways in which selected cells are specialized to carry out particular life functions and explain how cells use food as a source of energy to grow and develop. Students were also able to compare the transformations of matter and energy during photosynthesis and cellular respiration. This was evident in their scores on the pre/post tests.

Overall, this unit on cellular respiration and photosynthesis was a pleasure to teach. My students were genuinely interested and eagerly receptive to all the fresh labs, innovative teaching strategies, and new techniques I integrated. This unit allowed me to focus extraordinary amounts of time on the success of my students by providing them with excellent teaching. Compared to previous years, my students seemed less overwhelmed with the material presented and took away a more thorough understanding of photosynthesis and cellular respiration as indicated by the statistical analysis of the data. In the future, I will surely continue to utilize all of the labs and demos involved with this unit. I will also allow for more time to be spent on the unit so those few items that were left out this year can be reinstated. Someday, I would like to transform one or more additional units within my curriculum so that they too can more successfully meet the needs of my students.

Problems that were Encountered

A few problems were encountered in implementing this unit. The most overwhelming obstacle to overcome was the lack of time to complete the unit. This was the last unit before the end of the first trimester and the beginning of exams dictated when the unit needed to be finished. This left only four and a half weeks to complete a unit that could have easily spanned five and a half weeks. In the future, I would like to spend one additional day on fermentation. Students performed poorly on this concept as indicated by Figure 13, question nine. I would also like to spend an additional day completing *Lab #4: Part 1: Paper Chromatography* (Appendix D-4). Additional time could also be spent exploring leaf structure and function because while implementing this unit I did not have time to talk about the air spaces, mesophyll, stomata, or guard cells. I believe covering these topics would really help with *Lab #5: A Study of the Rate of Photosynthesis* (Appendix D-5). I would also like to implement a microscope lab to look at these structures in a prepared leaf cross-section slide. Another additional day could be spent administering the quiz that covered both cellular respiration and photosynthesis. Finally, I would spend some extra time reviewing with students for the unit test and another day on the test itself. I believe a little extra review time after a unit that spans more than five weeks (70 minutes a day) will help to refresh the students' minds and help them make connections. As for the test, it was extremely long and overwhelming for many students with more than 75% of them still working with only ten minutes left in the 70 minutes. Instead of shortening the test, in the future, I would like to conduct it in two segments. This would still allow me to assess all the objectives, but decrease student anxiety.

The second problem surfaced when looking at the post-unit survey. When analyzing a few objectives I saw a discrepancy in what the students thought they knew and what was indicated on the pre/post test comparison. For instance, 93% of students indicated that they "always" or "usually" felt confident explaining the relationship between photosynthesis and cellular respiration. But, according to multiple choice question four on the pre/post test comparison, only 62% of students could answer how these two processes were related. This was also the only question on the multiple choice section of the pre/post test comparison that showed students performing worse on the post-test compared to the pre-test. Having students fail to grasp this major objective was disappointing. In the future, more time will need to be spent going over the answers to the conclusion questions of *Lab #6: Observing the Relationship between Photosynthesis and Cellular Respiration* (Appendix D-6).

Secondly, 96% of students said they could explain how fermentation in muscle cells is different from fermentation in yeast cells. But, according to question nine in the pre/post test comparison, only 58% of students were capable of answering this question correctly. As mentioned before, next time this unit is taught, additional time and activities will need to be incorporated to address this concept.

Finally, 46% of students indicated on the post-unit survey that they could "sometimes" or "never" explain what chemical energy is and how cells release it from food through cellular respiration. Contrary to what they believed, 81% of students scored a 90% or higher on the post writing assignment for cellular respiration.

Overall, this unit was a success. It met the goals I set forth to accomplish in a way that improved student learning on the topics of cellular respiration and photosynthesis.

APPENDICIES

APPENDIX A

OBJECTIVES

Chapter 6: A Tour of the Cell
(6.5) pages 128-129

Objectives:

- Compare and contrast the functions of chloroplast and mitochondria

New Key Terms:

- Chloroplast
- Mitochondria
- ATP

Chapter 7: The Working Cell: Energy from Food
(7.1-7.6) pages 134-155

Objectives:

- Compare and contrast how autotrophs and heterotrophs obtain food
- Explain the relationship between photosynthesis and cellular respiration
- Distinguish between kinetic and potential energy
- Explain what chemical energy is and how cells release it from food
- Describe the structure of ATP and how it stores energy
- Give examples of work that cells perform
- Summarize the ATP cycle
- Relate breathing and cellular respiration
- Identify the overall reactants and products of cellular respiration
- Summarize Glycolysis, the Kreb's Cycle and the Electron Transport Chain and identify where ATP is made
- Identify the types of organisms that carry out cellular respiration
- Explain how fermentation in muscle cells is different from fermentation in yeast cells
- Give examples of products that depend on fermentation in microorganisms

New Key Terms:

- Autotroph
- Heterotroph
- Producer
- Consumer
- Photosynthesis
- Cellular respiration
- Enzyme
- Kinetic energy
- Potential energy
- Thermal energy
- Chemical energy
- ATP
- Aerobic
- Electron transport chain

- Metabolism
- Glycolysis
- Kreb's Cycle
- ATP synthase
- Fermentation
- Anaerobic respiration

Chapter 8: The Working Cell: Energy From Sunlight (8.1-8.4) pages 158-173

Objectives:

- Identify the overall reactants and products of photosynthesis.
- Explain how white light is captured in plant cells
- Identify the chemical reactants and products of the light reactions
- Explain how the Calvin Cycle makes sugar
- Summarize the overall processes of the light reactions and the Calvin Cycle
- Describe variables that affect the rate of photosynthesis
- Identify the types of organisms that carry out photosynthesis

New Key Terms:

- Chloroplast
- Chlorophyll
- Light reactions
- Calvin Cycle
- Wavelength
- Electromagnetic spectrum
- Pigments
- paper chromatography

APPENDIX B

GRADED MATERIALS

APPENDIX B-1

CELLULAR RESPIRATION WORKSHEET

Questions on Cellular Respiration

1. How many steps are involved with the process of cellular respiration?

2. Where do autotrophs get the glucose needed to start CR?

   How about heterotrophs?

3. What does the term "aerobic" stand for? How does this apply to aerobic exercise and aerobic respiration?

4. Why is aerobic respiration unable to occur without oxygen?

5. Some ATP is produced at the end of glycolysis. What is the advantage of continuing cellular respiration through the Kreb's Cycle and Electron Transport Chain?

6. State the reactants and products of each of the following processes…
   a. Glycolysis **Reactants** **Products**

   b. Kreb's Cycle

   c. ETC

7. In what part of the cell does each of the following take place?
   a. Glycolysis

   b. Kreb's Cycle

   c. ETC

8. In what cells of the body might you find the most mitochondria? Why?

9. What would be considered the 2 "waste products" of Cellular Respiration?

10. What is the advantage of the inner membrane of the mitochondria having many flaps and folds?

11. Does glycolysis require oxygen?

12. How many molecules of ATP are generated by "aerobic respiration"?

13. What two things are needed to regenerate ATP from ADP? Where does each come from?

APPENDIX B-2

CELLULAR RESPIRATION WRITING ASSIGNMENT

Name ______________________

Cellular Respiration

Purpose: To show that the writer knows something about the topic or has thought about it. This type of writing has content that can be right or wrong.

Basic Guidelines:

Always skip a line
Always label the type of writing
Has maximum time limit
Avoid numbering
Write in paragraph form

Part I:

Directions: On a separate piece of paper, write about the following… When finished, staple your paper to the back of this sheet before you turn it in.

Your teacher has asked you to help some new students your age learn about cellular respiration. Below he/she has given you a list of words that correspond to the concepts you will most likely want to teach. Using what you have learned about cellular respiration in school, outside of school, from TV, games, books, etc. write these students an essay using ALL of the words correctly as they pertain to respiration. Feel free to include drawings, organize your ideas on a separate piece of paper, and cross off each word as it is used.

Mitochondria	Autotrophs	Heterotrophs
ATP	ADP	Oxygen
Carbon Dioxide	Glucose	Water
Fermentation	Lactic acid	Ethanol
Kreb's Cycle	Electron Transport Chain	Glycolysis
Anaerobic	Aerobic	Yeast
Human muscle cells	Energy	Phosphate

APPENDIX B-3

PHOTOSYNTHESIS WORKSHEET

Name ____________________

Questions on Photosynthesis

1. List the complete, balanced equation for photosynthesis. Circle the reactants and underline the products.

2. Where does the energy for this chemical reaction come from?

3. In what organelle does photosynthesis take place in?

4. What is the name of the pigment stored in this organelle that absorbs the sunlight's energy. What wavelengths of color does this pigment absorb and reflect?

5. What types of organisms go through PTS?

6. Why might it be important to talk to your plants even though they have no ears?

7. List the products and reactants for each step of photosynthesis…

	Reactants	Products
Step 1 **Light Reactions**		
Step 2 **Dark Reactions/** **"Calvin Cycle"**		

8. Why must NADPH & ATP be made during the light reactions?

9. What is the waste product of the light reactions? Where did it come from?

10. What is the glucose produced during PTS used for?

11. What do you think is one of the things happening as a green banana ripens? (Hint: Think back to why leaves change colors in the fall.)

12. Where do autotrophs obtain the majority of the atoms needed to make glucose?

Answer the following in the space provided at the bottom of the page.

APPENDIX B-4

PHOTOSYNTHESIS WRITING ASSIGNMENT

Name ____________________

Photosynthesis

Purpose: To show that the writer knows something about the topic or has thought about it. This type of writing has content that can be right or wrong.

Basic Guidelines:

Always skip a line
Always label the type of writing
Has maximum time limit
Avoid numbering
Write in paragraph form

Part I:

Directions: On a separate piece of paper, write about the following… When finished, staple your paper to the back of this sheet before you turn it in.

Your teacher has asked you to help some new students your age learn about photosynthesis. Below he/she has given you a list of words that correspond to the concepts you will most likely want to teach. Using what you have learned about photosynthesis in school, outside of school, from TV, games, books, etc. write these students an essay using ALL of the words correctly as they pertain to photosynthesis. Feel free to include drawings, organize your ideas on a separate piece of paper, and cross off each word as it is used.

Chlorophyll	Photosynthesis	Absorbs
Chloroplasts	All colors but green	Reflects
Sunlight	Green	Stomata
Water	Mesophyll	Guard Cells
Carbon dioxide	Roots	Energy
Oxygen	Light Dependent Reactions	Calvin Cycle
Glucose	Autotrophs	Heterotrophs

Part II:

Directions: The new students have a few questions for you. Write your explanations in the space provided below.

1. In what ways is photosynthesis important to animals?

2. How does chlorophyll make plants look green?

3. How do plants that lose their leaves in the winter have the energy they need to stay alive?
   What process releases this energy?

APPENDIX C

DEMOS

APPENDIX C-1

CO_2 PRODUCTION BALLOON DEMO

CO_2 Production Balloon Demo
Teacher Notes & Student Materials

Materials Needed:

1- 20 oz. soda bottle (600mL)
400 mL warm water
12 grams baker yeast
1- large balloon
2- Pieces of string
1- Metric Ruler
40 grams sugar

Preparation of Solutions:

Minimum of 15 minutes to activate yeast
3% yeast solution
10% sugar solution

Procedure:

1. Mix sugar solution and yeast solution in a 600mL soda bottle.
2. Attach a deflated large balloon over the top of the soda bottle to catch the released gas.
3. Set the demo up on the front lab table for easy visibility and explain set-up.
4. Have students answer all questions on the student questionnaire once the balloon has begun to inflate.
5. For the next 40 minutes have one student measure the circumference of the balloon in 5 minute intervals using the string and metric ruler
6. Have all students record the data in their notebooks during the course of the lecture time.
7. After 40 minutes facilitate a classroom discussion revolving around the students observations over the last 40 minutes.
8. Once numerous ideas have been generated, drop CO_2 into a small flask and show how it puts out a lit match. Ask students what they think the gas is!
9. Alternative – have a student blow into a flask of BB to show color change with CO_2. Then place balloon over a flask of BB to show what color change it creates.
10. 2^{nd} Alternative- Use phenolphthalein to show CO_2 production.
11. You can also ask students to practice mathematical skills by calculating the volume of the balloon at each interval. (sphere $V=4\Pi r^3/3$) ($c=2\Pi r$)
12. They may then graph the balloon volume over time.
13. Also ask students to determine the dependent and independent variables

Name ____________________________

Thought Questions

What is in the balloon?

Where did it come from? (Name of the process?)

What is the purpose of the yeast?

What is the purpose of the sugar?

What other products are produced?

What do you think would happen to the volume of the balloon over time if the % of yeast was decreased?

Increased?

What do you think would happen to the volume of the balloon over time if the % of sugar was increased?

Decreased?

APPENDIX D

LABORATORY ACTIVITIES

APPENDIX D-1

LAB 1: ATP VS ADP

Name ____________________
Hour _________

Lab 1: ATP vs. ADP

Introduction: ATP stands for adenosine triphosphate and is the source of energy used for all cellular work. The "adenosine" part consists of a nitrogen-containing compound called adenine and a five-carbon sugar called ribose. The triphosphate "tail" consists of three phosphate groups. When one or more of the bonds between the phosphate groups is broken, potential energy is released. If only one phosphate group is removed and two phosphate groups are left the resulting structure is called ADP.

Objective: To model the changes in structure of ATP and ADP using an analogy.

Materials: (per group of 2)

- 1 Rubber band, wind-up toy, clothespin, spring, or mouse trap
- 1 ½ sheet of poster board
- 2-3 different colored markers
- 1 baggie of ATP/ADP parts
- 1 sheet of plain white paper

Procedure:

1. Using the materials present in your baggie and a sheet of plain white paper as the background, build a model of ATP and ADP using Velcro between the phosphate molecules.
2. Show these structures to you teacher before continuing to step 3.
3. Using the unique object assigned to your group, come up with an analogy modeling the energy transition from ATP to ADP and from ADP to ATP. Make sure you could "show" what the object would look like if it were to represent each of these different structures.

Conclusion Questions:

1. What do the bonds in-between the phosphate groups represent in both ATP and ADP?

2. What is the only difference between the structures of ATP and ADP?

3. What is the difference between kinetic energy and potential energy?

4. What type of energy is represented by ATP?

5. What type of "work" does this energy eventually end up doing in your cells? Be specific and give at least three examples.

6. What must you give ADP to "reset" ATP (2 things)? Where does this come from?

7. What is meant by the term "cycle?" How do ATP and ADP represent a cycle?

8. Using the model analogy you have created answer the following in detail:

   a. ATP is like a...

   because...

   b. ADP is like a...

   because...

Follow-up: Using your poster board and markers, draw and explain how your model represents the ATP/ADP cycle. Make sure to include your answer to Question #7 on your poster.

On the back of your poster explain one misconception that your analogy may show.

APPENDIX D-2

LAB 2: CELLULAR RESPIRATION: MEASURING CO_2 PRODUCTION

Name ______________________

Hour ________

Lab 2: Cellular Respiration
Measuring CO_2 Production

Introduction:

The respiration rate of non-photosynthetic material, particularly that of fruits and vegetables, can be quantified by determining the conversion of $Ba(OH)_2$ to $BaCO_3$ and water in the presence of CO_2. As plant material respires in a closed experimental system (fruit or veggies in an inverted large plastic container with a dish of $Ba(OH)_2$ stored glucose is converted (via cellular respiration) to ATP, CO_2, and water. Because CO_2 is heavier than the surrounding atmosphere, it sinks into the dish of $Ba(OH)_2$, and reacts to form $BaCO_3$ according to the following equation:

$$Ba(OH)_2 + CO_2 \rightarrow BaCO_3 + H_2O$$

After 30 minutes, the remaining $Ba(OH)_2$ can be titrated with hydrochloric acid to determine the extent of the reaction and thus the quantity of CO_2 produced during respiration. The amount of HCl used in the titration inversely reflects the amount of CO_2 produced by the respiring fruit tissue. **Therefore, the more HCl required the less cellular respiration and the less HCl required the more cellular respiration.** A control will also be set-up to factor out the amount of CO_2 that reacts with the barium hydroxide due to the air that is present under the apparatus set-up.

Objectives:

- To quantify the amount of CO_2 produced via cellular respiration by different types of fruit during a set time period.

Materials: (per group of 3)

- 0.025 M $Ba(OH)_2$
- 0.1 M HCl
- 1% phenolphthalein indicator solution
- 1- 60 cc syringe
- 1- 250 mL beaker
- 1 – graduated cylinder
- 2- Petri dishes
- 2- plastic storage containers
- 200-300 grams of fruit

Procedure:

1. Obtain two similar, large, plastic containers. One jar will serve as the experimental set-up and the other will be the control.
2. Record in the data section the type of fruit available to your lab group and the mass of the fruit as indicated at your lab station.

3. Measure out exactly 25mL of .025 M $Ba(OH)_2$ in a graduated cylinder and place it all in one of the two Petri dishes. Repeat for the second Petri dish.
4. Position the fruit and the $Ba(OH)_2$ solution under one of the plastic containers and cover tightly. If you feel that any air may be leaking in the sides of your container, place a biology book on top of the apparatus set-up as extra weight.
5. Repeat with the other container minus the fruit – this is the control!
6. Record the start time in the data section. Leave the air tight containers undisturbed for 30 minutes.
7. After 30 minutes you will see the formation of a white precipitate in the Petri dishes- this is $BaCO_3$. Remove the Petri dish from the experimental container and empty only the underlying liquid into a 250mL beaker. Next, add 3 drops of phenolphthalein. The solution should turn a bright pink.
8. Fill up your 60 cc syringe with .01 M HCl to the 50 mL point.
9. Titrate the left over $Ba(OH)_2$ in the beaker until the pink color just disappears. If you need to refill your 60 cc syringe remember to keep track of the total volume of HCl used. Record this volume in the data section below.
10. Repeat for the control container.

Data:

1. Type of Fruit = ________________________
2. Mass of Fruit = _______ grams
3. Start time _____________ End time (30 minutes later) _____________
4. Volume of HCl used to titrate the left over $Ba(OH)_2$ in the fruit container=________ mL
5. Volume of HCl used to titrate the left over $Ba(OH)_2$ in the control container= ________ mL

Calculations: Please show all work and include <u>units</u>.

1. Calculate the mL of HCl used to titrate the CO_2 that was released by ONLY the respiring fruit in the space provided.

   (mL of HCl used to titrate the control) – (mL of HCl used to titrate the fruit)

   ~ this alleviates the CO_2 that came from the atmosphere

2. Calculate the mL of HCl (use your answer from #1) per gram of fruit tissue below.

3. Record your answer to #2 in the correct location on the board.

4. When all lab groups have finished, record the classes information in the following data table.

   Average each of the columns and record.

   Rank the fruit according to their rate of cellular respiration. 1= fastest/most CO_2 produced, 6= slowest/least amount of CO_2 produced

** Remember that the mL of HCl used inversely reflects the amount of CO_2 produced. The most HCl = the least amount of cellular respiration and vice versa.

	Milliliters of HCl Used to Titrate Per Gram of Tissue (mL/g)					
	Blueberries	**Bananas**	**Green Peppers**	**Other**	**Other**	**Other**
Group 1						
Group 2						
Group 3						
Group 4						
Average (mL/g)						
Rank						

Conclusion Questions:

1. Draw a picture of a piece of fruit in the space provided and show what goes into and out of the fruit during the process of cellular respiration.

2. What would make a mass of fruit tissue respire more?

   Less?

3. What does a high cellular respiration rate mean?

4. What does a low cellular respiration rate mean?

5. What is the dependent variable in your experiment?

6. What is the independent variable in your experiment?

7. What is the purpose of the control in your experiment?

APPENDIX D-3

LAB 3: CELLULAR RESPIRATION: ANAEROBIC RESPIRATION IN YEAST

Name ____________________

Hour ______

Lab 3: Cellular Respiration
Anaerobic Respiration in Yeast

Introduction:
All living things go through cellular respiration. Yeast (unicellular fungi) obtain energy through aerobic respiration or fermentation. During this process, food, usually in the form of "glucose" is "burned" and energy in the form of ATP along with CO_2 is released. The rate at which carbon dioxide is released during cellular respiration indicates the rate at which ATP is being synthesized. In this investigation you will compare the respiration rates of yeast at two different temperatures.

Problem: What will happen to the number of CO_2 bubbles that are released from yeast that are exposed to a warm environment compared to yeast that are exposed to a cold environment?

Hypothesis:

I believe this will happen because:

Objectives:
1. To measure yeast's production of carbon dioxide as a result of anaerobic respiration.
2. To determine if there is a statistical difference in the production of carbon dioxide by yeast in warm water compared to cold water.

Materials: (per group of 2)
- 2- 20 oz. pop bottles
- 4- hardware nuts
- 2- plastic pipettes
- 2 mL 3% yeast solution
- 2 mL 10% sugar solution
- Stopwatch
- Warm water (40-45 °C)
- Cold water (20-25 °C)

Procedure:
1. Obtain two 50 mL beakers and measure out 2 mL of 3% yeast solution into each using the syringe provided.
2. Add 2 mL of the 10% sugar solution to each of the 50 mL beakers using the syringe provided.
3. Swirl the contents and return them to your lab station.
4. Obtain 2 plastic pipettes and fill each separately with the yeast/sugar solution you've just created. (One beaker full of solution into each pipette.) Make sure to tap the end of the pipette on the lab table several

times to make sure ALL of the solution is out of the tip. This is tricky and may take you several attempts.

5. Each set of partners will also need two 20 oz. pop bottles. Fill one bottle up with room temperature water and the other with warm water. Use two thermometers to obtain the temperatures of each in degrees Celcius. Record your results in the data table below.
6. Place two hardware nuts over the top of each pipette and simultaneously place one into the warm water bottle and the other into the cold water bottle.
7. Immediately begin the stop watch and begin counting the number of bubbles that escape from the tip of the pipette each minute.
8. Continue taking readings for 30 minutes and record your data in the table below.

Data:

DATA TABLE 1: *Temperature of warm water =* °*C*
Temperature of cold water = °*C*

Time *(minutes)*	Number of CO_2 Bubbles *Warm Water*	Cummulative Number of Bubbles *Warm Water*	Number of CO2 Bubbles *Cold Water*	Cummulative *Number of Bubbles Cold Water*
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				

24				
25				
26				
27				
28				
29				
30				

Graph:

Directions: Using EXCEL, reconstruct the table above with the following exception. When entering your data for the number of bubbles, ONLY record the cumulative totals. Next, graph the data by placing the independent variable on the x-axis and the dependent variable on the y-axis. Place an appropriate title on the top of the graph and include units when needed. Remember to select the XY scatter graph and choose the middle left option so EXCEL will connect your data points. When finished, print the data table and graph on the same sheet and show your instructor. Save all your work in case you have to go back and correct any mistakes.

Calculations: (Make sure to show all your work in the space provided)

1. Calculate the average number of bubbles released in the warm water bottle per minute.

2. Calculate the average number of bubbles released in the cold water bottle per minute.

3. Looking at the slope of each line on your graph, between which time intervals is the rate of CO2 production in the warm water bottle the greatest?

   The least?

4. Looking at the slope of each line on your graph, between which time intervals is the rate of CO2 production in the cold water bottle the greatest?

   The least?

5. If 20 gas bubbles equal 1 mL, how many milliliters of gas were released in the warm water bottle?

6. How many milliliters of gas were released in the cold water bottle?

Conclusion Questions:

1. Identify the dependent variable: ____________ ________________
2. Identify the independent variable: ____________ ______________
3. State the appropriate control: ______________________________
   ____
4. List at least 3 standardized variables:__________________________
   ____
   ____
5. What is the name of the gas being released from the yeast? Why can the production of this gas be used as a means of measuring the rate at which ATP is produced in yeast?
6. What other products are being produced by the yeast?
7. What is the purpose of sugar in this experiment?
8. How does this same process relate to making home-made bread?
9. Make a statement concerning the effect of temperature on yeast fermentation. Why do you think this happened?

Follow-up:

1. Select another variable and design an experiment that would test it as a factor in yeast fermentation.
   a. Dependent Variable ________________________________
   b. Independent Variable ______________________________
   c. Standardized Variables ____________________________
   ____
   ____
   ____
   ____
   d. Control ____
   ____
   ____
   e. Set-up

APPENDIX D-4

LAB 4: PHOTOSYNTHESIS: PAPER CHROMATOGRAPHY LAB & THE ABSORPTION SPECTRUM OF SPINACH CHLOROPLASTS

Name ______________________

Hour __________

Lab 4: Photosynthesis
Part 1: Paper Chromatography Lab

Introduction: The existence of life is totally dependent upon photosynthetic organisms. Photosynthetic organisms include bacteria and other autotrophs which manufacture their own food by transforming light energy into chemical energy.

The light energy used by photosynthetic organisms is provided by the sun. Sunlight is considered "white" in color, but what colors truly make up this "white" light?

An autotroph's ability to photosynthesis is determined by its ability to absorb certain colors (wavelengths) of white light. This absorption is performed by pigments found in the chloroplasts of their cells.

Paper chromatography is a useful technique for separating and identifying pigments that are found in the cells of photosynthetic organisms. The solvent (in our case isopropyl) moves up the paper by capillary action, which occurs as a result of the attraction of solvent molecules to the paper and the attraction of the solvent molecules to one another. As the solvent moves up the paper, it carries along any substances dissolved in it (i.e. the pigments). The pigments are carried along at different rates because they are not equally soluble in the solvent and because they are attracted, to different degrees, to the fibers of the paper through the formation of intermolecular bonds, such as hydrogen bonds.

Objectives:
1. Extract and identify the various photosynthetic pigments from spinach leaves.
2. Determine the absorption spectrum of these spinach chloroplast pigments.

Materials: (per group of 2)
- Filter paper
- Scissors
- Pencil
- Metric Ruler
- Quarter
- Small piece of spinach
- Graduated cylinder
- 10 mL isopropyl
- 300 mL beaker
- Petri dish

Procedures:

1. Make a chromatogram strip by cutting a strip of circular filter paper 5.5 inches long and ½ inch wide. Taper the bottom end to a long point as shown in Figure 1. The tapered part (the point) should be 1 inch long.
2. Draw a light pencil mark in the center of the strip where the tapering ends (one inch above the point, see Figure 1). Load the chromatogram (filter paper) with chlorophyll by placing a small piece of spinach face down on top of the pencil mark and rubbing a quarter across it lengthwise. You may want to repeat this process 2 or more times over the same spot to increase the amount of pigment on the filter paper.
3. Measure out 10 mL of isopropyl into a graduated cylinder and add to the bottom of a 300 mL beaker. Cut a second piece of filter paper (see Figure 2) so that it fits nicely around the inside edges of the beaker. Carefully saturate the filter paper inside the beaker by slowly tipping the beaker to the side and rotating it in your hand.
4. Place your chromatogram strip, point downward, into the isopropyl solution. Be careful not to let the bottom portion touch the sides of the beaker AND make sure that the line of chlorophyll pigment is ABOVE the solvent level. If the spot falls below, the line will rinse off. Fold the top of the chromatogram strip over the side of the beaker so that it will stay in place even after you let go.
5. Place the Petri dish upside down on the top of the beaker and run the reaction at room temperature for 30 minutes.
6. After 30 minutes remove the paper from the test tube. Use your pencil to mark how far up the solvent front moved. Use a pencil to also mark the top edge of the colored bands (you will usually see 2-3 different colors).

Data:

DATA TABLE 1: Distance Moved by Pigment Band (mm)

Band Number	Band Length (mm)	Color
1		
2		
3		

Distance Solvent Front Moved in 30 minutes ____________mm

Calculations:

$$R_f = \frac{\text{Distance pigment migrated (mm)}}{\text{Distance solvent front migrated (mm)}}$$

** Show your calculation in the space provided below.

CALCULATION TABLE 1:

	= R_f for carotene and xanthophylls (orange/yellow)
	= R_f for chlorophyll a (bright green to blue green)
	= R_f for chlorophyll b (yellow green to olive green)

Conclusion Questions:

1. According to your results in Calculation Table 1, which pigment is the most soluble?

2. Which was the least soluble?

3. How did you reach your conclusions for Questions 1 & 2?

4. Would you expect the R_f value of a pigment to be the same if a different solvent were used? Explain.
5. If the chlorophyll a & b pigments are both green in color, what wavelengths of light are being absorbed? ______________________________
   Reflected? ______________________________
6. If the carotene & xanthophylls pigments are orange and yellow in color, what wavelengths of light are being absorbed? ______________________________
   Reflected? ______________________________
7. Anthocyanin is an additional pigment found in many plants. If it displays the colors red and purple, what wavelengths of light are being absorbed?
   ____
   Reflected? ______________________________
8. Which of the above pigments is the most abundant in photosynthetic organisms throughout the summer months?

9. How did you come to your conclusion for #8?

Follow-up:

10. Thinking back on all you know about plants and plant pigments… why do the leaves of deciduous trees change colors in the fall?

    What might be some environmental triggers of this change?

11. What do you think is one of the things happening as a green banana ripens?

12. How would you design an experiment that would determine the pigments found in a plant or algae species of your choice?

Part 2: The Absorption Spectrum of Spinach Chloroplasts

The absorption of different wavelengths of light by a pigment is represented by an **absorption spectrum**. This spectrum spans the entire visible spectrum extending from 380 nanometers (violet) all the way to 700 nanometers (far red). In-between you will find all the wavelengths for ROY G BIV. In the space provided below, sketch a graph that would show what <u>you think</u> is the absorption spectrum for the spinach leaf pigments you just investigated. Remember, spinach has 3 main pigments (carotene, xanthophylls, and chlorophyll). If you think the spinach is absorbing a lot of a particular wavelength than you should draw a peak for that wavelength on the graph. On the other hand, if you think the spinach is reflecting most of a particular wavelength than you should draw a valley for that wavelength on the graph.

Absorption Spectrum of Spinach Leaves

Violet Indigo Blue Green Yellow OrangeRed

WAVELENGTH

The following is the actual absorption data for spinach leaf pigments obtained through the use of a spectrophotometer. A spectrophotometer works by shining white light through a prism that breaks it into its individual colored wavelengths. These different wavelengths are then passed through a sample solution of spinach pigments and the absorption for each color is recorded.

Directions: Using EXCEL, reconstruct the table below and graph the data by placing the independent variable on the x-axis and the dependent variable on the y-axis. Place an appropriate title on the top of the graph and include units when needed. Remember to select the XY scatter graph and choose the middle left option so EXCEL will connect your data points. When finished, print the data table and graph on the same sheet and show your instructor. Save all your work in case you have to go back and correct any mistakes.

DATA TABLE 2:

Wavelength (nm)	Absorption	Wavelength (nm)	Absorption	Wavelength (nm)
Violet-380	.734	490	.189	600
390	.708	500	.105	610
Indigo-400	.724	510	.067	620
410	.764	Green-520	.054	Orange-630
420	.808	530	.057	640
Blue-430	.825	540	.054	650
440	.756	550	.056	Red-660
450	.654	560	.063	670
460	.574	Yellow-570	.077	680
470	.490	580	.086	690
480	.348	590	.096	700

Conclusion Questions:

1. What differences can you locate between the graph you sketched at the beginning and the graph you just finished drawing?

2. Which wavelengths of light does spinach utilize the most?

3. Which wavelengths of light does spinach utilize the least?

APPENDIX D-5

LAB 5: PHOTOSYNTHESIS: A STUDY OF THE RATE OF PHOTOSYNTHESIS

Name ____________________
Hour ________

Lab 5: Photosynthesis
A Study of the Rate of Photosynthesis

Introduction:

In this lab, you will compare the rates of photosynthesis in spinach leaf disks that are subjected to different colors of light. This will be accomplished by measuring the length of time it takes the disks to generate enough gas to float upward in a solution-filled syringe.

You may recall that chloroplasts are located in the cells of the mesophyll, the green tissue in the center of a leaf. The cells of the mesophyll have air spaces around them used for gas exchange. You will use these characteristics of leaf structure and function to measure and compare the rates of photosynthesis of leaves placed under different color filters.

Rates describe how measurable quantities change over time. As oxygen gas is produced during photosynthesis, the rate of photosynthesis in a leaf can be determined by measuring the amount of oxygen the leaf produces in a certain period of time. In this lab, you will measure oxygen production indirectly. You will suspend leaf disks in a solution and apply a vacuum. The air spaces inside each leaf disk will become filled with liquid and the leaf disks will sink downward. You will then measure how quickly the leaf disks float upward. When the light reactions of photosynthesis produce oxygen as a waste product, liquid is forced out of the air spaces and the leaf disks become more buoyant. In general, the more quickly the leaf disks become buoyant enough to float, the faster they are photosynthesizing.

Objectives:

- To measure and compare the rates of photosynthesis in spinach leaf disks that are subjected to different colors of light.

A Photosynthesis Race:

The race will take place in three solution-filled syringes. You will suspend 15 spinach leaf disks in each syringe, pull back on the plungers to apply a vacuum, and let the air inside the leaf disks flow out. As the air is replaced by liquid, the leaf disks will sink downwards to the "starting line", which is the bottom of the syringe. When you place all three syringes near the light source to start photosynthesis, the race begins. As the leaf disks produce oxygen gas and become more buoyant, they will "race" to their own finish line, which is the top of the syringe.

Winning the Photosynthesis Race:

The winning syringe will be the one that has the most spinach leaf disks cross the finish line (float to the top) within 25-30 minutes.

Pre-lab Questions:

1. During this lab the three syringes will be subjected to white, red and green light. Which syringe do you predict will photosynthesize the fastest and win the race? Explain the reasoning behind your prediction. (This is your hypothesis.)

2. Rank the three colors listed above from the best wavelength for photosynthesis to the worst wavelength for photosynthesis.

3. A rate measures how a quantity changes over time. Give an example of something you could measure the rate of. What would the units of your measurement be (for example, meters/sec)?

Materials: (per group of two or three)

- 45- spinach leaf disks (from young, fresh spinach leaves) Placed in 200mL beakers.
- 3- 60cc syringes with plungers
- Red cellophane wrap
- Green cellophane wrap
- Lamp with incandescence bulb
- Bicarbonate/detergent solution in a plastic cup (4g bicarbonate in 400mL distilled water)
- Stopwatch
- 1000 mL beaker filled with water

Procedure:

1. Obtain 45 spinach leaf disks and carefully drop 15 into each of your three 60cc syringes.
2. After all three syringes are loaded, put in the plungers, pushing down until the plunger is touching the leaf disks. Take care not to squish them.
3. Measure out 150 mL of bicarbonate/detergent solution into a plastic cup.
4. Draw up about 40 mL of the bicarbonate/detergent solution into each syringe.
5. Invert each syringe (turn it upside down) and tap it to release air bubbles.
6. Push in the plungers to move all the air out of the tips of the syringes.

7. Place your finger over the tip of one syringe while pulling the plunger back to 50mL. Be careful not to pull back too far or you will pull the plunger out. This creates a vacuum, allowing air to flow out of the air spaces in the leaf disks.
8. Hold the vacuum by keeping your finger on the tip and shake the syringe several times to release the bubbles.
9. With the tip of the syringe pointing up, quickly let go with your finger and push out the excess air while watching to see if the leaf disks sink. If they do, stand the syringe up in front of the light source (which is turned off). If some of the leaf disks are still floating, repeat steps 6-9 until they all sink. This may take several tries. If there are one or two stubborn disks after several tries, ask for help from your instructor.
10. Check to make sure all three syringes have 35 cc of solution in them. Add more solution or squirt some out to obtain this value in all three.
11. Obtain one piece of red cellophane and one piece of green cellophane. Wrap these carefully around two of the three syringes (the third will be left clear/white to act as a control). Secure the cellophane with a small piece of scotch (clear) tape. These cellophane pieces will act as a filter and only let through that wavelength of light.
12. Place all three syringes in their "starting blocks" near the light source, turn on the light and start timing. The race has begun! After each minute has elapsed record the <u>**TOTAL**</u> number of disks that have floated to the top for each individual color. Carefully invert each syringe every two minutes to loosen the disk from the bottom and each other. Then, quickly return them to their upright position as soon as possible. Run experiment for 30 consecutive minutes.

Hint: We will record the cumulative totals for class when everyone is finished.

Data: Data Table I: Time it Takes Each Disk to Float

Time (min)	Red Cellophane	Class Totals for Red	Green Cellophane	Class Totals for Green	Clear/White (control)	Class Totals for white
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						

13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						

Graph:

1. Dependent Variable = ____

2. Independent Variable = ______________________________________

Using EXCEL, reconstruct the table above. When entering your data for the number of bubbles, ONLY record the cumulative totals. Next, graph the data by placing the independent variable on the x-axis and the dependent variable on the y-axis. Place an appropriate title on the top of the graph and include units when needed. Remember to select the XY scatter graph and choose the middle left option so EXCEL will connect your data points. When finished, print the data table and graph on the same sheet and show your instructor. Save all your work in case you have to go back and correct any mistakes.

Calculations:

Calculate each colors rate of photosynthesis y completing the calculations below:

1. Red – _______ number of disks total/ 30 minutes = __________disks/min.

2. Green – _______ number of disks total/ 30 minutes = _________disks/min.

3. White - _______ number of disks total/ 30 minutes = ________disks/min.

Conclusion Questions:

1. Did you predict the winner? ______________________________________

2. Based upon the results of your experiment, rank the three colors in order of best to worst in terms of photosynthesis.

3. Why do you think the "winner" was the best color for photosynthesis?

4. What allowed the disks to float to the top?

5. If the chemical formula for sodium bicarbonate is $NaHCO_3$, why do you think it is needed for the experiment to work?
6. Draw a picture of a spinach leaf disk in the space below that shows what goes into and out of the leaf during the process of photosynthesis.

Follow-up:

1. What other factors (besides color) may affect the spinach leaf's ability to photosynthesize? Give at least 3 examples.

2. Based on your knowledge of photosynthesis, what would you predict would happen in a syringe covered in blue cellophane?

3. What about yellow cellophane?

APPENDIX D-6

LAB 6: OBSERVING THE RELATIONSHIP BETWEEN PHOTOSYNTHESIS AND CELLULAR RESPIRATION

Name ____________________________

Hour ____________

Lab 6: Observing the Relationship Between Photosynthesis and Cellular Respiration

Introduction: Green plants bask in sunlight. They use the energy in the sun's rays to make food. The production of food also requires raw materials. When plants synthesize food, more precisely sugars, they use carbon dioxide and water. The process of synthesizing sugar with the aid of energy in light is known as photosynthesis. The sugars that plants make are used by plants and animals alike as a source of energy. To release the energy contained in the bonds of sugar molecules, the chemical reactions of photosynthesis must be revered. The process in which energy is released from food is called cellular respiration. Cellular respiration also produces waste products, carbon dioxide and water, which are the same substances that serve as the raw materials for photosynthesis.

In water, carbon dioxide dissolves to form a weak acid. As a result, an acid-base indicator such as bromthymol blue can be used to indicate the presence of carbon dioxide. In this lab, you will use bromthymol blue to explore the relationship between photosynthesis and cellular respiration.

Carbon Dioxide (CO_2) Indicator Chart for Bromthymol Blue

Amount of Carbon Dioxide in Water	Color of Bromthymol Blue Solution
No Carbon Dioxide	Shade of blue
Low Amount of Carbon Dioxide	Shade of green
High Amount of Carbon Dioxide	Shade of yellow

Objectives:

- Determine the relationship between photosynthesis and cellular respiration in organisms that are kept in the dark and in the light.

Materials: (per group of two)

- 2 large test tubes
- 2 rubber stoppers
- Bromthymol blue solution
- 2 small Elodea sprigs (in fresh tap water with a bit of sodium thiosulfate)
- Drinking straw
- Small funnel

Procedure:

1. Using a small funnel, fill both large test tubes ¾ full of bromthymol blue solution. **CAUTION: Bromthymol blue is a dye and can stain your hands and clothing.**

2. Insert one end of a drinking straw into the bromthymol blue solution in one of the flasks. Gently blow through the straw. Keep blowing until there is a change in the appearance of the bromthymol blue solution. Repeat this procedure with the other flask. Record your observations in the data table.
3. Place a small sprig of Elodea into each flask. Stopper the flasks.
4. Place one flask in the dark for 24 hours. Place the other flask on a sunny windowsill for the same amount of time. Artificial light may be used to supplement sunlight if needed.

Data:

Data Table I

	Color of Bromthymol Blue (Before)	Color of Bromthymol Blue (After)
Breath		
Elodea (Light)		
Elodea (Dark)		

Observations:

1. What was the color of the bromthymol blue solution before and after you exhaled into it?

2. What was the color of the bromthymol blue solution in the flask placed in the dark for 24 hours? In the flask on the windowsill?

Dark = Light =

Conclusion Questions:

1. How was the carbon dioxide you exhaled into the bromthymol blue solution produced in your body?

2. Explain why the color of the bromthymol blue solution changed after you exhaled into it.

3. Why was an Elodea sprig placed in both flasks?

4. What is the dependent variable? ______________________________

5. What is the independent variable? ____________________________

6. Describe the control?

7. Why are the results for the two flasks different? What process(es) were each test tube going through?

8. How are photosynthesis and cellular respiration related?

9. Why is the process of cellular respiration common to all forms of life?

Follow-up:

10. Carbon dioxide was bubbled through two flasks of bromthymol blue until they became acidic. Then a sprig of Elodea was placed in each flask. One flask was left in green light for 24 hours, while the other flask was left in red light. No change occurred in the flask left in green light. The bromthymol blue in the flask that was left in the red light turned back to blue. Explain these results.

11. Looking at your results for the Elodea that was kept in the light, what proof do you have that photosynthesis is faster than cellular respiration?

12. What would happen IF plants carried out photosynthesis and cellular respiration at the same rate?

13. Based on your understanding of the chemistry of photosynthesis, why do plants need animals in order to survive?

14. On a separate piece of white paper, **DRAW** and **COLOR** a picture of a plant and an animal of your choice. Use arrows to represent how they are connected.
Make sure to label each of the following on your drawing.

- O_2
- CO_2
- Glucose
- ATP
- Sunlight
- H_2O
- Photosynthesis
- Cellular Respiration
- Autotroph
- Heterotroph
- Producer
- Consumer

APPENDIX E

QUIZZES

APPENDIX E-1

CELLULAR RESPIRATION QUIZ

Name ______________________________
Hour __________

Cellular Respiration Quiz
Glycolysis, Aerobic Respiration, Fermentation

1. Write the complete, balanced equation for cellular respiration. Circle the reactants and underline the products.

2. Which type of organisms carry out cellular respiration?

3. When does cellular respiration occur in living things?

4. What is the energy produced during cellular respiration used for?

5. In what organelle does the last 2 steps of cellular respiration take place?

A scientist set up a respiration chamber as shown below. She placed a mouse in flask B. Into flasks A, C, and D, she poured distilled water mixed with the acid-base indicator phenolphthalein. In the presence of CO_2, phenolphthalein turns from pink to clear. She allowed the mouse to stay in the chamber for about an hour.

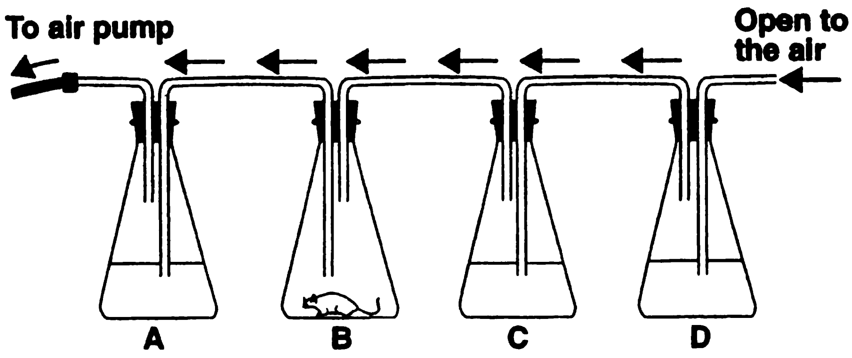


Figure 7-1

6. Based on the complete balanced equation for cellular respiration and the setup shown in Figure 7-1, what substance(s) would you expect the mouse in flask B to give off?

7. What will the mouse require to carry out cellular respiration?

8. Will the mouse receive fresh air so that it can survive?

9. Based on Figure 7-1, how will the scientist be able to detect whether the mouse is carrying out respiration?

10. Assume that the scientist set up an identical respiration chamber, except that in this setup she placed a cricket in Flask B instead of a mouse. At the end of one hour, she measured the amount of CO_2 given off by the cricket (total mass 5 grams) and the mouse (total mass 200 grams). A small amount of CO_2 had been given off by the mouse, but little to no CO_2 had been given off by the cricket. Was the cricket undergoing cellular respiration? Explain these results.

11. Assume that the scientist set up an identical respiration chamber, except that in this setup she placed a mouse that had been exercising on a hamster wheel. Then, the scientist measured the amount of CO_2 given off by both mice at the end of 15 minutes. Predict which setup produced the most CO_2. Explain your answer.

12. Assume that the scientist set up an identical respiration chamber, except that in this setup she left flask B empty as a control. What should she expect to see in flask A?

13. What does glycolysis mean?

14. What is the net gain of ATP molecules by the end of glycolysis? ____________.

15. In the presence of oxygen, glycolysis is followed by the Kreb's Cycle and the Electron Transport Chain. What is the name of the two "waste" products that are given off during these stages?

16. How many additional ATP molecules can be produced during the Kreb's Cycle and ETC? ________. This makes for a grand total (including glycolysis) of ________ produced for every one molecule of glucose!

17. What molecule accepts all the "waste" from the end of the ETC, making water?

18. What are two differences between lactic acid fermentation and alcoholic fermentation?

APPENDIX E-2

PHOTOSYNTHESIS QUIZ

Name ______________________________
Hour ___________

Photosynthesis Quiz

1. In the space below write the complete, balanced equation to photosynthesis.

2. What is the name of the organelle that allows plants to perform photosynthesis?

3. What is the energy source for the light reactions?

4. What pigment do plants use to capture this energy source?

5. What two individual wavelengths (colors) of light do plants use the most?

6. What are the three products of the light reactions (one will be a waste product; the other two will be used in the next step)?

7. What is another name for the Calvin cycle?

8. What are the three reactants for the Calvin cycle? Circle the two that are the energy source.

9. What is the product of the dark reactions?

10. In the early 1600's Jan Van Helmont did a classic experiment with soil and plants. Read his observations, then answer the questions that follow:

I put 200 pounds of dried earth in a plant pot. I moistened the pot with rain water. Next, I planted a stem of a willow tree that weighted 5 pounds. When the experiment was complete the plant weighted 169 pounds and 3 ounces. The plant was watered regularly for 4 falls. I weighted only the tree without the leaves that fell every autumn. At the end of 4 years, I dried the earth in the pot and the earth weighted 200 pounds minus 2 ounces. Therefore, 164 pounds of wood and bark arose out of water only.

a. What was Van Helmont's hypothesis?

b. How much weight did the willow gain? (Make sure to include units.)

c. How did Van Helmont explain the weight gain?

d. What would he have found if he included the leaves?

e. What kind of experiment would you suggest to find out if new plant tissue grows from water only?

f. What major discovery happened after Van Helmont's time that led us to knowing that water is not the only compound that leads to an increase in plant mass?

g. What besides water led to the majority of the weight gain in the plant tissue? Where does this compound come from?

11. A student put together two different experimental setups as shown below.

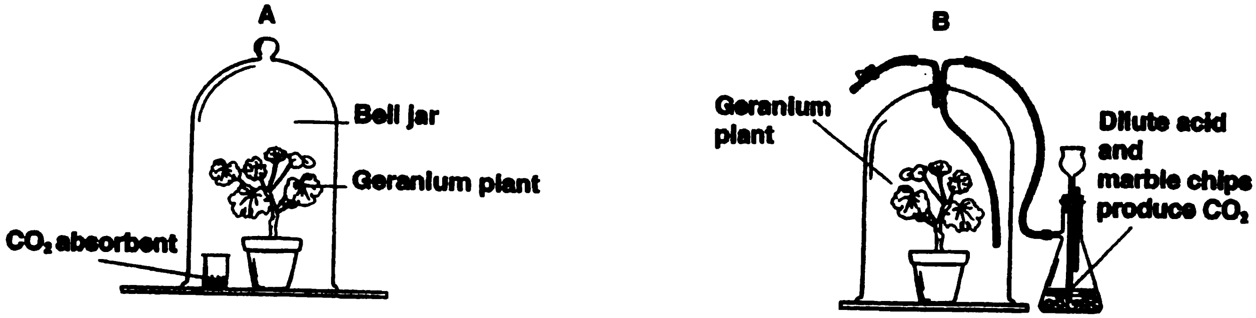


Figure 8-3

a. Looking at Figure 8-3, assume that the student tested the oxygen content of Jar B, quickly watered the geranium and then placed it in direct sunlight for two days. After this time, the student tested the air in the bell jar again for oxygen content. What would you expect the results to be <u>and why</u>?

b. Looking at Figure 8-3, assume that the student placed Jar A in direct sunlight for two days. After this time, the student tested one leaf from the plant for starch content. (Remember that plants make starch from sugar.) What would you expect the results to be <u>and why</u>? How would the starch content of this plant compare with the starch content of the leaves of the plant in Jar B?

APPENDIX E-3

CELLULAR RESPIRATION VS PHOTOSYNTHESIS QUIZ

Name ________________________

Hour _______

Photosynthesis and Cellular Respiration QUIZ

1. Explain the relationship between photosynthesis and cellular respiration in detail.

2. Carbon dioxide was bubbled through a flask of Bromthymol blue until it turned green. A second flask was filled with Bromthymol blue, but NO carbon dioxide was bubbled through it. An Elodea sprig was placed in each flask. The flask that was blue was placed in the dark; the green flask was left in the light. Twenty-four hours later the flask in the dark was greenish-yellow. The flask in the light was blue.

   Thoroughly explain why the color changed in the flask left in the dark.

   Thoroughly explain why the color changed in the flask left in the light.

3. What is the dependent variable in this experiment?

4. What is the independent variable in this experiment?

5. Perbuterol is a yellow substance that turns red in the presence of oxygen. Two flasks were filled with perbuterol and an Elodea sprig was placed in each. Flask number one was then turned red by adding oxygen, and it was placed in the dark. Flask number 2, which was left yellow, was placed in the light. The flasks were left alone for 24 hours. Predict what changes, if any, occurred in the 2 flasks and thoroughly explain why these changes would occur.

   Flask 1:

   Flask 2:

6. Why must photosynthesis occur at a faster rate than cellular respiration?

APPENDIX F

TESTS

APPENDIX F-1

PRE-TEST

Name ____________________________

Hour ________

Photosynthesis and Cellular Respiration Pre-Test

PART I:

Directions: Please place the letter of the BEST answer in the space provided at the left of each question.

_____ 1. One bean plant is illuminated with green light and another bean plant of similar size and leaf area is illuminated with blue light. If all other conditions are identical, how will the photosynthetic rates of the plants most probably compare:

a) Neither plant will carry on photosynthesis.
b) The plant under the blue light will carry on photosynthesis at a greater rate than the one under the green light.
c) Photosynthesis will occur at the same rate in both plants.
d) The plant under the green light will carry on photosynthesis at a greater rate than the one under the blue light.

_____ 2. At optimum (perfect) light conditions, which atmospheric gas most directly influences the rate (speed) of photosynthesis:

a) Carbon dioxide
b) Nitrogen
c) Oxygen
d) Hydrogen

_____ 3. Plants gather the sun's energy with light-absorbing molecules called:

a) Pigments
b) Mitochondria
c) Chloroplasts
d) glucose

_____ 4. How are cellular respiration and photosynthesis almost opposite processes:

a) Photosynthesis releases energy, and cellular respiration stores energy
b) Photosynthesis uses carbon dioxide, and cellular respiration produces it
c) Photosynthesis uses oxygen, and cellular respiration produces it
d) All of the above

_____ 5. Energy is released when:

a) AMP becomes ADP
b) ATP becomes ADP
c) ADP becomes ATP
d) GTP becomes ATP

_____ 6. What is misleading about this statement: Producers carry out photosynthesis and consumers carry out cellular respiration.

a) Both producers and consumers carry out photosynthesis
b) Consumers carry out photosynthesis and producers carry out cellular respiration.
c) Both producers and consumers carry out cellular respiration.
d) Neither producers nor consumers carry out photosynthesis and cellular respiration.

_____ 7. Which term is **least** closely related to the others?

a) Anaerobic
b) Aerobic
c) Lactic acid fermentation
d) Alcoholic fermentation

_____ 8. What metabolic stage begins both aerobic respiration and fermentation:

a) Glycolysis
b) Kreb's Cycle
c) Calvin Cycle
d) Dark Reactions

_____ 9. Which of the following molecules in not involved in fermentation:

a) Glucose
b) Lactic Acid
c) Ethanol
d) Oxygen

_____ 10. What happens to the chemical energy in food that is not converted to useful cellular work:

a) It is destroyed
b) It is ALL converted to useful cellular work
c) It is lost as light energy
d) It is lost as heat energy

PART II:

Directions: Answer the following short answer questions to the best of your ability.

1. If you were to race the process of photosynthesis against the process of cellular respiration, which would be faster? Explain two reasons why this is important?

2. What are the inputs and outputs of photosynthesis and cellular respiration?

	INPUTS	**OUTPUTS**
PHOTOSYNTHESIS		
CELLULAR RESPIRATION		

3. How do plants that lose their leaves in the winter have the energy they need to stay alive? How is this energy released?

PART III:
Directions: In the space provided, write about the following.

Your teacher has asked you to help some new students your age learn about photosynthesis by sharing everything you know about the topic. Below he/she has given you a list of words to help spark your memory. Using what you have learned about photosynthesis in school, outside of school, from TV, games, books, etc., write these students an essay using **ALL** of the words below. Even if you're not sure exactly what a word means or how it relates to photosynthesis, include it in your essay to the best of your ability. Feel free to include drawings, organize your ideas on a separate piece of paper, and cross off each word as it is used.

Chlorophyll	Photosynthesis	Absorbs
Chloroplasts	All colors but green	Reflects
Sunlight	Green	Stomata
Water	Mesophyll	Guard Cells
Carbon dioxide	Roots	Energy
Oxygen	Light Dependent Reactions	Calvin Cycle
Glucose	Autotrophs	Heterotrophs

Directions: Attempt to do the same as above, but now change over to the topic of cellular respiration.

Mitochondria	Autotrophs	Heterotrophs
ATP	ADP	Oxygen
Carbon Dioxide	Glucose	Water
Fermentation	Lactic acid	Ethanol
Kreb's Cycle	Electron Transport Chain	Glycolysis
Anaerobic	Aerobic	Yeast
Human muscle cells	Energy	Phosphate

APPENDIX F-2

POST-TEST

TEST # ___________

Photosynthesis and Cellular Respiration

Please write your **TEST NUMBER** on your answer sheet and record all your answers on your answer sheet. Please **DO NOT** write anywhere on this test. You may use scrap paper or the answer sheet to help you figure out problems if needed.

Multiple Choice: Choose the **BEST** answer to each of the following questions.

1. One bean plant is illuminated with green light and another bean plant of similar size and leaf area is illuminated with blue light. If all other conditions are identical, how will the photosynthetic rates of the plants most probably compare:
   a. Neither plant will carry on photosynthesis.
   b. The plant under the blue light will carry on photosynthesis at a greater rate than the one under the green light.
   c. Photosynthesis will occur at the same rate in both plants.
   d. The plant under the green light will carry on photosynthesis at a greater rate than the one under the blue light.

2. At optimum (perfect) light conditions, which atmospheric gas most directly influences the rate (speed) of photosynthesis:
   a. Carbon dioxide
   b. Nitrogen
   c. Oxygen
   d. Hydrogen

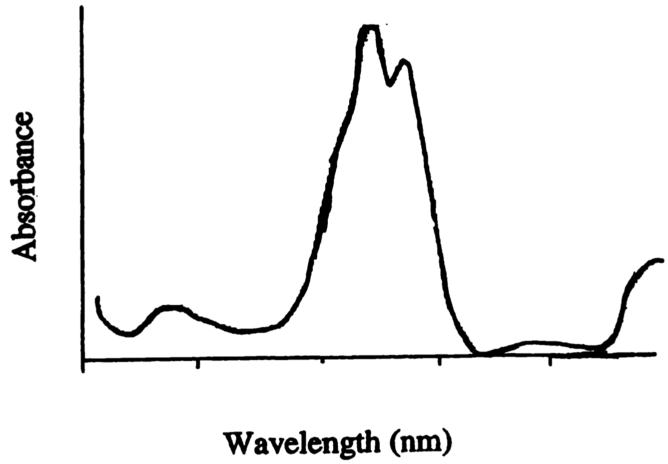
3. Photosynthesis requires each of the following except:
   a. Light
   b. Oxygen
   c. Chlorophyll
   d. Water

4. Which organisms carry out photosynthesis:
   a. Heterotrophs
   b. Autotrophs
   c. Organisms that do not contain chlorophyll
   d. All living organisms

5. Leaves of a plant appear green because chlorophyll:
   a. Reflects blue light
   b. Absorbs blue light
   c. Reflects green light
   d. Absorbs green light

6. When all wavelengths of light are absorbed, we see which color?
   a. White
   b. Green
   c. Black
   d. Blue

Use the diagram below to answer questions 7 & 8:

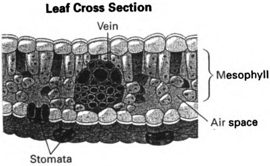


7. Beta-carotene is an additional pigment besides chlorophyll that is usually found in green plants. Looking at the absorption spectrum above, what color of white light is MOST utilized by this pigment:
   a. Red
   b. Orange/Yellow
   c. Green
   d. Blue
   e. Indigo/violet

8. What color does beta-carotene appear to the human eye? HINT: If this is the second most abundant pigment inside a plant leaf, when chlorophyll is destroyed in the fall, the leaves of the plant will appear this color:
   a. Red
   b. Orange/Yellow
   c. Green
   d. Blue
   e. Indigo/violet

9. The reactants for photosynthesis are:
   a. H_2O and $C_6H_{12}O_6$
   b. O_2 and $C_6H_{12}O_6$
   c. O_2
   d. Energy and $C_6H_{12}O_6$
   e. H_2O and CO_2 and sunlight

Use the diagram below for questions 10 & 11:



10. In the diagram above, the part of the leaf that allows CO_2 to enter from the atmosphere is the:
    a. Vein
    b. Stomata
    c. Air space
    d. Mesophyll

11. In the diagram above, the part of the leaf where most photosynthesis occurs is the:
    a. Vein
    b. Stomata
    c. Air space
    d. Mesophyll

12. The "waste" product of the light reaction in photosynthesis is:
    a. Glucose
    b. H_2O
    c. O_2
    d. ATP

13. The Calvin Cycle converts carbon dioxide and hydrogen to:
    a. ADP
    b. ATP
    c. glucose
    d. water

14. Plants take in energy by absorbing:
    a. Sugars
    b. Chlorophyll a
    c. Chlorophyll b
    d. Sunlight

15. The role of ATP and NADPH in the Dark Reactions is to:
    a. Donate carbon atoms to make glucose
    b. Split CO_2 molecules to combine with Hydrogen to build glucose
    c. Capture the sunlight's energy
    d. Keep the plant hydrated

16. The stage of photosynthesis that uses the most ATP molecules is:
    a. Light reactions
    b. Glycolysis
    c. Calvin Cycle
    d. Kreb's Cycle

17. The function(s) of the light reactions of photosynthesis is to:
    a. Convert chemical energy to light energy
    b. Split water molecules to yield hydrogens and O_2
    c. Form glucose
    d. Convert light energy to chemical energy
    e. A and C
    f. B and D

18. Which material **produced** during the light reactions are necessary for the Calvin Cycle because they provide the energy needed:
    a. ATP molecules
    b. Oxygen atoms
    c. Hydrogen atoms
    d. Electrons

19. The oxygen produced by photosynthesis comes from:
    a. The breakdown of carbon dioxide
    b. The breakdown of both carbon dioxide and water
    c. The breakdown of water
    d. The breakdown of glucose

20. The Calvin Cycle of photosynthesis is also known as the:
    a. Dark Reactions
    b. Krebs Cycle
    c. Citric Acid Cycle
    d. Carbon Cycle

21. Photosynthesis occurs in the:
    a. Cytoplasm
    b. Chloroplast
    c. Mitochondria
    d. Ribosome

22. Plants gather the sun's energy with light-absorbing molecules called:
    a. Pigments
    b. Mitochondria
    c. Chloroplasts
    d. Glucose

23. How are cellular respiration and photosynthesis almost opposite processes:
    a. Photosynthesis releases energy, and cellular respiration stores energy
    b. Photosynthesis uses carbon dioxide, and cellular respiration produces it
    c. Photosynthesis uses oxygen, and cellular respiration produces it
    d. All of the above

24. Energy is released when:
    a. AMP becomes ADP
    b. ATP becomes ADP
    c. ADP becomes ATP
    d. GTP becomes ATP

25. What are the three parts of an ATP molecule:
    a. Adenine, guanine, ribose
    b. Chlorophyll, adenine, monophosphate tail
    c. Adenine, ribose, triphosphate tail
    d. Ribose, chlorophyll, diphosphate tail

26. The process that involves **oxygen** and breaks down food molecules to release energy in the form of ATP is:
    a. Aerobic Respiration
    b. Lactic acid fermentation
    c. Alcoholic fermentation
    d. Glycolysis

27. What is misleading about this statement: Producers carry out photosynthesis and consumers carry out cellular respiration.
    a. Both producers and consumers carry out photosynthesis
    b. Consumers carry out photosynthesis and producers carry out cellular respiration.
    c. Both producers and consumers carry out cellular respiration.
    d. Neither producers nor consumers carry out photosynthesis and cellular respiration.

28. When your muscle cells run out of oxygen, the following happens:
    a. Alcoholic fermentation
    b. Aerobic respiration
    c. Lactic acid fermentation
    d. Cellular respiration

29. Anaerobic means:
    a. Without carbon dioxide
    b. With oxygen
    c. With carbon dioxide
    d. Without oxygen

30. Which term is **least** closely related to the others (Doesn't fit in)?
    a. Anaerobic
    b. Aerobic
    c. Lactic acid fermentation
    d. Alcoholic fermentation

31. Bread rises as a result of:
    a. Glycolysis
    b. Lactic acid fermentation
    c. Pyruvic acid production
    d. Alcoholic fermentation

32. A total of 38 ATP are produced from 1 molecule of glucose as a result of:
    a. Glycolysis and aerobic respiration
    b. Glycolysis and lactic acid fermentation
    c. Glycolysis and alcoholic fermentation
    d. Lactic acid and alcoholic fermentation

33. What happens to the chemical energy in food that is not converted to useful cellular work:
    a. It is destroyed
    b. It is ALL converted to useful cellular work
    c. It is lost as light energy
    d. It is lost as heat energy

34. During the Krebs cycle, the carbon atoms that were originally part of glucose become part of which "waste" product:
    a. Citric acid
    b. ATP
    c. Pyruvate
    d. Carbon dioxide

35. The Kreb's Cycle and ETC of aerobic respiration occurs in the:
    a. Cytoplasm
    b. Chloroplast
    c. Mitochondria
    d. Ribosome

36. What metabolic stage begins both aerobic respiration and fermentation:
   a. Glycolysis
   b. Kreb's Cycle
   c. Calvin Cycle
   d. Dark Reactions

37. What is the net gain of ATP molecules produced directly by glycolysis:
   a. 2
   b. 4
   c. 34
   d. 38

38. Which of the following molecules is not involved in fermentation:
   a. Glucose
   b. Lactic Acid
   c. Ethanol
   d. Oxygen

39. What are the "**waste**" products of cellular respiration:
   a. Glucose and energy
   b. H_2O and CO_2
   c. Energy
   d. O_2 and energy
   e. Both B and C

40. The reactant of glycolysis is:
   a. Citric acid
   b. Pyruvate
   c. Glucose
   d. Water

41. Which organisms carry out cellular respiration:
   a. Heterotrophs
   b. Autotrophs
   c. Organisms that do not contain chlorophyll
   d. All living things

42. Below is the equation for which process:

$$\text{glucose} \rightarrow \text{ethanol} + CO_2 + \text{ATP}$$

   a. Photosynthesis
   b. Lactic acid fermentation
   c. Alcoholic fermentation
   d. Cellular respiration

43. What molecule is used to collect the "waste" at the end of the electron transport chain so the assembly line does not get backed up. Hint: When this substance combines with the waste it makes H_2O.

a. O_2
b. CO_2
c. $C_6H_{12}O_6$
d. CH_4

44. Which process(es) produce the most energy:

a. Glycolysis
b. Aerobic respiration
c. Glycolysis and lactic acid fermentation
d. Glycolysis and alcoholic fermentation

45. Which process(es) burn the most glucose to produce 100 ATP:

a. Aerobic respiration
b. Glycolysis and lactic acid fermentation
c. Glycolysis and aerobic respiration

46. The reactants for aerobic respiration are:

a. H_2O and $C_6H_{12}O_6$
b. O_2 and $C_6H_{12}O_6$
c. O_2
d. Energy and $C_6H_{12}O_6$
e. H_2O and CO_2

47. What is the ultimate goal of cellular respiration:

a. Create H_2O
b. Create O_2
c. Create CO_2
d. Create ATP

A student wanted to investigate the relationship between two pond organisms (organisms A and B). The student placed the organisms in a series of test tubes and added bromthymol blue to each. Bromthymol blue is a chemical indicator known to respond to the presence of carbon dioxide by changing from blue to green or yellow depending on the concentration.

Carbon Dioxide (CO_2) Indicator Chart for Bromthymol Blue

Amount of Carbon Dioxide in Pond Water	**Color of Bromthymol Blue**
No Carbon Dioxide	Shade of blue
Low Amount of Carbon Dioxide	Shade of green
High Amount of Carbon Dioxide	Shade of yellow

Test Tube Number	Organism in Test Tube	Starting Color	Light Conditions	Observations 24 Hours Later
1	A only	Blue	Light	Yellow
2	B only	Yellow	Light	Blue
3	B only	Blue	Dark	Yellow
4	A and B	Blue	Light	Blue
5	A and B	Yellow	Light	Yellow
6	None	Blue	Light	Blue
7	None	Yellow	Light	Yellow
8	None	Blue	Dark	Blue
9	None	Yellow	Dark	Yellow

Using the information above, choose the **BEST** answer for questions 48-51.

48. Which test tube(s) would provide the data needed to determine if organism A gives off carbon dioxide in light:
    a. Test tube 1 only
    b. Test tube 1 & 4 only
    c. Test tube 1 & 6 only
    d. Test tube 1 & 7 only
    e. Test tube 1 & 8 only

49. Which of the following hypotheses is supported by the results observed in test tube 3 and 8:
    a. Organism B produced carbon dioxide in the light
    b. Organism B uses carbon dioxide in the light
    c. Organism B uses carbon dioxide in the dark
    d. Organism B does not produce carbon dioxide in the dark
    e. Organism B produces carbon dioxide in the dark

50. Based on the results obtained in this experiment and general knowledge about plant and animals, which organism is a plant and which is an animal:
    a. A is an animal and B is a plant
    b. A is a plant and B is an animal
    c. Both A and B are animals
    d. Both A and B are plants
    e. Neither A nor B is an animal or plant

51. To determine if organism B needs light in order to use carbon dioxide, the experimenter would need to set up which of the following vials along with vials 1 through 9:
    a. Organism A in yellow bromthymol blue, in the dark
    b. Organism B in blue bromthymol blue, in the dark
    c. Organism B in yellow bromthymol blue, in the dark
    d. Organism A in blue bromthymol blue, in the dark
    e. Organisms A & B in yellow bromthymol blue, in the dark.

Name ________________________________

Hour ________

Photosynthesis and Cellular Respiration

Short Answer/Essay

1. Write the complete, balanced equation of photosynthesis and cellular respiration.

Photosynthesis ____

Cellular Respiration ____

2. Suppose an experiment is performed in which plant I is supplied with normal carbon dioxide, but with water that contains radioactive oxygen atoms. Radioactive means that the oxygen can be traced as it moves throughout the plant. Plant II is supplied with normal water, but with carbon dioxide that contains radioactive oxygen atoms. Each plant is allowed to perform photosynthesis and the oxygen gas and glucose produced are tested for radioactivity. Using all you knowledge, which plant would you expect to produce radioactive glucose and which plant would you expect to produce radioactive oxygen gas? Why?

3. If you were to race the process of photosynthesis against the process of cellular respiration, which would be faster? Explain two reasons why this is important?

4. Three students are investigating the effect of light intensity on photosynthesis by the aquatic plant Elodea. They varied the light intensity by placing a lamp at five different distances from the aquarium. The students left the room lights on and the window shades up. Then they measured how much oxygen gas the plant produced per hour at the different lamp distances. Below is their data.

Rate of Photosynthesis in Elodea

Lamp Distance (cm)	5	10	15	20	25	30	35	40	45
Oxygen Gas Produced (mL/hr)	10.31	8.98	7.25	6.78	6.44	6.25	5.00	4.50	4.50

Identify the dependent variable: ____

Identify the independent variable: ____

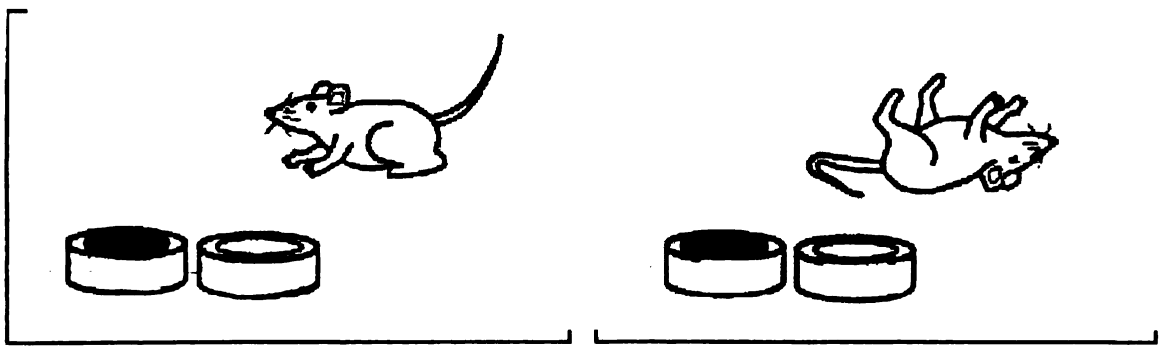
Use the data to create a graph on the chart below.

At which lamp distance(s) is photosynthesis occurring at the fastest rate?

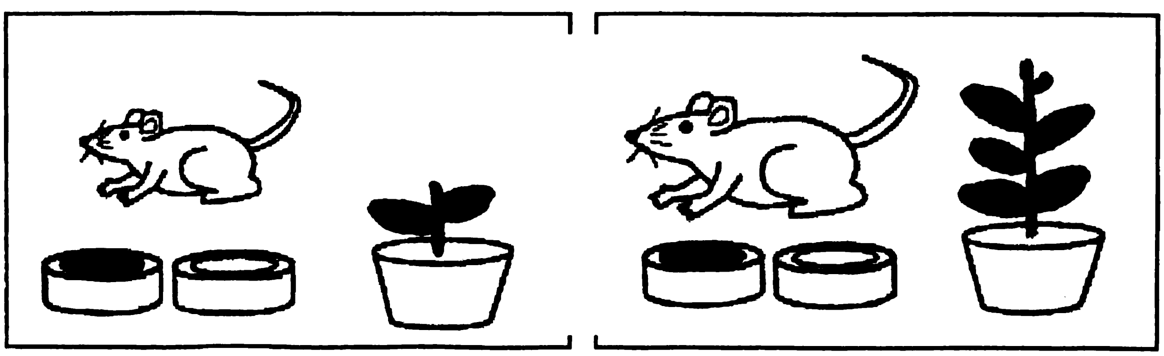
At which lamp distance(s) is photosynthesis occurring at the slowest rate?
The students designed the experiment to test this hypothesis: the closer the lamp, the faster photosynthesis will occur. Do their results support their hypothesis? Why or why not?

5. The following experiment was done more than 200 years ago by a scientist.

In a large covered glass box, the scientist put a young mouse, and a large amount of food and water. The scientist closed the box completely so that nothing could get in or out of the box. He put the box outside where it would get some sun light. Soon the mouse died. Most of the water and food was still in the box.



Later the scientist tried the experiment again. This time, however, the scientist put some living green plants in the glass box along with the food, water, and another young mouse. The plants were in small pots with soil and some water. The scientist closed up the box again and put it outside in the same place. The mouse did not die. It lived a long time and continued to grow larger. The plants in the box also lived and grew. Think about what you have learned in this class to answer the following.



Why did the young mouse die in the first experiment?

Why did the mouse not die in the second experiment?

In the second experiment, the mouse had food and water. The green plants were in soil and only had water. How were the plants able to live?

How were the plants able to increase in mass? **Explain in detail**

Predict and explain what would happen if the mouse ate all the leaves off the plant one day.

Describe an experiment you could do to investigate what effect, if any, air temperature might have on what happens to the mouse and the plant in the box.

Lab/Demo Set-up:

In the front of the room is an apparatus set-up consisting of three parts; a large, clear, plastic bottle, single-hole black stopper, and s-shaped gas bubbler. Inside the plastic bottle is a solution of 3% yeast, water, and 10% sugar. Inside the s-shaped gas bubbler is a solution of phenolphthalein and water. Remember that phenolphthalein is pink in a basic solution and clear in a acidic solution. Using this information, answer the following.

6. How do you explain the color change in the phenolphthalein over the last 55 minutes?

7. What life process do you think was involved in the color change?

8. What is the purpose of the yeast?

9. What is the purpose of the sugar?

10. What do you think would happen to the rate of the reaction if the % of yeast was decreased? Why?

11. What do you think would happen to the rate of the reaction if the % of sugar was increased? Why?

APPENDIX G

STUDENT SURVEY

APPENDIX G-1

PRE-SURVEY

Pre-Unit Survey

Circle the answer that fits you best. You are **not** required to put your name on this assignment.

1) Do you plan to continue your education after graduating from Thornapple-Kellogg?
   Yes   No   Not Sure

2) If you answered yes to the previous question, please indicate where you will continue your education:

3) If you plan to continue your education, will you need to take another life science course either in high school or beyond?
   Yes   No   Not Sure

4) Do you plan to have a career that is related to science?
   Yes   No   Not Sure

5) If you answered yes to the previous question, please list what career you are considering.

6) My favorite class is:
   Math   Science   English   Foreign Language
   History/Social Studies   Other (please list which one)____________

7) My least favorite class is:
   Math   Science   English   Foreign Language
   History/Social Studies   Other (please list which one) ____________

8) My usual grade in math class is:
   A   B   C   D   F

9) My usual grade in science class is:
   A   B   C   D   F

10) When you have trouble in class, what do you do? Please number your choices with 1 being the first thing you do and 6 being the last thing you would try.
   ____ Read the textbook   ____ Talk to the teacher
   ____ Talk to a friend who had the class   ____ Go back through the class notes
   ____ Ask questions in class
   ____ Other (please describe) ______________________________________

11) When you study, which of the following do you do? Please number your choices with 1 being the thing you are most likely to do and 6 being the thing you are least likely to do.

____ Listen to music

____ Turn on the TV for background noise

____ Go to a friend's house

____ Go to the public or school library

____ Find a room in the house that is quiet

____ Other (please describe) ______________________________

12) When you are assigned a story problem, do you do any of the following? Circle all that apply.

Draw pictures
Summarize the important information
Write formulas/equations that might be needed
Discuss the problem with someone else in the class
Ask the teacher for help
Other (please describe) ______________________________

13) What do you feel is the most **helpful** part of science class?

Lecture/Class discussion
In-class work
Homework
Labs
Quizzes/Tests
Other (please describe) ______________________________

14) What do you feel is the least **helpful** part of science class?

Lecture/Class discussion
In-class work
Homework
Labs
Quizzes/Tests
Other (please describe) ______________________________

15) What is you **favorite** part of science class?

Lecture/Class discussion
In-class work
Homework
Labs
Quizzes/Tests
Other (please describe) ______________________________

APPENDIX G-2

POST-SURVEY

Post-Unit Survey

Answer each of the following questions. You are **not** required to put your name on this assignment.

1) Please shade the box that most fits how you feel.

I can describe the functions (jobs) of the chloroplast and mitochondria	**Always**	**Usually**	**Sometimes**	**Never**
I can explain the relationship between photosynthesis and cellular respiration	**Always**	**Usually**	**Sometimes**	**Never**
I can distinguish between kinetic and potential energy	**Always**	**Usually**	**Sometimes**	**Never**
I can explain what chemical energy is and how cells release it from food through cellular respiration	**Always**	**Usually**	**Sometimes**	**Never**
I can describe the structure of ATP and how it stores energy	**Always**	**Usually**	**Sometimes**	**Never**
I can give examples of work that cells perform	**Always**	**Usually**	**Sometimes**	**Never**
I can relate breathing and cellular respiration	**Always**	**Usually**	**Sometimes**	**Never**
I can identify the overall reactants and products of cellular respiration	**Always**	**Usually**	**Sometimes**	**Never**
I can summarize glycolysis, the Kreb's Cycle and the Electron Transport Chain and identify where ATP is made	**Always**	**Usually**	**Sometimes**	**Never**
I can explain how fermentation in muscle cells is different from fermentation in yeast cells	**Always**	**Usually**	**Sometimes**	**Never**
I can summarize the overall reactants and products of photosynthesis	**Always**	**Usually**	**Sometimes**	**Never**
I can explain how white light is captured in plant cells	**Always**	**Usually**	**Sometimes**	**Never**
I can identify the chemical reactants and products of the light reactions	**Always**	**Usually**	**Sometimes**	**Never**
I can explain how the Calvin Cycle makes a simple sugar	**Always**	**Usually**	**Sometimes**	**Never**
I can summarize the light reactions and the Calvin Cycle	**Always**	**Usually**	**Sometimes**	**Never**
I can describe the types of organisms that carry out photosynthesis and cellular respiration	**Always**	**Usually**	**Sometimes**	**Never**

2) Please shade the box that most fits how you feel.

If given a graph I can identify the dependent and independent variables in an experiment.	**Always**	**Usually**	**Sometimes**	**Never**
I can organize data into a data table.	**Always**	**Usually**	**Sometimes**	**Never**

If given a data set, I can make a graph using paper and pencil.	**Always**	**Usually**	**Sometimes**	**Never**
If given a data set, I can make a graph using Excel.	**Always**	**Usually**	**Sometimes**	**Never**
I can draw conclusions about an experiment by analyzing the data table	**Always**	**Usually**	**Sometimes**	**Never**
I can analyze a graph and determining what it is trying to tell me.	**Always**	**Usually**	**Sometimes**	**Never**
I can apply previously learned knowledge to help me understand new labs, diagrams and story problems, even if I may never have seen them before.	**Always**	**Usually**	**Sometimes**	**Never**

3) Rate the activities and labs from this unit by shading the box that most fits how you feel.

Lab 1: ATP	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Lab 2: CO2 Production	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Lab 3: Yeast Fermentation	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Lab 4: Paper Chromatography	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Lab 5: Rates of Photosynthesis	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Lab 6: Photosynthesis vs. Cellular Respiration	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**

4) What did you like BEST about this unit?

5) What could be improved?

APPENDIX H

STUDENT CONSENT FORM

Improving Student Comprehension of Photosynthesis and Cellular Respiration through Hands-on Activities and Laboratory Experiments

Parental Consent and Student Assent

Dear Parents/Guardians and Students:

During the past six weeks, I implemented a unit on photosynthesis and cellular respiration in my Biology I classes. I developed this unit for my Master's thesis project through Michigan State University's Department of Science and Mathematics Education (DSME). During these six weeks, students actively learned the science concepts involved in photosynthesis and cellular respiration through participation in multiple laboratory experiments and hands-on activities.

To evaluate the effectiveness of this unit, data was collected from students through standard assessment tools such as pre and post tests, quizzes, lab questions and surveys. With your permission, I would like to include your child's data in my thesis. Your child's privacy will be a foremost concern and will be protected to the maximum extent allowable by law. All data generated has and will continue to remain confidential and secure. At no time will your child's identity be associated with the data nor will they be identified in any images that are used in the thesis presentation.

Participation in the study is voluntary. Your child will receive no penalty in regard to their grade should you deny permission for the use of their data. You may request that your child's information not be included in this study at any time and your request will be honored.

There are no risks associated with participation in this study. Your child's participation in this study may contribute to the understanding of how hands-on activities and laboratory experiments enhance the learning process. In addition, it may help determine a way to teach students how to obtain, organize, and interpret experimental data.

If you will allow your child's data to be included in this study, please complete the attached form and return it to me by November 21, 2006. If you have any questions, please feel free to contact me at Thornapple-Kellogg High School (269) 795-5400 ext. 4459 or by e-mail at mjasper@tk.k12.mi.us. Questions regarding the thesis project can also be directed to Dr. Merle Heidemann at DSME, 118 N. Kedzie, Michigan State University, East Lansing, MI 48824, by phone at (517) 432-2152 or by e-mail at heidema2@msu.edu. If you have any questions or concerns regarding your rights as a study participant, or are dissatisfied at any time with any aspect of this study, you may contact- anonymously, if you wish - Peter Vasilenko, Ph.D., Director of the Human Subject Protections, by phone (517) 355-2180, fax (517) 432-4503, e-mail irb@msu.edu, or regular mail 202 Olds Hall, Michigan State University, East Lansing, MI 48824-1047.

Sincerely,

Marie Jasper
Biology Teacher
Thornapple-Kellogg High School

Please fill out the following consent information.

I voluntarily agree to have ____ participate in the study.

(print student name)

Please check all that apply.

Data:
_____ I give Mrs. Jasper permission to use data generated from my child's work in this class for this thesis project. All data from my child shall remain confidential and secure.

_____ I do not wish to have my child's work used in this thesis project.

Images:
_____ I give Mrs. Jasper permission to use images of my child during her work on this thesis project. My child will not be identified in any image.

_____ I do not wish to have my child's image used at any time during this thesis project.

____ ______________________

(Parent/Guardian Signature) (Date)

I voluntarily agree to participate in this thesis project.

____ ______________________

(Student Signature) (Date)

REFERENCES

GENERAL REFERENCES

Amir, R., Tamir, P. (1994). In-depth analysis of misconceptions as a basis for developing research-based remedial instruction: The case of photosynthesis. *The American Biology Teacher*, 57(2), 94-100.

Case S. (2006). Leaf Stomata as Bioindicators Stimulating Student Research. *The American Biology Teacher,* 68(2), Educational Module, 88-91.

Oakes, J. (1997). Discovery Through Graphing. *The Science Teacher*, 64(1), 33-35.

Pernezny, K., Pernezny, B., Lentini, R. (1996). Recapturing Quantitative Biology. *The Science Teacher*, 63(9), 28-30.

Texley, J. (2001). Adding Math to Biology. *The Science Teacher*, 68(4), 36-39.

SITED REFERENCES

Anderson, S. (1990). The Effects of Instruction on College Nonmajors' Conceptions of Respiration and Photosynthesis. Journal of Research in Scinece Teaching, 27(8), 761-776.

Barman, C., Stein, M., McNair, S., Barman, N. (2006). Student's Ideas About Plants & Plant Growth. *The American Biology Teacher*, 68(2), 73-79.

Batzli J., Heidemann, M. (2002). Especially for Teachers Uptake of CO_2 by Elodea some Preliminary Experiments pages 13-14 Fall Edition Natural Science

Chan, S. (1996). Focus on Photosynthesis. *The Science Teacher,* 63(8), 46-48.

Christensen, A., Christian, B. (1997). Dealing with Data. *The Science Teacher*, 64(6), 38-41.

Clements, L., Jackson, K. (1998). Visualization of the Light & Dark Reactions of Photosynthesis Through Dynamic Demonstrations. *The American Biology Teacher*, 60(8), 601-605.

Collins, L., Bell, R. (2004). How to Generate Understanding of the Scientific Process in Introductory Biology. *The American Science Teacher,* 66(1), 51-65.

Crandall, G. (1997). Old Wine Into New Bottles. *Journal of College Science Teaching.* 19, 413-418.

Drummond, C. (1998). Foundations in Earth Science- Adventures in Nature and Mathematics. New York: Kendall/Hunt.

Drumond, C. (1999). Skills for the Future. *The Science Teacher*, 66(4), 30-33

Hershey, D. (2004) Avoid Misconceptions When Teaching about Plants. American Institute of Biological Sciences.

National Research Council. (1996). *National Science Education Standards*. Washington, D.C.: National Academy Press.

Nelson, G. (2001). Choosing Content That's Worth Knowing. *Educational Leadership*, 59(2), 12-16.

NSF 96-139 (1996). Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering and Technology. Melvin D. George, Chair, Committee on the Review of Undergraduate Education.

Osborne, R., Freyberg, P. (1985) Learning in Science. London: Heinemann

Piaget, J. (1970). The Science of Education and the Psychology of the Child. New York: Orion.

Rehorek, S. (2004). Inquiry-Based Teaching: An Example of Descriptive Science in Action. *The American Biology Teacher,* 66(7), 493-499.

Rutledge, M. (2005). Making the Nature of Science Relevant: Effectiveness of an Activity That Stresses Critical Thinking Skills. *The American Biology Teacher,* 67(6), 329-333.

SEAQL is funded by the National Science Foundation, grant number EST-9355717.

Weise, L. (2006). Simple Inexpensive Respirometers & Demonstrations. *The American Biology Teacher*, 68(5), 293-295.

Wilke, R., Straits, W. (2005). Practical Advice for Teaching Inquiry-Based Science Process Skills in the Biological Sciences. *The American Biology Teacher*, 67 (9), 534-540.