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THE IMPACT OF FORMATIVE ASSESSMENT TECHNIQUES ON THE INSTRUCTION OF THE HIGH SCHOOL BIOLOGY UNITS OF PHOTOSYNTHESIS AND CELLULAR RESPIRATION

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SHANNA FAWN TURY

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By

Shanna Fawn Tury

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ABSTRACT

THE IMPACT OF FORMATIVE ASSESSMENT TECHNIQUES ON THE INSTRUCTION OF THE HIGH SCHOOL BIOLOGY UNITS OF PHOTOSYNTHESIS AND CELLULAR RESPIRATION

By

Shanna Fawn Tury

The effect of formative assessment on student learning during student-centered, inquiry-based instruction was studied in a high school biology class. The objective of this study was to test whether increasing the level of formative assessment, including feedback to students and reflection on laboratory activities, would make an impact on the learning of concepts related to cellular metabolism, such as cellular respiration and photosynthesis. Two units of instruction were evaluated, one utilizing active learning strategies along with formative assessment techniques, and the other taught in a more teacher-centered manner. The revised methodology showed a statistically significant increase in student learning gains as compared to the unimproved technique. The increased amount of hands-on activities for students, observation of students in an informal context, student and teacher interaction, immediate feedback to students, public discussion and reflection on lab activities and results, and modification of instruction by the teacher is implicated in the trend found in these data. The results suggest that the combined effect of active, inquiry-based instruction and a variety of formative assessments can have a significant positive effect on student learning of topics related to cellular metabolism, such as photosynthesis and cellular respiration

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INTRODUCTION

Statement of Problem and Rationale for the Study

The fundamental biology processes of photosynthesis and cellular respiration are challenging for many students due to their abstract and complex nature (e.g. Salter, 2008; Keeley, Eberle, and Tugel, 2007). These processes are difficult to comprehend and therefore poorly understood by students, because they contain many new and unfamiliar molecules, chemical reactions, as well as an advanced and technical vocabulary (Patro, 2008). The essential role that these processes play within organisms, ecosystems, and the biosphere at large makes it imperative that students recognize their significance. Not only must biology teachers facilitate learning of curriculum content objectives, they must model the overarching goals of science and its process-driven nature, such as increasing knowledge about the natural world through investigation and analysis, and using explanations to make predictions. This can be achieved by asking questions, testing hypotheses, and drawing conclusions through the analysis of empirical data. To mentor students to think and write like scientists, educators must foster scientific literacy and allow time for practice and development of scientific method and experimental design skills (Berber-Jimenez, et. al, 2008; Wilke and Straits, 2005). Students need to conduct scientific inquiry that is embedded within and relevant to discipline-specific content knowledge.

The limitations of teaching the basic molecules and chemistry of photosynthesis and cellular respiration to underclassmen in high school are evident in low levels of comprehension, low test scores on summative assessments, and low motivation for learning. The latter complicates the task since not only is the subject matter extremely challenging, students also have little appreciation for what they are learning. In addition, most students are required to enroll in Biology prior to Chemistry in high school, making it difficult for them to fully understand biological molecules and the associated chemical reactions taking place within cells. Relevant chemical concepts are addressed by biology teachers, but often are not internalized by students until much later in their educational career.

The importance of planning and facilitating an inquiry-based science program for students is strongly emphasized in the National Science Education Teaching Standards as it allows for the development of investigative skills "as well as the curiosity, openness to new ideas and data, and skepticism that characterizes science" (NRC, 1996). Inquiry can be defined as an approach to learning that is student-constructed as opposed to information that is teacher-transmitted. A spectrum of inquiry-based learning exists since investigations can be teacher-guided or completely student-led, or anywhere in between. The National Science Education Teaching Standards also stress the importance of ongoing assessment of learning by utilizing multiple methods to "gather data about student understanding and ability". In addition, the analysis of these assessment data is crucial for the reflection on and improvement of teaching practices (NRC, 1996).

While the use of inquiry as a pedagogical guide to instruction is a useful method for science educators, I have noticed in my own teaching that inquiry-based activities and labs that lack necessary individual and group reflection time and follow-up discussion with students fall short of their goals. In short, the absence of formative laboratory and activity assessment in the biology classroom makes it difficult to recognize and respond to student needs and challenges as they participate in daily tasks and labs. Not only is the need for continuous evaluation great in this setting, negative perceptions of assessments by students and even teachers makes their presence even more formidable.

I predict that by using more continuous, formative assessment I will gain a more thorough knowledge of student understanding as they perform classroom activities and laboratory investigations. This will enable me to better guide their learning toward a more accurate and complete comprehension of photosynthesis and cellular respiration. Student-centered activities to use in this formative assessment process will be necessary as they will allow for direct interaction of teacher and student and more emphasis on "responding to individual student's interest, strengths, and needs" (NRC, 1996). Through the use of demonstrations, group discussions, modeling activities, manipulatives, individual and group white boarding, lab results presentations, participation assessments, and peer evaluations, I expect to be able to effectively evaluate my students as they progress through the learning of these challenging concepts and to adjust my instruction to better suit their specific needs.

Theoretical Framework

The importance of inquiry-based learning during which students take an active role in performing investigations and formulating answers to testable questions, as well as the authentic, real time (formative) assessment of that learning by teachers should not be undervalued in the science classroom (Carlson, Humphrey, and Reinhardt, 2003). Both inquiry and formative assessment are valuable tools available to educators as they seek to facilitate student learning about scientific concepts. Inquiry-based instruction allows students to increase their knowledge through direct observation of organisms and related phenomena, much like science is conducted by researchers in the real world.

Formative assessment enables teachers to continuously gauge student understanding and adjust instruction to meet the needs of those students as difficulties arise.

The call for "hands-on, minds-on" science education is strongly emphasized in the National Science Education Standards, where it is clearly stated that learning science is an active process, and is "something that students do, not something that is done to them" (NRC, 1996). The goal of the Standards is to promote reform throughout the educational system by changing the emphasis from the teacher as a technician presenting knowledge through lecture, text, and demonstration to the teacher as an "intellectual, reflective practitioner" who "[guides] students in active and extended scientific inquiry." Also important is the placing of more emphasis on communicating ideas and work to classmates in a public forum and continuous assessment of student understanding, and less emphasis on private communication between student and teacher as well as evaluating student's knowledge of factual information at the conclusion of an instructional period (NRC, 1996). Clearly, the need for students as active learners performing inquiry-based lab investigations mentored by thoughtful instructors that focus on formative assessment is a vital component of science education as it progresses further into the twenty-first century.

It has been stated that "inquiry as an instructional method is here to stay" (Erekson, 2004). Therefore, imperative that teachers of science not only provide opportunities for students to conduct inquiry, but also to develop a learning environment where increased assessment and reflection on the process as well as content subject matter is both the norm and the expectation. Students must recognize that the process of science produces knowledge, and when performing inquiry-based activities they are engaging in many of the same thinking processes "as scientists who are seeking to expand human knowledge of the natural world" (NRC, 2000). Traditional assessment techniques may not be as effective for evaluating student comprehension during inquiry-based learning; revised methods must be considered and researched (Erekson, 2004).

The advantages of inquiry-based science teaching are numerous and include active, meaningful, and higher level learning (Wilke and Straits, 2005). Active learning strategies that require involvement by students promote "deep content learning" instead of just memorizing factual information and vocabulary (Ueckert and Gess-Newsome, 2008). This "knowledge reorganization", in which recognition of major concepts and relationships among ideas are added to student's existing knowledge base, has the ability to challenge preexisting ideas and misconceptions. The problem is that what many students experience in the classroom, and while studying at home, is often described as "passive learning" (Bransford, Brown, and Cocking, 2000), which is "contrary to what we know about both learning and the generation of scientific knowledge" (Ueckert and Gess-Newsome, 2008). Scientists and students alike must be actively engaged in the process of asking questions, observing, proposing hypotheses, designing experiments, collecting and analyzing data, interpreting evidence and making conclusions. Science is never performed in isolation, and active learning necessitates that individuals "engage with the content, and with others, unveil prior ideas, and construct new knowledge from their experiences" (Ueckert and Gess-Newsome, 2008).

Accordingly, the 5E approach (engage, explore, explain, elaborate, and evaluate) has been recently popularized in education research and practice because, unlike commonly encountered teaching methods, this instructional format allows students to take on a more active role in their learning. The various components of the 5Es appeal to different learning styles and are easily incorporated into an inquiry-based classroom. Patro (2008) found that utilizing the 5E technique to teach cellular respiration improved the test scores of his students and increased their engagement during class time. In addition, using this method allows for presentation of the material in a variety of modes, including "visual, auditory, tactile etc.", and provides a system to monitor student learning continuously and modify instruction as needed (Patro, 2008).

As evidenced by the wealth of literature concerned with changing teaching strategies to include more active learning strategies, it is necessary to focus more attention on accurately assigning assessment methods with types that align with these learning goals (Crowe, Dirks, and Wenderoth, 2008; Ueckert and Gess-Newsome, 2008; Peters, 2008; Straits and Wilke, 2002; Hackett, 1998). Bloom's taxonomy is a well known and accepted tool for categorizing thinking into different levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. Not only do educators need to facilitate student use of the higher order cognitive skills of Bloom's taxonomy (application, analysis, synthesis, and evaluation) through inquiry-related practices, but relevant formative assessment methods must be developed to accentuate the learning process.

Assessments, whether diagnostic, formative, or summative, must employ a variety of methods to completely and accurately gauge the learning of students in the science classroom. Diagnostic assessments, such as pretests, allow educators to find out what prior knowledge students possess, while summative assessments, including paper and pencil tests and quizzes, quantify learning at the end of a unit or class. Many types of formative assessments occurring during the instructional period offer students "feedback on their work to improve their learning" (Heady, 2000). Assessment should take the form of a cycle between student and instructor in which adjustments are made by each party as necessary to enhance learning; this feedback should be focused and immediate (Wilke and Straits, 2005). One of the advantages for teachers is that formative assessments, while useful and productive for students, do not require formal grading. This is a time saver in an era of increased accountability and paperwork for educators and reduced state funding for schools. For example, my school district has eliminated prep periods for teachers in order to save money, so therefore I will be teaching one extra hour each day, decreasing the amount of time I can devote to grading of homework and other summative assessments.

The primary purpose of assessment is "to help students do higher quality work" (NRC, 2001). Formative assessments are ongoing, built into the design of teaching, and provide teachers with a wealth of data about their student's needs and challenges while students are experiencing them. When that assessment information is used to inform and influence teaching and learning, only then is it formative in nature (NRC, 2001). The techniques of continuous, formative assessment may include: participant observation, purposeful questioning, science conversations, and student self-assessment. The purposes and uses may include: serving instruction while monitoring growth, enhancing student learning, enabling teachers' professional growth, and providing information to report students' progress (Carlson, Humphrey, and Reinhardt, 2003).

A review of more than 250 sources (Black and William, 1998) cites formative assessment as an essential feature of classroom work, and also reports that the "learning gains from systematic attention to formative assessment are larger than most of those found for any other educational interventions" (NRC, 2001). The Black and William study also states that formative assessment practices are currently underused by a majority of educators. When assessment becomes a daily classroom focus, it becomes less intimidating to students, and has been shown to have a positive effect on learning and achievement in science classrooms. Thus, assessment is a powerful tool not only for grading and placement of students, but also to improve learning and inform instruction.

Since formative assessment can improve the abilities of educators to promote high quality student outcomes, and inquiry learning can produce higher achievement and positive student attitudes, it is imperative that the development and use of these assessments takes place within an inquiry-based science curriculum (Straits and Wilke, 2002). Formative assessments used to glean information during the learning process can be informal and serve as "spot checks" to reveal students' current level of understanding. In addition, this sort of reflection by educators can act as an impetus for the continual improvement of teaching, "ensuring that inquiry learning activities become more refined, appropriate, and effective" (Straits and Wilke, 2002). It should be noted that inquiry-based learning and formative assessment techniques are not the answer to all problems associated with science education today, but do deserve a prominent place in the pedagogical repertoire of quality science teachers.

Successful teachers use a variety of methods to measure student understanding of science concepts including laboratory-based assessment techniques. Erekson (2004) reports that lab group presentations using whiteboards coupled with guided teacher questions can help "assess student understanding of inquiry-related activities." When students visually and orally present their findings from lab investigations, they are mirroring the work of scientists as they share information. This process is a formative assessment technique because it helps to identify misconceptions and gaps in student learning, produces a less-threatening environment for exchange of ideas, and helps to guide further instruction for educators.

Reflective thinking and writing immediately following inquiry-based learning activities allow students to analyze and make judgments about what happened during the investigation. Reflection may help students to improve communication skills, both written and oral, and informs the instructor of students' current level of expertise with the topic or question. McDonald and Dominguez (2009) state that science journal reflections, small group reports, and guided reflection papers all help students to construct meaning and expand learning and understanding. They also emphasize that much of the information gathered from these assessments should be utilized to adjust teaching, and not to assign grades. Peters (2008) provides strategies for improving inquiry assessment, such as letting students show what they know, multiple types of assessment, and frequent feedback loops, in order to develop a classroom culture that views assessment "as information rather than judgment". Allowing opportunities for frequent peer assessment and self-assessment can show students that evaluations such as these can provide information to improve their work and increase their learning (Peters, 2008).

One type of advanced literacy that is practiced and developed throughout high school science classes is writing lab reports. This expository form of writing can benefit students as they become more familiar with the text, style, and language used in science (Berber-Jimenez, et al, 2008). A well-written lab report, specifically the conclusion section, can show instructors that students have made connections between the observed results and scientific concepts. Furthermore, when students conduct a task in which they use their data to form and defend an explanation, they are developing and refining scientific inquiry skills (Hackett, 1998). It seems logical that providing students with a rubric in advance of a task such as a lab report conclusion, as well as providing feedback during the reflective writing process, will improve the quality of work students are able to produce.

In summary, active learning fosters opportunities for students to engage with science content, interact socially, consider prior understandings, connect ideas, and construct new knowledge. Inquiry-based investigations are a type of active learning that does the aforementioned activities and also develops scientific method and experimental design skills. Additionally, assessment of student learning must be expanded beyond the limited scope of the traditional types of summative tests used as ending activities to include a more varied and progressive assortment of formative assessments to help both teachers and students monitor progress.

Scientific Background

The topic of cellular metabolism, specifically the processes of photosynthesis and cellular respiration within living organisms, plays an essential role in the maintenance of life on earth (see Michigan Science Content Expectations, Appendix A). Photosynthesis captures light energy from the sun and converts it into chemical energy in the form of carbohydrates and other organic biological molecules within plants, some protists and bacteria. Cellular respiration, taking place within autotrophs and heterotrophs alike, releases this stored chemical energy transforming it into a readily useable and renewable molecule, known as ATP, which living organisms utilize to drive endergonic metabolic reactions taking place within cells. Although many students are under the misconception that photosynthesis and cellular respiration are inverse reactions of each other due to the reciprocal nature of their overall chemical equations, it should be noted that these processes take place within different organelles and involve completely different sets of chemical reactions and associated enzymatic catalysts.

In order to maintain homeostasis and life processes, the cells of living organisms must take in energy from outside sources. This energy enters ecosystems as sunlight which is utilized during the process of photosynthesis to drive the formation of organic compounds which are later oxidized by cellular respiration, transferring chemical energy to produce ATP to be used for cellular work. This energy ultimately leaves the ecosystem as heat given off by respiring organisms. Photosynthetic organisms comprise the base of the food chains and food webs within ecosystems and therefore most of the energy within living things is indirectly derived from their metabolism. Net primary production is the amount of organic material produced by autotrophs that is available to higher trophic levels after subtracting the amount necessary to sustain respiration, growth, and homeostasis within the cells of the autotrophs themselves. Heterotrophic organisms then feed on this organic material, incorporating it into their own bodies or using it for energy. The amount of available energy decreases as it progresses through the various trophic levels due to the fact that most of this energy is lost as heat. Therefore, the processes of photosynthesis and cellular respiration are relevant not only at the cellular level but also to organisms, communities, and ecosystems because of their relationship to physiology and energy flow.

Photosynthetic pigments, such as chlorophyll, are contained within protein complexes known as photosystems embedded in the thylakoid membranes of the chloroplast. The energy-capturing pigment chlorophyll reflects green wavelengths of visible light making photosynthetic cells appear green to an observer. Students often are under the impression that plants appear green because they absorb green light, when just the opposite is true. The remaining wavelengths of the spectrum are absorbed and the light energy gained is used to drive the light-dependent reactions of photosynthesis. The light reactions are carried out by enzymes and electron-carrying molecules in the thylakoid membranes, including photosystems I and II and the associated electron transport chains, converting light energy to the chemical energy of ATP and NADPH. Water is also split during this process and O_2 is released as a byproduct to the atmosphere or is used by the organism for its own cellular respiration. The Calvin cycle reactions, sometimes referred to as the dark reactions, take place in the stroma of the chloroplast and utilize the chemical potential energy of ATP and NADPH made previously in the light reactions to convert CO_2 to the three carbon sugar glyceraldehyde-3-phosphate, which is later converted to other organic compounds such as sucrose, starch, amino acids, and fatty acids. The Calvin cycle reactions take place whenever ATP and NADPH are available from the light reactions, but not while the organism is in the dark.

Another misconception held by students is the idea that photosynthesis is the direct conversion of sunlight into food. Although it is true that the energy gathered, converted, and stored during the light reactions is later used to build sugar in the Calvin cycle, the laws of conservation of energy and mass make it impossible to transform energy into mass. The atoms used to build organic material during the Calvin cycle originate primarily from the atmosphere in the form of CO_2 taken in by photosynthesizers. It is also largely inaccurate when students believe that photosynthetic organisms, such as plants, consume soil and water to gain mass. The minerals and water obtained from the soil are necessary to the biochemical reactions taking place within these organisms, but a plant's mass is derived almost entirely from carbon dioxide, with only a small percentage of it coming from hydrogen atoms of water taken up by the root system.

Cellular respiration is a central metabolic process in aerobic organisms that is used to harvest energy through the oxidation of glucose and other organic compounds and use it to regenerate ATP, the universal energy molecule used to power most energy requiring metabolic reactions. The three main parts of cellular respiration are glycolysis, the Krebs cycle (citric acid cycle), and oxidative phosphorylation taking place in the cell cytoplasm, mitrochondrial matrix, and mitochondrial membranes, respectively. Glycolysis is a series of enzyme-catalyzed reactions in most living cells that effectively converts the six carbon sugar glucose (or other energy-containing organic compound) into two molecules of the three carbon acid pyruvate. Some of the energy in the C-C and C-H bonds in glucose is converted into a small amount of ATP (2) and NADH (2) under usual conditions. Following glycolysis, fermentation by facultative anaerobes converts pyruvate into ethanol (yeast) or lactic acid (human muscle cells), although this does not produce any additional ATP.

Under aerobic conditions, carbon dioxide is removed from pyruvate and coenzyme A is added to form the two carbon molecule acetyl CoA which feeds into the Krebs cycle. The Krebs cycle is another enzyme-catalyzed series of oxidation-reduction (redox) reactions occurring in the mitochondrial matrix in eukaryotes (and the cytoplasm in prokaryotes) that transforms acetyl CoA into CO_2. Some of the energy in the C-C and C-H bonds in acetyl CoA is converted into a small amount of ATP (2), NADH (2-3), and $FADH_2$ (2) under usual conditions. Lastly, much of the chemical energy in NADH and $FADH_2$ is converted to chemical energy in ATP as electrons removed from NADH and $FADH_2$ travel through the electron transport chain and are involved in a series of redox reactions in the inner mitochondrial membrane in eukaryotes (and the plasma membrane in prokaryotes). At the end of the electron transport chain, the electrons combine with hydrogen ions and oxygen gas to form water. This oxidative phosphorylation (ultimately removing electrons from food molecules) produces a large amount of ATP through chemiosmosis of hydrogen ions across the inner mitochondrial membrane. The ATP produced during cellular respiration is used by cells to maintain homeostasis and provide chemical energy for anabolic reactions within organisms.

Correspondingly, students sometimes assume that only plants photosynthesize while only animals respire, or that photosynthesis is a plant's form of cellular respiration. This of course is not true, as all organisms, regardless of their nutritional requirements, need to conduct cellular respiration and/or fermentation to produce ATP for life processes. It is also a misconception that plants respire only when they are not photosynthesizing, when in reality cellular respiration is a continuous process carried out at all times by most living things. Fermentation is also often misunderstood by students who do not recognize that the purpose of this process is to regenerate NAD+, and not to generate additional ATP post glycoysis.

Finally, the distinctions between cellular respiration, external respiration (breathing), digestion/absorption, and nutrient circulation by the cardiovascular system within advanced animals, such as humans, are particularly unclear to students. While digestion, absorption, and the blood function to break down and deliver organic nutrients to cells, and breathing with lungs delivers oxygen to cells via the blood, cellular respiration through redox reactions releases energy through the oxidation of food thus regenerating ATP for cellular work.

School Demographics

The Hartland Consolidated School District, located in the northeastern corner of Livingston County, is home to eight schools and a total enrollment of nearly 5,600 students in grades K-12. During the past three decades the district has experienced a rapid rate of growth, transforming itself from a small rural farming community into a large suburban bedroom community. Hartland High School is an NCA-endorsed, Class A high school of approximately 1800 students with a graduation rate of 97.9%. The student population displays low ethnic diversity: 97% Caucasian, 1% Hispanic, 1% African American, and 1% Asian/Pacific Islander, and approximately 10% of students receive free and reduced lunch (HHS School Profile, 2009).

Data for the graduating classes of 2008, 2009, and 2010 indicate that 74% of eleventh grade students achieved Michigan Merit Exam (MME) proficiency in the area of science, as compared to the statewide level of 56% for those years. In addition, the average score for the Science portion of the ACT exam is generally about one point higher than the state average and two points higher than the national average (Hartland Class of 2009: 21.9; Michigan 2009: 20.1; and U.S. 2009: 20.9) (HHS Annual Report, 2009). Although Hartland students continue to score above the state and national average, they have been shown to perform poorly on the test items based on objectives that contained the verbs, "analyze, synthesize, understand, justify, and reflect." Therefore, one of the NCA target goals for the high school includes the improvement of critical thinking across the curriculum, with an emphasis on math and science instruction incorporating inquiry-oriented instruction, inferring from data, and using contextual clues to make conclusions (HHS Annual Report, 2009).

The research study documented here, in which the use of formative assessment of inquiry-based activities to enable a more thorough knowledge of student understanding and better guide learning toward a more accurate and complete comprehension of photosynthesis and cellular respiration, was conducted in 4 sections of Biology taught to primarily tenth grade students. The data were collected from a group of 31 consenting students consisting of 4 freshman and 27 sophomores, which is a representative sample of the age distribution of the students enrolled in those sections. The parental consent and student assent form utilized for this study is located in Appendix B. The sample group contained 12 female students and 19 male students, earning the following semester grades in Biology: 12 "As", 11 "Bs", 5 "Cs", 2 "Ds", and 1 "E". The average grade point average (GPA) for the sample group was 3.087, while the overall average GPA for Hartland High School is 2.839.

IMPLEMENTATION

Description

This research study focused on the comparison of two units of instruction incorporating inquiry-based learning that were taught with varying types of assessment techniques. The topic of the first unit was photosynthesis and was taught using previous methods of instruction, laboratory-based activities, and formal summative assessments.

The topic of the second unit was cellular respiration and was taught using a more student-centered mode of instruction, laboratory-based activities with increased discussion and reflection, and many embedded informal formative assessments in addition to the formal summative evaluations. The data set collected from the photosynthesis unit served as the control group, while the data from the cellular respiration unit was used as the experimental group for this study.

A pre-unit survey (Appendix F) was developed to gauge student perceptions about various topics including classes, grades, studying, class activities, laboratories, tests and quizzes, etc. A lab survey (Appendix F) was also administered to students with questions on the topics of student preferences and expectations for learning in the laboratory setting. Student responses for both of these surveys were gathered at the beginning of the photosynthesis unit, while a post-unit survey (Appendix F) was given after the completion of the cellular respiration unit. The compiled results of these surveys are tabulated in Appendix G, and will be further discussed in the results section of this paper.

A pretest (Appendix D) was also developed and administered for these two units of instruction in order to evaluate the prior knowledge of students regarding the topics of photosynthesis and cellular respiration. Both of the pretests consisted of open-ended essay questions covering the major concepts of their respective biological processes. A posttest, with identical essay questions as the pretest, was given to students at the conclusion of each instructional unit as a portion of their summative unit test. The data collected allowed for the comparison of average pretest and posttest scores for the photosynthesis unit; the same comparison was made for the cellular respiration unit. In addition, the average levels of improvement for the photosynthesis unit were directly compared with those of the cellular respiration unit to evaluate the effectiveness of the instructional and assessment techniques utilized in the second unit.

Both units of instruction consisted of a pretest, various class work and homework assignments, one standard lab with detailed procedure, one student designed, inquiry-based lab, review materials, and a posttest. Students wrote lab report conclusions for the inquiry-based labs that were formally assessed along with the pretests and posttests and included in the data set. To increase formative assessment opportunities, more student-centered activities were incorporated into the cellular respiration unit. These activities included a calorimetry demonstration and group discussion, molecular modeling of compounds with chemistry kits, a kinesthetic flow chart activity, individual whiteboard reflections and group sharing, and lab group whiteboard presentations, in addition to daily lab participation grades given by the instructor and peer evaluations of student lab groups.

Despite attempts to isolate and control variables present, this study is limited by its design since direct comparisons were made between the different, but related topics of photosynthesis and cellular respiration. In addition to the varying content, the cellular respiration unit was taught after the photosynthesis unit making it possible that conceptual knowledge was transferred from the latter to the former. Therefore, conclusions made from the data collected are tentative since the combination of variables present makes it likely that a synergistic effect was taking place.

Timeline/Unit Outlines

Tables 1.1 and 1.2 overviews of the curriculum and instruction provided to students during the photosynthesis and cellular respiration units. These units took place during the middle of the school year, specifically December and January, after students were familiar with the topics of organization and taxonomy of life, cells and molecules, cell transport, and cell life cycles.

Table 1.1 Photosynthesis Unit Outline (* indicates new activies/labs)

Day/Date	Topic/ Curriculum Objective(s)	Warmup	Lesson
Day One 12/8/09	ATP & Energy (B2.5e)	Pg. 230, Skill Review #6	• Class Lecture/Discussion on ATP structure and energy (powerpoint) • Work time for Bioluminescence WS
Day Two 12/9/09	Introduction of Research/ PreSurvey/ Pretest	Pg. 228, Problem Solving Lab #1-2	• Introduction of Master's Thesis Research • Administered Pre-Survey and Photosynthesis Pre-test to students
12/10/09	No Class	N/A	ACT Plan test for all 10^{th} graders
Day Three 12/11/09	* Plant Pigment Chromato-graphy Lab (B2.5f; B1.1C; B1.1E)	N/A	• Discussion of plant pigments/absorbance spectrum graph/lab procedure (powerpoint)* • Completion of labs in groups of 2-3 (students chose groups)
Day Four 12/14/09	Photosynthesis Overview (B3.1A; B3.1B; B3.1C; B3.1f)	Why does a leaf on a tree appear green? Why do you see other colors in the Fall?	• Lecture/Discussion on Plant Pigments, Light Reactions & Calvin Cycle of Photosynthesis (powerpoint) • Work time for Photosynthesis WS
Day Five 12/15/09	Design Photosynthesis Inquiry Lab (B1.1h; B1.1f)	Photosyn-thesis Concept Map	• Introduce Photosynthesis Lab • Discuss step #1 & 2 as a class • Students choose groups and work on steps #3-6 • Monitor/assist groups as needed, teacher approval on all steps
Day Six 12/16/09	Photosynthesis Inquiry Lab (B1.1C; B1.1h; B1.1B; B1.2h)	Lab Pre-Survey	• Perform Photosynthesis Lab in groups • Monitor, assist as needed

Table 1.1 Continued

Day Seven 12/17/09	* Historical Perspective/Lab Recap and Lab Report Conclusions (B1.2h; B1.1E; B1.1B)	Define the following terms: xylem, phloem, stomata, transpiration	• Notes/Discussion on Historical Photosynthesis Experiments—(powerpoint)* • Lab groups report their results to the class orally • Discussion of how to write lab report conclusions*
Day Eight 12/18/09	Energy, Photosynthesis, Plants Review (B3.1D; B3.1e)	Problem Solving Lab 23-2, #1-4, pg. 639	• Discuss answers to Photosynthesis WS • Grade Photosynthesis Review
Day Nine 12/21/09	Photosynthesis Unit Test	N/A	• Students take PhotosynthesisUnit Test—Multiple Choice and Post-test Essay Questions

Table 1.2 Respiration Unit Outline (* indicates new activies/labs; ♦ indicates formative assessments)

Day/Date	Topic/ Curriculum Objeective(s)	Warmup	Lesson
Day One 1/4/10	*Intro to Cellular Respiration (B3.1B)	Free Topic	• Respiration Pretest • Cellular Respiration Information Article & Qs*
Day Two 1/5/10	*Potato Chip Demo/Cellular Respiration Modeling (B3.1B; B3.1C; B3.1e)	How is cellular respiration used in everyday life?	• Burning Potato Chip Demo* ♦ • Cellular Respiration Modeling with chemistry kits (glucose + oxygen → carbon dioxide + water)* ♦

Table 1.2 Continued

Day Three 1/6/10	Cellular Respiration—The Details (B2.5e; B2.5f; B3.1B; B3.1e)	Questions from previous day's demo: see lesson	Warmup:* ♦ 1. What happened to the potato chip? What happened to the water? Why? 2. What must happen to the food you eat before your cells can use the food's energy? 3. Explain how the process of burning is similar to cellular respiration; explain how it is different. 4. Write the chemical equation for respiration. Identify the reactants and products of this process. • Class Notes/Discussion on Cellular Respiration (powerpoint)
Day Four 1/7/10	*Cellular Respiration & Exercise Lab B1.1C; B1.1E; B3.1B)	Pg. 33 Understand-ing Main Ideas #1-5, & Thinking Critically #1	• Students complete Cellular Respiration & Exercise Lab in groups of 3-4* • Monitor and assist as needed
Day Five 1/8/10	*Lab Reflection/ Fermentation (B1.1B; B1.1E; B3.1B)	Pg. 255, # 1-10	• Individual whiteboard activity—concepts learned from yesterday's exercise lab, share ideas as a class* ♦ • Cellular Respiration Flowchart Activity* ♦ • Class Notes/Discussion on Fermentation (powerpoint)
Day Six 1/11/10	Design Fermentation Inquiry Lab (B1.1h; B1.1f)	Pg. 249 Assessing Knowledge & Skills, #1-4	• Introduce Fermentation Lab, discuss step #1& 2 as a class • Teacher selected groups, work on steps #3-6 • Monitor/assist groups as needed, teacher approval on all steps
Day Seven 1/12/10	Perform Fermentation Inquiry Lab (B1.1C; B1.1h; B1.1B; B1.2h)	What is an acid? What is a base? Describe the pH scale.	• Perform Fermentation Lab in groups • Monitor and assist as needed

Table 1.2 Continued

Day Eight 1/13/10	*Lab Presentations/ Lab Report Conclusions (B1.2h; B1.1E; B1.1B)	Free Topic	• Students design lab result presentations of Fermentation Lab in groups on large whiteboards* ♦ • Each group presents to the class* ♦ • Discussion of expectations for lab report conclusions using critical thinking rubric, show examples of "good" and "bad" conclusions from photosynthesis lab*
Day Nine 1/14/10	Photosynthesis vs. Respiration/ Aerobic Respiration vs. Fermentation (B2.5e; b2.5f; B3.1B; B3.1C; B3.1D; B3.1e)	Why would human muscle cells contain more mitochondr-ia than skin cells?	• Venn Diagram Activity comparing Photosynthesis vs. Respiration and Aerobic Respiration vs. Fermentation • Share ideas on board as a class
Day Ten 1/15/10	External Respiratory System (B2.3d; B2.3f)	Respiratory System WS	• Peer evaluation of group members from Fermentation Lab* ♦ • Class Notes/Discussion on Human Respiratory System (powerpoint)
1/18/10	NO SCHOOL	N/A	In observance of MLK Day
Day Eleven (1/19/10)	Respiration Review	Pg. 255, Thinking Critically #3	• Individual whiteboard activity—3 concepts learned from the unit, share ideas as a class* ♦ • Grade Respiration Review
Day Twelve 1/20/10	Respiration Unit Test	N/A	• Students take Respiration Unit Test—Multiple Choice and Post-test Essay Questions

Explanation/Overview of Activities for Photosynthesis Unit

Plant Pigment Chromatography Lab (Appendix C)

The plant pigment chromatography lab required students to apply the technique of paper chromatography to separate individual plant pigments from spinach leaves. The various pigments found in plants absorb and reflect various colors of light, and are used for photosynthesis, to attract pollinators, to signal fruit ripeness, to serve as chemical defense, or to block UV radiation, for example. Pigments from fresh spinach leaves were transferred to chromatography paper using coins and the paper was placed into a solution containing a mixture of acetone and ether. The chromatography solution moved up the paper thus separating the pigments by kind and color. This lab contained a standard detailed procedure for students to follow as they performed the experiment and analyzed the results. It did not require the use of inquiry-based skills, but did necessitate that students use proper lab technique and care. Questions following the results section were used to evaluate student comprehension of plant pigments, and their respective colors and functions. Students were given the responsibility to select their own lab groups for this exercise.

This lab was successful and showed students that green plants such as spinach contain chlorophyll a and b, as well as carotene and xanthophylls, which were faint on the chromatographs and in some cases hard for students to visualize. Although most students did make the connection that the color observed is reflected by the pigment and the colors not observed are absorbed, approximately one-third of them were not able to accurately extend this knowledge to explain why the seasonal color change of deciduous trees is caused by various pigments in addition to chlorophyll within the leaves.

Photosynthesis Inquiry Lab (Appendix C).

This guided inquiry lab allowed students to develop and implement an experiment to test the effect of a chosen variable on the rate of photosynthesis in the aquatic plant *Elodea*. This was quantified by the rate of release of oxygen gas, which was compared under varying environmental conditions chosen by the students.

This activity began with students reflecting individually, and then as a class, the factors that affect the process of photosynthesis. Possible methods for measuring the rate of photosynthesis in *Elodea* were discussed. Students were asked to investigate how changes in the environment of *Elodea* could affect its rate of photosynthesis, by formulating hypotheses and conducting experiments that included identification of the independent variable, the dependent variable, the experimental group, the control group, the number of samples/trials, a materials list, a plan for data collection, and a step-by-step procedure. The instructor monitored the progress of groups along the way and required that students obtain "teacher initials" on their lab indicating approval before going on to the next step.

Students collected and recorded data in a table of their own design, and graphed the results. Most of the student groups seemed to be in a general rush to complete the lab, and did not seem very engaged with their procedures and data collection. Students were given the responsibility to select their own lab groups for this exercise. Each student group also shared the results of their experiment orally with the class following the completion of the lab, and students wrote a detailed conclusion based on their results. The instructor explained the requirements for a lab conclusion using the critical thinking rubric (Appendix E).

Other Activities

The other activities within the photosynthesis unit included primarily teacher-centered lecture and discussions regarding the topics of ATP and cellular energy, plant pigments, light-dependent & Calvin cycle reactions, and historical data from early photosynthesis experiments. In addition, various reading assignments, worksheets, concept maps, and warm-up questions were used during this instructional period (Table 1.1).

Explanation/Overview of Activities for Cellular Respiration Unit

Calorimetry Demonstration

A class discussion was started by asking students how much energy there is in a single potato chip. The purpose of this activity was to elicit interest among students and to determine what they already knew about the energy stored within food and how it could be released. The calorimetry demonstration consisted of using student volunteers to burn a large potato chip and measuring how much heat energy it released by raising the temperature of a small amount of water in a soda can attached to a ring stand, as referenced in Patro, 2008 (Table 1.2). A reconfigured paper clip was used to hold the potato chip on the base of the ring stand. The temperature of 20 ml of water was measured before and after burning of the potato chip.

Class discussion continued regarding energy containing molecules in a potato chip, digestion, absorption, enzymatic oxidation via cellular respiration of those carbohydrates and fats, energy transfer, and the production of ATP to be used for cellular work. Students were also asked to reflect on the calorimetry demo in writing. The connection of a real world event to the abstract nature of the chemical reactions of cellular respiration was crucial for student comprehension in this case.

Molecular Modeling of Cellular Respiration

This activity involved students using molecular modeling kits (wooden balls and sticks) to visualize the structures of glucose, oxygen, carbon dioxide, and water and the changes in atomic associations that occur during cellular respiration (modeled after Patro, 2008, Table 1.2). Students used the kits to build models of the molecules glucose and oxygen gas which represented the inputs of cellular respiration. Building glucose and oxygen was challenging for most students since they have limited knowledge of the structure of biological molecules and covalent bonding patterns. Despite having access to around twenty molecular modeling kits, there was not enough “carbon” atoms for every student pair to build a glucose molecule. Therefore, some students were asked to build diatomic oxygen gas instead. (In the future I would use an alternative modeling system in which each student pair could build one glucose and six oxygen molecules). One glucose molecule and six oxygen molecules were selected for deconstruction by the students and rearranged into the outputs of cellular respiration, namely carbon dioxide and water.

The students were able to see that the inputs were rearranged during the reactions of cellular respiration and formed six molecules of carbon dioxide and six molecules of water as products. As the students worked, the instructor was able to answer questions and offer support as needed. This activity allowed the students to explore the rearrangement of atoms during cellular respiration, essential for understanding this process. This activity concluded with a discussion about the energy stored within the chemical bonds of the glucose molecule, which is released as it is oxidized into smaller molecules; that released energy is utilized for the production of ATP within the mitochondria.

Cellular Respiration Flowchart Activity (Appendix C)

This kinesthetic student-centered activity was a model of cellular respiration. This activity allowed the instructor to interact one-on-one with each of the students and ensured that they were individually responsible for their own learning. This was a useful formative assessment since it allowed the instructor to determine where students were experiencing shortfalls in their understanding of the chemical reactions and overall results of cellular respiration. A major area of difficulty was the branch point between aerobic respiration and fermentation, and the fact that the presence or absence of oxygen controls how pyruvate will next be utilized in a facultative anaerobe.

Respiration and Exercise Lab (Appendix C)

This lab required students to test the effects of physical exertion on muscle activity, compared to resting values, as indicated by breathing rate, heart rate, and carbon dioxide production. Breathing rate was measured in breaths per minute, heart rate in beats per minute, and carbon dioxide in the time it takes Bromothymol blue to change color. This activity did not incorporate the use of inquiry based skills, but did require that students use proper lab technique and care. Detailed data tables, calculations, and questions following the results section were used to summatively evaluate student comprehension of the effect of exercise on the metabolic process of energy production in muscle cells.

During the execution of this lab, a daily participatory grade was assigned to each student based on their performance. This evaluation was based on their level of contribution to their group, their attentiveness and on-task behavior, and nature of their questions to the instructor. Students asking questions of the instructor that could reasonably have been answered by reading the lab procedure or concurring with their lab group received a deduction of points. Students were told by the instructor that non-trivial questions were encouraged and appreciated. The lab groups were assigned at random by the instructor instead of being chosen by students.

Many students were enthusiastic about this lab activity and collected their data with vigor and excitement; only a few students were apprehensive about using their own body as a test subject and perhaps may have been embarrassed to exercise in front of their peers. Following class discussion, the majority of students made the connection between an increased amount of physical exertion and an increase in the amount of cellular respiration occurring in muscle cells. This was evidenced by increased breathing rates, heart rates, and decreased time for the BTB solution to change from blue to yellow. Students realized that the more carbon dioxide you breathe into the BTB solution, the faster it will change color to yellow. Some students struggled with the completion of the data tables since breathing rate and heart rate were tested with multiple trials and average values were calculated.

At the conclusion of the lab, students used whiteboards to individually reflect on their learning experiences during the exercise and respiration lab. Each student wrote three ideas, trends, or concepts that they noticed during the completion of this lab that related to exercise and its effect on breathing rate, heart rate, or production of carbon dioxide. It was requested that their entries contain specific information about relationships and internal body processes and not just superficial data observations.

Each student shared one of their reflections during a subsequent group discussion in which no repeated information was allowed. Each student was required to contribute a unique idea to this sharing activity. Most students were engaged and offered their reflections eagerly to the class, although a minority of students experienced difficulty coming up with a unique idea that had not already been mentioned. This activity held each student accountable to the class as a whole for a contribution to the overall knowledge gained during the lab, and allowed the instructor to formatively assess each student's comprehension level. The class discussion allowed the instructor to ask specific guiding questions that helped students with a somewhat limited understanding of the concepts to gain a more thorough level of comprehension.

Fermentation Inquiry Lab (Appendix C)

This guided inquiry lab allowed students to design and implement an experiment to test the effect of a variable on the rate of fermentation in yeast. In this investigation the fermentation rates of yeast, quantified by the release of carbon dioxide gas, were compared under different environmental conditions chosen by the students. Students were assigned a daily participatory grade based on their performance throughout this lab just like for the Respiration and Exercise lab. This evaluation was based on their level of contribution to their group, their attentiveness and on-task behavior, and nature of their questions to the instructor. In addition, lab groups were assigned at random by the instructor instead of being chosen by students.

This procedural design of this lab offered lots of possibilities and allowed students the freedom to test variables that interested them. The lab commenced with observation, followed by a discussion of the factors that influence aerobic respiration and fermentation. Students were asked to investigate how changes in the environment of yeast cells could affect their rate of fermentation. The format for the execution of this lab mirrored that of the photosynthesis lab. Students conducted their experiments, collected and recorded data in a table of their own design, and graphed the results.

Many students were excited about getting to do “whatever they wanted”, and even incorporated additional techniques they had learned from the Exercise and Respiration lab such as the use of Bromothymol blue as an indicator of carbon dioxide production. A few lab groups were so interested in their experiment that they let it run past the normal class period and came back at intervals during the day to check on its progress. Other groups put forth minimal effort during the planning and execution of this lab activity. Students were also asked for the first time during this lab to complete peer evaluations of lab group members in which it was later found that they were open and honest about each other's attitudes, skills, and contributions (Appendix F).

Following the completion of the lab, each lab group made a poster and gave a presentation of their results on a whiteboard (as explained in Erekson, 2004). The posters contained a title, a short summary of the experimental procedure, a graphic representation of the data collected, and a conclusion about the effects of the chosen variable on the rate of fermentation. The presentations allowed for public communication of lab results between groups that tested different variables and/or utilized alternative quantitative methods for gathering data. The instructor could reflect on the depth of the knowledge that the students had gained and adjust instruction for the next phase which was the reflective process of conclusion writing, completed by each student, guided by the critical thinking rubric used in the photosynthesis inquiry lab.

In addition, students were shown sample conclusions written by their peers for the photosynthesis lab. These samples were discussed at length and analyzed for positive and negative qualities to model for the students expectations for this component of the cellular respiration lab assessment. Lab report conclusions were later evaluated using the critical thinking rubric and included in the data analysis for this study.

RESULTS AND EVALUATION

Student Survey Results (Appendix G)

The results of the pre-unit survey showed a sampling of student interests, preferences, and perceptions. Twenty five percent of students chose science as their favorite subject, while only 10% chose science as their least favorite subject. Typical grades in science classes were reported to be 33% "As" and 34% "Bs", while math grades were 37% "As" and 46% "Bs". Students perceived the most helpful part of science class with regard to learning to be labs (30%) and lecture/discussion (29%), and the least helpful part of science class to be homework (47%). When asked what their favorite part of science class was, a majority of students, (69%) reported labs. When studying for science class, most students listened to music (40%) or went to a quiet room in the house (39%). Students tended to ask other students in class (45%) or referred to class notes (32%) when experiencing difficulty in science class.

Although 72% of students agreed or strongly agreed that performing labs in science class helped them learn, this is compared to only 30% that stated labs were the most helpful component of science class, as previously stated. Fifty two percent of students agreed that tests and quizzes required that they learn concepts studied in the lab, while 33% of students were neutral regarding that statement. If students knew something in class or in the lab was going to be on a test or quiz, they would work harder to learn that concept; 84% agreed or strongly agreed. Finally, 43% of students plan to take more life science classes in high school, 95% of students plan to continue their education after graduating from high school, and 29% plan to have a career that is related to science. Overall, many students seemed to possess an favorable impression of science in general, and most preferred hands on labs as compared to other forms of instruction. Students also believed that completing labs aids their learning, and were motivated to learn if they know that assessments would test lab-based concepts.

The results of the lab survey displayed preferences of the students with regard to their learning experiences in the laboratory. Eighty four percent of students preferred to work in a lab group of three or four students, while 79% of students believed that they learn best in a group of three or four students. While working in the laboratory, 83% agreed or strongly agreed that they preferred to perform a lab in which they just follow the written procedure. Only 14% of students agreed that designing their own lab procedure was preferred, while 32% were neutral, and 54% disagreed or strongly disagreed. Many students (33%) were neutral when asked if designing their own lab procedure and performing their own experiment helped them to better understand science concepts, as compared to a traditional lab activity.

The results of the post survey that showed that the lab exercises helped them to learn. Seventy three percent agreed or strongly agreed; this result was almost identical to the previous surveys in which a total of 70% and 72% of students agreed or strongly agreed that learning was aided by lab activities. In addition, 72% agreed or strongly agreed that the lab exercises were enjoyable and stimulated their interest, while 68% agreed or strongly agreed that they were stimulated to think and/or want to learn more during the lab exercises. Many students also believed (agreed/strongly agreed) that their scientific reasoning and technical skills were improved as a result of the lab exercises, shown as 73% and 78% respectively.

Ninety one percent of students surveyed agreed or strongly agreed that they had positive interactions with the instructor during the lab exercises. Only 57% of students agreed or strongly agreed that they prefer to learn by doing hands-on activities, while 22% were only neutral on this topic. Students agreed or strongly agreed 72% of the time that they were more focused and on task during the lab exercises if they knew they was receiving a daily lab grade (participation points). Fifty eight percent of students agreed or strongly agreed that using white boards for sharing group lab results and conclusions as a class helped their understanding of lab concepts, while 35% were neutral on this topic. Similarly, 59% of students thought that using individual whiteboards for sharing ideas about labs helped them learn.

The compilation of responses from the surveys showed that student's attitudes were generally positive when asked about laboratory experiences in Biology. Although ambivalent about inquiry-based labs, many felt that lab exercises in general were worthwhile and recognized the value of reflection and sharing of ideas following the completion of lab procedures.

Photosynthesis Unit Results

This unit of instruction was presented to the students in a streamlined fashion without any extra activities or formative assessments, as compared to previous years. Information was presented primarily via teacher-centered lecture and notes format with traditional and inquiry-based laboratory exercises interspersed throughout. The data collected from this portion of the study included scores from identical pre and post assessments containing open ended essay questions scored with a specific rubric (Appendix E). Each of the nine identical questions on the pretest and posttest was scored using a 0-3 scale, with 0 indicating an unanswered question, 1 characterized by an inaccurate or vague answer, 2 showing some accuracy of detail, and 3 displaying a complete and accurate answer. The photosynthesis pretest/posttest rubric contains detailed expectations and examples of student responses awarded each score 1-3 (Appendix E).

Furthermore, an overall average score was calculated for each student on both the pretest and the posttest (Appendix G). These averages were compared in Figure 1.1, and show that 29 of 31 students improved their average score between administration of the pretest and posttest. One student's average score decreased between assessments (student #10), and one student's average score did not change (student #12). Both #10 and #12 were female students earning above average grades in my Biology class, so it is unclear as to why their scores did not improve. The average differences in comprehension made by students between the pretest and the posttest were compared using a paired student's t-test. The overall average score on the photosynthesis pretest was 1.5, while the average on the posttest was 2.1 for the 31 students in the sample. The results of the t-test show that there was a statistically significant difference between the means of the two samples of scores (P= 3.65E-11, for a one-tailed t-test with 30 degrees of freedom).

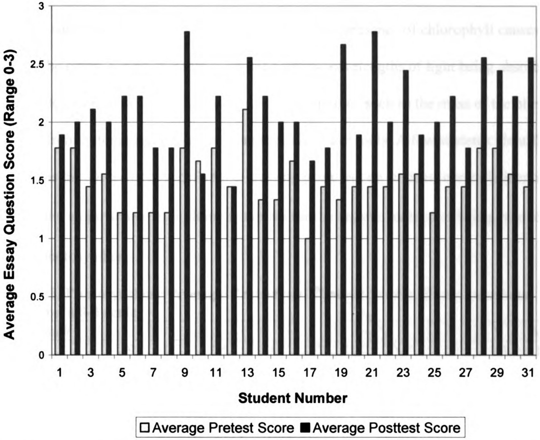

Figure 1.1. A comparison of average pretest and posttest scores for photosynthesis unit. The average score was 1.5/3 on the pretest and 2.1/3 on the posttest, overall. The difference between the means was statistically significant (P=3.65E-11, for a one-tailed t-test with 30 degrees of freedom).

A closer examination of the results revealed that students scored the lowest on pretest questions numbered 2, 4, 5, and 7 (Table 1.3). Questions 2 and 4 asked for the specific locations of photosynthesis and gas exchange within the plant. It is not surprising that students would be lacking details such as these prior to the instruction of the unit. Most students were able to ascertain that photosynthesis and gas exchange take place in the leaves of plants, but were not able to give any further details regarding the chloroplast or stomata structures or locations. Some students guessed that photosynthesis takes place in plant roots, revealing inaccurate prior knowledge. Question 5 asked why leaves appear green, while question 7 asked where the mass of a growing plant comes from. Many students were able to gather that the chloroplast or the presence of chlorophyll causes the plant to be green, but no students mentioned colors/wavelengths of light being absorbed or reflected. Question 7 revealed student misconceptions, such as the mass of the plant coming from nutrients and/or water from the soil and/or roots. A few students identified mitosis as the source of new cells for a growing plant, but no students correctly identified CO_2 as the major source of building materials for the organic molecules being produced during photosynthesis.

Table 1.3. Photosynthesis Average Pretest and Posttest Scores. Essay questions graded on a 0-3 scale.

Question #	1	2	3	4	5	6	7	8	9	Avg.
Pretest	1.9	1.2	2.6	1.1	1.0	1.7	1.1	1.7	1.3	1.5
Posttest	2.3	2.1	2.9	1.8	2.6	2.1	1.7	2.4	1.2	2.1
Improvement	0.4	0.9	0.3	0.7	1.6	0.4	0.6	0.7	-0.1	0.6

Furthermore, student scores on the posttest exhibited the highest levels of improvement on questions 2, 4, 5, and 8. Question 5 showed the highest level of improvement overall, but considering the fact that an entire lab was dedicated to photosynthetic pigments, this was not too surprising. One interesting result was that student scores decreased slightly from pretest to posttest for question number 9. This question asked that students design an experiment to test the rate of photosynthesis in a plant. This skill was practiced during the photosynthesis inquiry lab with *Elodea*, so it was unexpected that students would perform worse on the posttest. Other factors could have been at play here including the vagueness of the question on both tests, student motivation for a lengthy essay question, and lack of inquiry-based skills despite performing the *Elodea* lab.

In addition, responses to question 7 showed that some students came to a proper understanding of the origination of plant mass through photosynthesis, but many responses revealed the same misconceptions as before. Approximately one half of students correctly identified CO_2 as the source of atoms used for increases in plant mass. It is clear that additional instructional activities and formative assessment techniques need to be developed to aid student learning of this common photosynthesis misconception.

Cellular Respiration Unit Results

This unit of instruction was presented to the students in an alternative manner with various active learning activities and formative assessments. Some of the information was presented via teacher-centered lecture and notes format, while other portions incorporated student-centered exercises in which the instructor could interact with students one-on-one or with small groups. Traditional and inquiry-based laboratory exercises were conducted by students followed by oral and written reflection and group presentations using whiteboards. The data collected from this portion of the study were scored in a manner identical to that from the photosynthesis unit. The cellular respiration pretest/posttest rubric contains detailed expectations and examples of student responses awarded each score 1-3 (Appendix E).

Moreover, an overall average score was calculated for each student on both the pretest and the posttest (Appendix G). These averages were compared in Figure 1.2, and show that 30 of 31 students improved their average score between administration of the pretest and posttest. Only one student's average score decreased between assessments (#30) who was a male student often lacking motivation for tasks despite being very capable intellectually. The average differences in comprehension made by students between the pretest and the posttest were compared using a paired student's t-test. The overall average score on the cellular respiration pretest was 1.5, while the average on the posttest was 2.3 for the 31 students in the sample. The average score on the cellular respiration pretest was identical to the photosynthesis pretest, while the cellular respiration posttest average score was slightly higher than the photosynthesis posttest, 2.3 vs. 2.1, respectively. The results of the t-test show that there was a statistically significant difference between the means of the two samples of scores (P=1.64E-11, for a one-tailed t-test with 30 degrees of freedom).

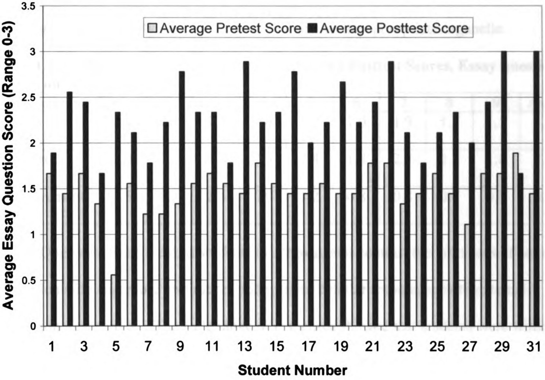

Figure 1.2. A comparison of average pretest and posttest scores for cellular respiration unit. The average score was 1.5/3 on the pretest and 2.3/3 on the posttest, overall. The difference between the means was statistically significant (P=1.64E-11, for a one-tailed t-test with 30 degrees of freedom).

Additionally, student scores on the cellular respiration pretest showed the lowest scores for questions 1, 3, 5, and 6. (Table 1.4). Question 1 asked that students state the purpose of cellular respiration, while question 3 asked for the specific location of this process in organisms. It was evident that many students guessed on question 1 since their answers contained the following inaccuracies regarding the purpose of cellular respiration: producing oxygen/food, cooling, breathing, excretion of waste, circulation of water, etc. A few students were able to state that cellular respiration is used to produce energy for the organism to survive, but no specifics were given to further develop those ideas.

Question 3 revealed that most students' prior knowledge about the location of cellular respiration was limited to saying that it occurs within cells or the lungs, although a couple of students did accurately identify the mitochondria as the appropriate organelle.

Table 1.4. Cellular Respiration Average Pretest and Posttest Scores. Essay questions graded on a 0-3 scale.

Question #	1	2	3	4	5	6	7	8	9	Avg.
Pretest	1.1	2.2	1.3	1.6	1.2	1.0	1.9	1.7	1.5	1.5
Posttest	2.4	2.3	2.7	2.5	2.4	1.8	2.7	2.2	1.8	2.3
Improvement	1.3	0.1	1.4	0.9	1.2	0.8	0.8	0.5	0.3	0.8

Questions 5 and 6 asked students to compare and contrast the processes of aerobic respiration with anaerobic respiration, and internal cellular respiration with external respiration, respectively. The wide range of responses showed that students were willing to take risks in their guessing on these tests, which made it easier to assess their level of understanding. For question 5, some students were able to state that aerobic respiration requires oxygen and anaerobic does not require oxygen, but many students gave inaccurate responses. Students responded that aerobic respiration happens in water, while anaerobic occurs in air, or that one process takes in energy and the other releases it. For question 6, most students stated that internal cellular respiration occurs within the body and/or cells, while external respiration occurs outside the body and/or cells, but no student was able to discuss that the processes occur within the mitochondria, lungs/respiratory system, and circulatory system.

Student responses on the posttest exhibited the highest levels of improvement on questions 1, 3, and 5. Most students were able to state that cellular respiration releases energy for organisms in question 1, but many responses were more specific, saying that food molecules are disassembled to produce energy in the form of ATP. A couple of students mentioned oxygen being involved in the process, but were unable to make any clear connections to its role in the process. For question 3, a majority of students correctly identified the mitochondria as the organelle that carries out cellular respiration, while only a small number of students incorrectly named the chloroplast, the lungs, or the stomach as the location for this process.

Student responses for question 5 were much more detailed and specific on the posttest comparing aerobic and anaerobic respiration; question 4 also showed a sizeable improvement of 0.9 over the pretest (comparing photosynthesis and cellular respiration). These improvements could be the result of orally reflecting on these questions in class using Venn diagrams to compare and contrast these processes. Lastly, question 9 deserves discussion because it directly relates to a common misconception about cellular respiration held by many students. This question was in some ways the inverse of question 7 on the photosynthesis pre/posttest, since it asked where the mass of a human goes when weight is lost. Students showed a small level of improvement on this question, but only two or three students accurately identified the loss of mass occurring from the breakdown of organic matter and release of CO_2 and H_2O from the body. Most students clung to misconceptions including mass turning into ATP or water that is excreted from the body as sweat. These central ideas continue to pose a challenge as students struggle to alter their knowledge bases away from misconceptions closer to accurate scientific understanding.

Comparison between Photosynthesis and Cellular Respiration Units

Potential differences in student learning gains between the two units were evaluated. The average improvement made between the pretest and the posttest was calculated for each student by subtracting the latter from the former (Appendix G). This calculation was performed for both the photosynthesis and cellular respiration sets of assessments to determine if one pedagogical methodology was more effective by these measures for increasing student comprehension.

The comparison of the average improvement for each student shows that 19 of 31 students made greater gains between the pretest and posttest for the cellular respiration unit (Figure 1.3). This graph also shows that 9 of 31 students showed increased improvement after the photosynthesis unit as opposed to the cellular respiration unit. In addition, three students (# 7, 24, & 28) demonstrated identical levels of improvement between units. The average improvements in comprehension made by students between the photosynthesis and cellular respiration units were compared using a paired student's t-test. The overall average improvement between the pretest and posttest for the photosynthesis unit was 0.62, while the average improvement on the cellular respiration unit was 0.81 for the 31 students in the sample. The results of the t-test show that there was a statistically significant difference between the means of the two samples of scores ($P=0.02$, for a one-tailed t-test with 30 degrees of freedom).

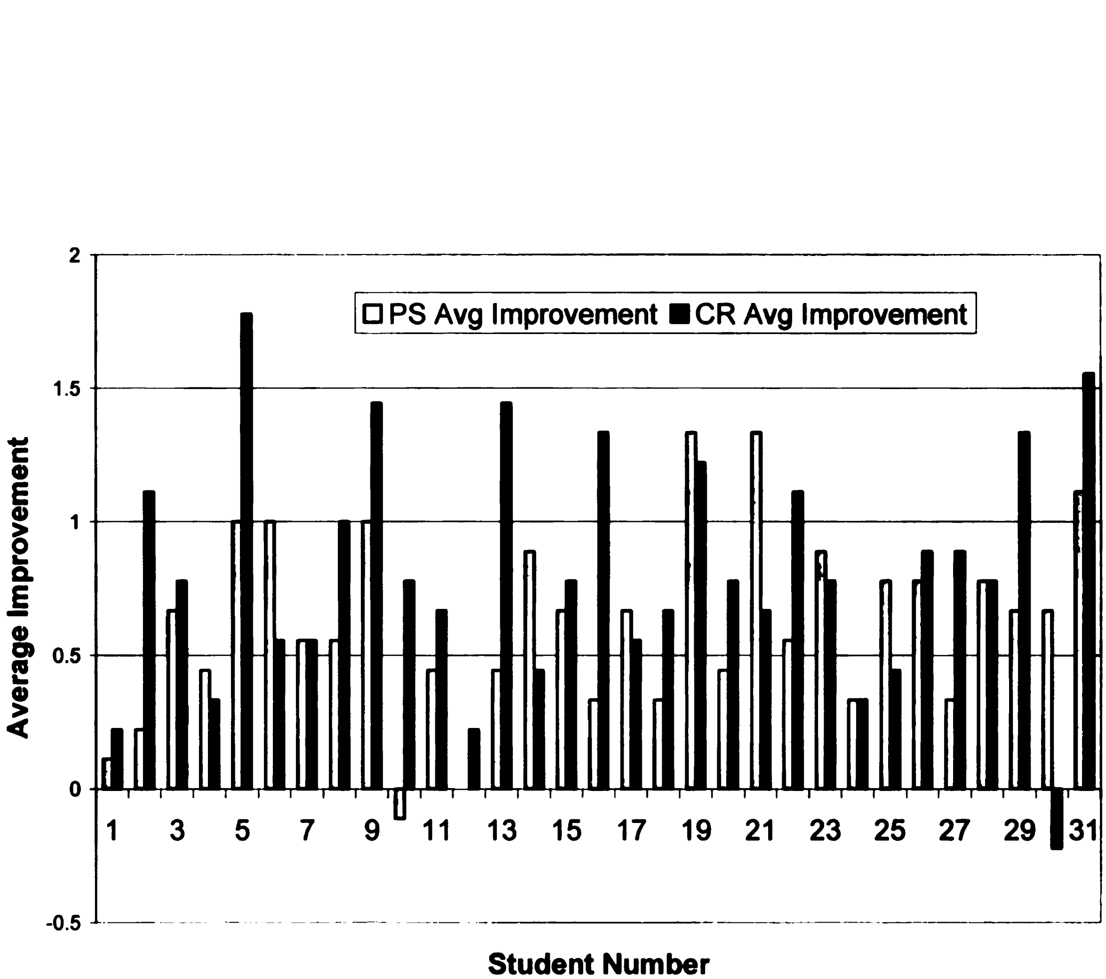

Figure 1.3. A comparison of average improvement between pretest and posttest for the photosynthesis and cellular respiration units. The average improvement was 0.62 for the photosynthesis unit and 0.81 for the cellular respiration unit. The difference between the means was statistically significant (P=0.02, for a one-tailed t-test with 30 degrees of freedom).

An additional measure of student learning gains was a comparison of lab report conclusions written after both the photosynthesis and cellular respiration inquiry labs. These conclusions were scored using the same rubric detailing the accurate use of critical thinking skills and reflection. Students were evaluated on the basis of four components: claim, evidence, reasoning, and reflection, with each section scored on a 0-5 scale for a total possible score of 20 (Appendix E). This rubric was designed to assess student abilities with lower and higher level cognitive skills as described in Bloom's taxonomy (Crowe, Dirks, and Wenderoth, 2008).

The data collected for these assessments (Figure 1.4) show that 21 of 24 students earned a higher score for the lab report conclusion written following the cellular respiration inquiry lab. Two students (#14 and #21 received identical score for both conclusions, and one student (#17) earned a higher score for the conclusion written for the photosynthesis inquiry lab. The scores earned by students on the photosynthesis and cellular respiration conclusions were compared using a paired student's t-test. The overall average score on the photosynthesis lab conclusion was 13/20, while the average on the cellular respiration lab conclusion was 15.3/20 for the 24 students in this sample. The results of the t-test show that there was a statistically significant difference between the means of the two samples of scores (P=7.29E-06, for a one-tailed t-test with 22 degrees of freedom). One possibility for this trend in the data could be that students were more familiar with the reflective process of writing for the second lab report conclusion (cellular respiration) and had gained understanding from the examples given in class.

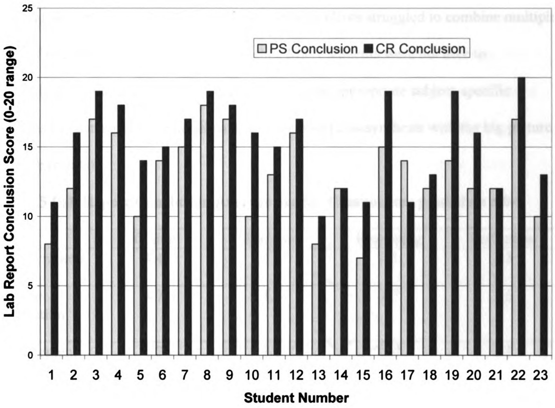

Figure 1.4. A comparison of lab report conclusions written by students after completing two inquiry-based laboratories. The average score was 13/20 for the photosynthesis unit and 15.3/20 for the cellular respiration unit. The difference between the means was statistically significant (P=7.29E-06, for a one-tailed t-test with 22 degrees of freedom).

A closer look at the conclusions written for the photosynthesis lab showed that students on average students scored highest on the Claim portion (4.4/5), and the lowest (2.1/5) on the Reasoning portion (Table 1.5). The first component, the Claim, was designed for students to demonstrate the lower-order cognitive skills (LOCS) of Bloom's taxonomy including comprehension and application, while the final three components, the Evidence, Reasoning, and Reflection, tested higher-order cognitive skills (HOCS) including analysis, synthesis, and evaluation, respectively. Therefore, it is reasonable that students scored well on the Claim since it only required a conclusive statement that answered the original question or hypothesis. The fact that scores were lowest for the reasoning section revealed lack of synthesis skills; students struggled to combine multiple pieces of information into coherent arguments. Many students were not able to effectively connect their claim with evidence by using appropriate subject-specific principles (i.e connecting the details of the process of photosynthesis with the big picture of the lab results).

Table 1.5 Lab Report Conclusion Average Scores. Components graded on a 0-5 scale.

	Claim	Evidence	Reasoning	Reflection
Photosynthesis Lab	4.4	3.2	2.1	3.3
Cellular Respiration Lab	4.7	4.3	2.7	3.6
Improvement	0.3	1.1	0.6	0.3

Analysis of the cellular respiration conclusions showed that students also scored the highest on the Claim portion, and made the highest level of improvement between the photosynthesis and cellular respiration labs on the Evidence section. This suggested an increased grasp in analysis skills; they were better able to support (or refute) their claim based on specific data and trends from the lab. A smaller level of improvement was made between the lab conclusions on the Reasoning portion displaying increased higher-order cognitive skills, such as the ability to carefully consider and evaluate information and data found in the lab. Overall, the data from the conclusions showed that gains were made between the photosynthesis and cellular respiration labs, but much practice is still necessary with regard to inquiry-based lab performance and the higher-order cognitive skills assessed therein.

DISCUSSION AND CONCLUSION

The instructional methodology used in this research study involved increasing the amount of continuous, formative assessment to gain a more thorough knowledge of student understanding as they perform hands-on, student-centered classroom activities and laboratory investigations. This form of assessment, rather than being used for assigning of grades, provides students with the chance to revise and improve their knowledge of course concepts and to witness their own progress. Teachers can then identify problems and pitfalls for students that can then be addressed; these problems may have not been visible without the assessments ((Bransford, Brown, and Cocking, 2000).

The goals of science education, as stated in the National Science Education Standards, encourage teachers to play a thoughtful, progressive role while facilitating inquiry-based instruction and assessing student understanding in a formative manner (NRC, 1996, 2000, 2001). It has been shown that active learning strategies (e.g. Ueckert and Gess-Newsome, 2008; Bransford, Brown, and Cocking, 2000) and inquiry-related labs (e.g. Wilke and Straits, 2005; Erekson, 2004), aid student learning in the science classroom and allow students to take responsibility for the work involved.

Science educators need to be mindful of and reflective on student learning as it progresses each day in the lab and classroom setting. The design, planning, and implementation of lessons in which students play an active role while interacting with content and have the opportunity to practice inquiry-based cognitive skills in small group and large group setting is essential (Ueckert and Gess-Newsome, 2008; Wilke and Straits, 2005). The ability to formatively assess the aforementioned processes, offer constructive feedback to students, and use these evaluations to inform and modify instruction is a critical feature of the work performed by effective science teachers (Peters, 2008; Straits and Wilke, 2002; Erekson, 2004; Carlson, Humphrey, and Reinhardt, 2003). Formative assessments should be ongoing in the classroom, during which “students’ thinking [is] visible to both teachers and students” and can “help both teachers and students monitor progress” (Bransford, Brown, and Cocking, 2000).

The importance of assessment cannot be understated; its role is pivotal is facilitating deep and meaningful learning of science content and laboratory process skills. Encouraging students to “think like scientists” while investigating natural phenomena fosters confidence and motivation for the task and helps to establish the discourse and interplay of ideas among students, and between students and teacher. Formative assessments herein can take the shape of feedback loops between teacher and student, as well as students performing self evaluations and peer evaluations. Teachers are able to actively engage with students regarding content, while also gaining a more thorough understanding of their progress during the learning process. Therefore, this study focused on the use of formative assessment during active learning to test its impact on student comprehension of cellular respiration and photosynthesis.

The methodology of this study allowed for similar units of instruction, photosynthesis and cellular respiration, to be evaluated on the basis of presence or absence of formative assessment techniques and active learning activities.
The variety of formative assessment techniques, such as class discussions, molecular modeling, use of whiteboards, and lab presentations, utilized in the experimental design did not themselves allow for quantitative results to be generated. Therefore, diagnostic

and summative assessments were used to test the effectiveness of active learning with formative assessments as a pedagogical methodology.

Diagnostic pretests were administered to students at the beginning of both the photosynthesis and cellular respiration units. Summative posttests were also given to students at the conclusion of each one. The first unit, photosynthesis, was taught using non-revised techniques and served as the control data set, while the second unit, cellular respiration, utilized an increased amount of formative assessment and active and/or inquiry based learning activities, and comprised the experimental data set. Comparisons were made of gains in student learning within units, and also between units.

Figure 1.1 shows that students made statistically significant learning gains during the photosynthesis unit which contained some student-centered, inquiry-based activities, but lacked formative assessments. Figure 1.2 shows data for the cellular respiration unit in which an increased amount of active learning activities and formative assessment opportunities were given to students. Student comprehension of subject specific content also increased in a statistically significant manner for this unit of instruction. It is logical that positive student progress was documented between pretest and posttest regardless of instructional/assessment method, but the question of whether the revised method provided an advantage over the usual one remained a valid question.

The results in Figure 1.3 compare the learning gains made between pretest and posttest for both the photosynthesis unit and the cellular respiration unit. While data analysis indicated that student learning increased under both sets of conditions (Figures 1.1 and 1.2; Tables 1.3 and 1.4), improvement was greater for the cellular respiration unit which was taught using increased levels of active learning and formative assessment

(Figure 1.3). The revised method employed during the cellular respiration unit displayed an increased level of improvement over the usual method utilized in the photosynthesis unit. Like Patro (2008) the results of this study exhibit students' increased mastery of the subject specific content of cellular respiration and its significance in the biosphere.

The results show that students more thoroughly internalized science concepts when exposed to activities and labs that required active, inquiry-based learning and ongoing interaction with their instructor through formative assessment. Focusing on a variety of formative assessments, while providing students with active and meaningful classroom activities and inquiry driven lab investigations, has a positive effect on the learning and comprehension of the biological concept of cellular respiration in the high school classroom. I plan to extend this methodology to other topics, such as photosynthesis, to better facilitate student learning.

When formative assessment becomes a daily practice in the classroom, its perception changes from a negative one to that of a useful, positive influence in which students recognize its value as a tool to increase their comprehension. Student-centered activities, such as molecular modeling, flowcharts, use of whiteboards, and student presentations, used during the cellular respiration unit, encourage increased communication in a public forum, and allow both students and teachers to be more reflective while helping to create a community of learners. These open lines of communication and discussion enable more transparency in the learning process and therefore an increased amount of formative assessment to take place.

The use of multiple modalities of student-centered instruction during the cellular respiration unit meant that students could directly interact with the material, manipulate models and schematics, reflect on their learning in writing, take part in a presentation, and contribute to a discussion about a demonstration, while interacting with and receiving specific feedback from the teacher. This approach utilized the main concepts behind the 5E approach (engage, explore, explain, elaborate, evaluate) as referenced in Patro (2008), but also relied heavily on formative assessment as a means of constantly evaluating student understanding as it developed in the classroom. The value of using formative assessment techniques to improve learning is well documented (Black and William, 1998; Carlson, Humphrey, and Reinhardt, 2003; Straits and Wilke, 2002; Peters, 2008; and Heady, 2000) and therefore should increasingly be utilized by science educators.

In addition, the methods used to assess student understanding were designed to foster student reflection both orally, through the use of whiteboard presentations of lab results, and in writing, using lab report conclusions. Erekson (2004) demonstrated the use of group presentations to communicate lab data as a means of formatively assessing his students' lab skills and comprehension. Like Erekson, this technique was used in this study, not as a grading tool, but an evaluative method to inform instruction and seemed to increase student comprehension. MacDonald and Dominguez (2009) stressed the importance of reflective thinking captured in student writing samples, while Berber-Jimenez, et al. (2008) stated that lab report conclusions communicate whether or not students have made connections between scientific concepts and empirical data. Instead of using the modified sentence completion task referenced in Berber-Jimenez, et al. (2008), this study required students to draft lab conclusions based on a critical thinking rubric designed to facilitate the higher-order cognitive skills of Bloom's taxonomy. The results (Figure 1.4 and Table 1.5) showed an increased skill set for the cellular respiration lab reports as compared to those written for the photosynthesis lab.

It is logical that more thoughtful instruction containing active, inquiry-based activities with ample amounts of formative assessment, feedback, and reflection would constitute better teaching and facilitate higher student achievement. However, this approach also requires more time to complete each unit in the classroom. Also, the comparison of the different conceptual topics of photosynthesis and cellular respiration makes it difficult to conclude that the trends in the data were based solely on the revised instructional and assessment techniques, and not on some other factors present.

The combinatorial effect on student learning of these revised strategies is exemplified in the results of this study, showing that it is fairly impossible to completely isolate variables while performing action research in education. It is likely that the effects of active learning, formative assessment, increased instructional time, and knowledge transfer from one subject to another were all playing a role. Overall, positive results were found with the new methodology during the cellular respiration unit. Although statistically significant results were found between both the photosynthesis pretest and posttest, and the cellular respiration pretest and posttest, the gains made by students were greater for the latter, as compared to the former.

Based on the trends in data found in this study, I plan to implement formative assessment techniques more thoroughly throughout my biology curriculum as a means to give continuous feedback to my students and to allow more thoughtful modification of instruction. Since collective understanding is much greater than that of individuals or single groups, I will also continue to utilize reflective laboratory activities such as whiteboard discussions and lab presentations to mirror how science is performed in the real world. These varied and diverse methods of instruction found in active, inquiry-based activities and labs are essential for “hands-on, minds-on” science and will remain at the forefront of education in the future.

APPENDIX A

Michigan Science Content Expectations (Curriculum Objectives)

Standard B1 INQUIRY, REFLECTION, AND SOCIAL IMPLICATIONS

- Statement B1.1 Scientific Inquiry

  B1.1B Evaluate the uncertainties or validity of scientific conclusions using an understanding of sources of measurement error, the challenges of controlling variables, accuracy of data analysis, logic of argument, logic of experimental design, and/or the dependence on underlying assumptions.

  B1.1C Conduct scientific investigations using appropriate tools and techniques (e.g., selecting an instrument that measures the desired quantity—length, volume, weight, time interval, temperature—with the appropriate level of precision).

  B1.1E Describe a reason for a given conclusion using evidence from an investigation.

  B1.1f Predict what would happen if the variables, methods, or timing of an investigation were changed.

  B1.1h Design and conduct a systematic scientific investigation that tests a hypothesis. Draw conclusions from data presented in charts or tables.

- Statement B1.2 Scientific Reflection and Social Implications

  B1.2h Describe the distinctions between scientific theories, laws, hypotheses, and observations.

Standard B2 ORGANIZATION AND DEVELOPMENT OF LIVING SYSTEMS

- Statement B2.3x Homeostasis

  B2.3d Identify the general functions of the major systems of the human body (digestion, respiration, reproduction, circulation, excretion, protection from disease, and movement, control, and coordination) and describe ways that these systems interact with each other.

  B2.3f Explain how human organ systems help maintain human health.

- Statement B2.5x Energy Transfer

  B2.5e Explain the interrelated nature of photosynthesis and cellular respiration in terms of ATP synthesis and degradation.

B2.5f Relate plant structures and functions to the process of photosynthesis and respiration.

Standard B3 INTERDEPENDENCE OF LIVING SYSTEMS AND THE ENVIRONMENT

Statement B3.1 Photosynthesis and Respiration

B3.1A Describe how organisms acquire energy directly or indirectly from sunlight.

B3.1B Illustrate and describe the energy conversions that occur during photosynthesis and respiration.

B3.1C Recognize the equations for photosynthesis and respiration and identify the reactants and products for both.

B3.1D Explain how living organisms gain and use mass through the processes of photosynthesis and respiration.

B3.1e Write the chemical equation for photosynthesis and cellular respiration and explain in words what they mean.

B3.1f Summarize the process of photosynthesis.

APPENDIX B

The Impact of Formative Assessment Techniques on the Instruction of the High School Biology Units of Photosynthesis and Cellular Respiration
Parental Consent and Student Assent Form

Dear Parents/Guardians and Students:

I am currently a graduate student in the Department of Science and Mathematics Education (DSME) at Michigan State University. My master's thesis research is focusing on the enhancement of student learning in the laboratory setting and connecting the knowledge and skills obtained therein to course concepts through authentic assessment techniques. The unit to be researched will include cellular metabolism, specifically the topics of energy capture and use within living organisms (photosynthesis and cellular respiration).

Data for my thesis will be collected from standard student work generated during the instruction of this unit and will include pre-tests, post-tests, quizzes, lab activities, lab write-ups, and surveys. I am requesting your permission to include your child's work as data in my study. Your child's confidentiality is a foremost concern and will be protected to the maximum extent allowable under the law. All data generated will remain confidential and in a secure location. Identities of students will not be presented with results at conferences or in write-ups. Research data will be stored with Merle Heidemann, my advisor at Michigan State University, for at least three years after the collection of the data and completion of the study.

Participation in this study may contribute to a better understanding of how active laboratory work and assessment of that work can enhance student comprehension of abstract biological concepts, such as photosynthesis and cellular respiration within organisms. Participation in this study is completely voluntary. Also, students who do participate will not be given any extra work to complete. Upon completion of instruction of the unit and after all grades have been assigned, I will de-identify all student work by removing names and then analyze this student work in my research. Students who do not participate in this study will not be penalized in any way. Whether students choose to participate or not will have no effect on their grades or evaluation. There are no known risks associated with participating in this study. You may request that your child's information not be included in my research at any time and this request will be honored.

If you will allow your child's data to be included in this study, please complete the attached form and return it to Mr. Pumford, Dean of Students, in the main office by February 28, 2010. All consent forms will be held in this secure location until the unit is complete and all student grades have been assigned.

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher(s): Responsible Researcher - Dr. Merle Heidemann at DSME, 118 N. Kedzie, Michigan State University, East Lansing, MI 48824, by phone at (517) 432-2152, or by email at heidema2@msu.edu. or the Secondary Researcher - Shanna Tury, shannatury@hartlandschools.us or by phone at (810) 626-2355.

If you have any questions or concerns regarding your role and rights as a research participant, or are dissatisfied at any time with any aspect of this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program by phone at (517) 355-2180, by fax at (517) 432-4503, or by email at irb@msu.edu, or regular mail at 202 Olds Hall, MSU, East Lansing, MI 48824.

Sincerely,

Shanna Tury
Biology Teacher
Hartland High School
shannatury@hartlandschools.us
810.626.2355

The Impact of Formative Assessment Techniques on the Instruction of the High School Biology Units of Photosynthesis and Cellular Respiration

Parental Consent and Student Assent Form
(For collection of master's thesis data by Shanna Tury)

Please fill out the following consent and assent information and return it to Mr. Pumford, Dean of Students, in the main office by February 28, 2010.

I voluntarily agree to allow ____________________________________ to participate in this research study. (print student name)

Data:

_____ I give Ms. Tury permission to use data generated from my child's work in biology class for this thesis project. All data from my child shall remain confidential.

_____ I do not wish to have my child's work used in this thesis project. I acknowledge that my child's work will be graded in the same manner regardless of their participation.

Pictures:

_____ I give Ms. Tury permission to use pictures of my child during her work on this thesis project. My child will not be identified in these mediums.

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

____ ____________________
(Parent/Guardian Signature) (Date)

I voluntarily agree to participate in this research study.

____ ____________________
(Student Signature) (Date)

APPENDIX C

PAPER CHROMATOGRAPHY SEPARATES PLANT PIGMENTS

Objectives:
1) Apply the technique of paper chromatography as a method for separating individual plant pigments from spinach.
2) Describe the application of this technique to the study of plant pigments and develop related testable questions.
3) Generate ideas about ways to improve the technique to yield better results.

INTRODUCTION TO PLANT PIGMENTS

A "**pigment**" is simply a molecule that absorbs and reflects light. Recall that white light actually consists of many colors – you may have learned "ROY G BIV" in high school science as a way to remember the colors of light that make up the white light of the "visible spectrum". Different pigments appear different colors because they have differing abilities to absorb and reflect various colors of light. The broad array of colors found in plant tissues such as leaves, flowers, and fruits, can be accounted for by the presence of literally thousands of different kinds of plant pigments.

Through plant breeding and horticultural practices, humans have manipulated plants' pigment producing capabilities to serve our own desires. News was made recently when a *true* blue rose cultivar was successfully created in Japan. In nature, color is an important attribute of plants that serves to attract pollinators to receptive flowers and signal fruit ripeness to seed dispersers. In some instances, colors may also serve to warn potential predators of poisonous or toxic substances contained in plant tissues.

Color-producing pigments have other important roles in plants beyond regulating interactions with animals. **Chlorophyll** is a pigment that reflects green light, but absorbs red and blue wavelengths and is critical for the light reactions of photosynthesis. **Flavonoids** are an important class of plant pigments that block ultraviolet (UV) radiation that can damage cell proteins and DNA. Many flavonoids, including **anthocyanins** (a subcategory of flavonoids) have a role in the chemical defense of plants as they are toxic to many herbivores and pathogens – especially insects and fungi.

As you may know from the popular media, there is currently a substantial research effort in place to explore the potential health benefits of plant pigments to humans. In popular literature, these plant-based compounds are often collectively referred to as "phytochemicals"; most are also pigments. Flavonoids, anthocyanins, and **carotenoids** are just some of the categories of plant pigments known to have antioxidant properties. "**Antioxidant**" is a general term used to describe any substance that has the ability to neutralize "**free radicals**" which cause cellular damage by removing electrons from surrounding molecules. Many lines of research suggest that consuming a diet rich in plant pigments may slow the process of cellular aging and reduce the risks of some types of disease, such as cancer, heart disease, and stroke. Cosmetic companies are even jumping on the "antioxidant bandwagon" by adding seductive blends of antioxidant-rich "botanical extracts" to their shampoos, makeups, and lotions in the hopes of prolonging our youthful glow!

A few categories of pigments are listed below along with their characteristic range of colors.

Pigment Type	**Colors**
Anthocyanins (subclass of flavonoids)	blue/purple/red
Anthoxanthins (subclass of flavonoids)	yellow – ivory
Betacyanins	yellow - red/purple
Carotenoids	yellow – red
Chlorophylls	greens
Xanthophylls (a subclass of carotenoids)	ivory – yellow

Some plant pigments you may be familiar with that are of current interest in nutritional and pharmaceutical research are listed below, though there are <u>many</u> more!

Pigment	**Color**	**Found in**
anthocyanins	blue/purple/red	berries, grapes, red peppers, beets, eggplant, plums
beta-carotene	orange/yellow	carrots, pumpkin, sweet potatoes, citrus, papaya, melon, squash
curcumin	yellow	Turmeric
Lutein	yellow/orange	kale, broccoli, spinach
lycopene	red	Tomatoes, watermelon, red grapefruits
zeaxanthin	yellow	Corn

Procedure

1. Obtain one piece of chromatography paper and a beaker with chromatography solvent (ether/acetone) in it.
2. Draw a line with a pencil about 1cm up from the bottom edge of the paper and another about 1cm from the top edge.
3. Place a spinach leaf over the bottom line drawn on your filter paper.
4. Roll the edge of a quarter over the leaf following the line on your filter paper. Repeat 4 times, using different parts of the leaf for each application. This should leave a dark green line over your pencil line on the filter paper.
5. Place your chromatography strip into the beaker with solvent in it. Make sure that the paper does not touch the sides of the beaker and that the solvent is not higher than the pigment streak on your paper.
6. When the solvent reaches the top line of your paper (about 10 minutes), remove the paper from the beaker and lay it on the lab station to dry.

Results

Tape your chromatograph to this paper. Label each of the visible color bands with the appropriate pigment.

Chlorophyll – green

Carotenoids – yellow (carotene); pale yellow (xanthophylls)

Anthocyanins – red if cell is acidic, blue if basic (found in red cabbage, works as a pH indicator)

Betacyanins – red (less common)

Analysis

1. Which pigments were you able to identify?

   ____

   ____

2. What colors of light will each band absorb? What colors will each band reflect? (Remember that you see the color that is reflected.)

   ____

   ____

   ____

   ____

3. Judging from the darkness of the pigment bands on your chromatograph, which pigment would you say is most abundant in spinach leaves?

   ____

4. Many leaves change color in the autumn. How is it possible for this color change to occur? Base your answer on your knowledge of pigments present in leaves. (HINT: Chlorophylls are broken down in the autumn when day length begins to shorten and temperatures decrease.)

   ____

   ____

   ____

   ____

   ____

   ____

Name ____ Date _________ Hr ________

EXPERIMENTAL DESIGN—PHOTOSYNTHESIS IN THE AQUATIC PLANT *ELODEA*

Introduction

Photosynthesis is the metabolic process used by many autotrophic organisms to capture light energy and convert it to chemical energy in the form of carbohydrate molecules. The actual energy-capturing molecule is chlorophyll, and generally organisms possessing this green pigment are called plants. Although numerous intermediary reactions are involved, the overall photosynthetic reaction is simple. Carbon dioxide combines with the hydrogen from water yielding a carbohydrate, glucose, and oxygen.

Before you conduct the experiment, you must have the first five steps approved by your teacher. This sheet will help you design a quality experiment. ☺ You will write a formal lab conclusion after conducting your experiment.

Step 1. Initial thoughts/Observations: What factors influence photosynthesis? How could the rate of photosynthesis be measured in an aquatic plant such as *Elodea*? List some possible variables that could be changed in the environment of the aquatic plant *Elodea* that could have an effect on its rate of photosynthesis.	**Teacher Approval/ Comments**
Step 2. Determine the specific problem you wish to investigate. How do changes in the environment of the aquatic plant *Elodea* affect its rate of photosynthesis?	
Step 3. Write down your hypothesis as a statement. Be specific and use IF/THEN format.	

Step 4. Design the experiment—Write out a step-by-step plan for your experiment. Detail each of the following: Independent Variable: Dependent Variable: Experimental Group: Control Group: Number of Samples/Trials: Plan for Data Collection: Step-by-Step Procedure:	**Teacher Approval/ Comments**
Step 5. List the materials (with quantities) you need to conduct your experiment. Materials: Quantities Needed:	**Teacher Approval/ Comments**

Step 6. Conduct the experiment and collect data.

Organize your data in the form of a table below (be sure to include a title):

Organize your data in the form of a graph below (be sure to include a title):

Step 7. Write a detailed conclusion according to the instructions given by Ms. Tury.

Cellular Respiration Flowchart Activity

Objective: To show cellular respiration visually.

Directions:

1. Pull the cellular respiration steps or molecule pieces out of the baggie.
2. With your partner arrange them into a flowchart that shows what happens in cellular respiration.
3. Copy that flowchart onto your own paper.
4. Answer the questions in complete sentences.
5. Turn your paper in.

Questions:

1. What does cellular respiration do?
2. What 2 things go into cellular respiration?
3. What molecule is stored energy for the cell?
4. What are all of the products of cellular respiration?
5. What part of cellular respiration uses oxygen?

Glycolysis

Kreb's Cycle
And Electron
Transport Chain

Fermentation

Aerobic Respiration
(Oxygen Present)

Fermentation
(No Oxygen)
Present)

Glucose
($C_6H_{12}O_6$)

6 Water (H_2O)

Alcohol and CO_2
Or Lactic Acid

6 Carbon Dioxide
(CO_2)

2 Pyruvate
(Pyruvic Acid)

2 ATP

38 ATP

6 Oxygen (O_2)

Name ______________________________________ Date ____________ Hr ______

Effects of Exercise on Cellular Respiration

I. Purpose. To observe the effects of exercise on breathing rate, heart rate, and cellular respiration.

II. Introduction. Cellular respiration (*see chemical reaction below*) is a chemical reaction that occurs in your muscle cells to create energy needed to contract the muscles. Cellular respiration requires oxygen (which is breathed in) and creates carbon dioxide (which is breathed out).

$$\mathbf{C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + ATP\ (energy)}$$

This lab will address the question, "Does cellular respiration occur at a faster rate during exercise?" You will measure 3 different indicators of muscle activity: breathing rate, heart rate, carbon dioxide production. You will measure these indicators at rest (with no exercise) and after 1 and 2 minutes of exercise. Breathing rate is measured in breaths per minute, heart rate in beats per minute, and carbon dioxide in the time it takes bromothymol blue to change color. Carbon dioxide production can be measured by breathing through a straw into a solution of BTB. Bromothymol blue (BTB) is an acid indicator; when it reacts with acid it turns from blue to yellow. When carbon dioxide reacts with water, a weak acid (carbonic acid) is formed (*see chemical reaction below*). The more carbon dioxide you breathe into the BTB solution, the faster it will change color to yellow.

$$\mathbf{6\ CO_2 + 6\ H_2O \rightarrow 6\ HCO_3 + 6\ H^+}$$

III. Materials. Read through the procedure and make a list of materials that you will need for this lab below.

IV. Procedure.

1. Use a graduated cylinder to measure out 20ml of distilled water and pour it into a small beaker. Use a dropper to add 4 drops of bromothymol blue to make a BTB solution. Using a straw, exhale into the BTB solution. (CAUTION: Do not inhale the solution!) Time how long it takes for the blue solution to turn yellow. Record the time in **Table 1**. Wash out the beaker and refill it with 20 ml distilled water and 4 drops of BTB.
2. Measure your breathing rate and heart rate. Count the number of breaths (1 breath = inhale & exhale) you take in one minute. Record this number in **Table 2.** Repeat this 2 more times. Average the 3 trials to get your average breathing rate. Record this in **Table 2**.
3. While you calculate your breathing rate, have your partner take your pulse. Count the number of beats in 30 seconds and multiply that number by 2. Record your heart beat in **Table 3**. Repeat this 2 more times. Average the 3 trials to get your average heart rate. Record this in **Table 3**.

4. Calculate your breathing rate, heart rate, and carbon dioxide production after 1 minute of exercise.
   Exercise for exactly 1 minute by doing "step aerobics" on your chair. Please be careful! Immediately after 1 minute of exercise, exhale through the straw into the BTB solution and time how long it takes for the BTB to turn yellow. Record this in **Table 1**. Then quickly calculate your breathing and heart rates as you did before. You only need to do this once. Record these values in **Tables 2 & 3**.
5. *Remake your BTB solution.*
6. Exercise as you did before, but for 2 continuous minutes. Immediately exhale through the straw into the BTB solution and time how long it takes for the BTB to turn yellow. Record this in **Table 1**. Then quickly calculate your breathing and heart rates as you did before. You only need to do this once. Record these values in **Tables 2 & 3**.
7. Next, repeat the entire procedure for your lab partner. Record data from 2 other subjects and calculate averages where indicated in the data tables.

V. Data & Results.

Table 1. Carbon Dioxide Production (time it takes BTB to change color)

Exercise	**1**	**2**	**3**	**4**	**Average**
No exercise					
1 minute					
2 minutes					

Table 2. Breathing Rate (breaths/minute)

Exercise	**1**	**2**	**3**	**4**	**Average**
Resting (Trial 1)					
Resting (Trial 2)					
Resting (Trial 3)					
Exercise (1 minute)					
Exercise (2 minutes)					

Table 3. Heart Rate (beats/minute)

Exercise	1	2	3	4	Average
Resting (Trial 1)					
Resting (Trial 2)					
Resting (Trial 3)					
Exercise (1 minute)					
Exercise (2 minutes)					

1. Make a line graph of your breathing rate in relation to exercise. On the X-axis, plot the amount of exercise (0, 1, 2 minutes). On the Y-axis, plot the breathing rate (breaths/min). Plot the data for each of the 4 subjects AND the averages. Use a different color for each subject and the average. (You should have 5 lines on your graph.)

2. Make a similar graph for heart rate. (You should have 5 lines on your graph.)

VI. Analysis & Conclusions. Answer the following questions **in complete sentences.**

1. What can you conclude about the effect of exercise on heart rate? Why is this so? What do your muscles need during exercise that the blood brings?

2. What can you conclude about the effect of exercise on breathing rate? Why is this so? What cellular process is involved? Explain.

3. What can you conclude about the effect of exercise on the amount of carbon dioxide that is present in your exhaled breath? Why is this so? What cellular process is involved? Explain.

4. The lines on your graphs probably varied from one subject to another. Discuss **3 reasons** that may have caused differences in the data.

Name ____ Date __________ Hr ________

EXPERIMENTAL DESIGN—FERMENTATION
INVESTIGATION OF YEAST CELL RESPIRATION

Introduction

All living things require energy, and therefore respire. During respiration, food, usually in the form of glucose, is "burned" or oxidized. Yeast cells (single-celled fungi) obtain their energy through fermentation. During fermentation, carbohydrates are broken down into carbon dioxide and ethyl alcohol and some energy in the form of ATP is produced. The rate at which carbon dioxide is released during respiration indicates the rate at which ATP is being synthesized. In this investigation, you will compare the fermentation rates of yeast in an experiment of your own design.

Before you conduct the experiment, you must have the first five steps approved by your teacher. This sheet will help you design a quality experiment. ☺ You will write a formal lab conclusion after conducting your experiment.

	Teacher Approval/ Comments
Step 1. Initial thoughts/Observations: What factors influence aerobic respiration? What factors influence anaerobic respiration (fermentation)? How could the rate of fermentation be measured in a fungus such as yeast? List some possible variables that could be changed in the environment of the yeast cells that could have an effect on their rate of fermentation.	
Step 2. Determine the specific problem you wish to investigate. How do changes in the environment of yeast cells affect their rate of fermentation?	
Step 3. Write down your hypothesis as a statement. Be specific and use IF/THEN format.	

Step 4. Design the experiment—Write out a step-by-step plan for your experiment. Detail each of the following: <u>Independent Variable</u>: <u>Dependent Variable</u>: <u>Experimental Group</u>: <u>Control Group</u>: <u>Number of Samples/Trials</u>: <u>Plan for Data Collection</u>: <u>Step-by-Step Procedure</u>:	**Teacher Approval/ Comments**
Step 5. List the materials (with quantities) you need to conduct your experiment. <u>Materials</u>: <u>Quantities</u> <u>Needed</u>:	**Teacher Approval/ Comments**

Step 6. Conduct the experiment and collect data.

Organize your data in the form of a table below (be sure to include a title):

Organize your data in the form of a graph below (be sure to include a title):

Step 7. Write a detailed conclusion according to the instructions given by Ms. Tury.

APPENDIX D

BIOLOGY A Name_____________________________Hr__
Photosynthesis Pretest

Please answer the following questions in complete sentences to the best of your ability.

1. What is the purpose of photosynthesis in plants? Be specific.

2. Where in a plant does photosynthesis take place? Explain.

3. Which gases does a plant exchange with the atmosphere during photosynthesis? Which ones are taken up, and which are given off?

4. Where in/on a plant does this gas exchange occur?

5. Why does a leaf on a plant appear green?

6. Explain why animals, such as humans, need photosynthesis.

7. When a plant grows larger in size, where does the mass of the plant come from? Explain.

8. Name some environmental factors that could affect the rate of photosynthesis in a plant. Predict the effect of each one.

9. Design a sample experiment to test the rate of photosynthesis in a plant.

BIOLOGY A | Name_________________________ Hr__

Cellular Respiration Pretest

Please answer the following questions in complete sentences to the best of your ability.

1. What is the purpose of cellular respiration in living things?

2. What types of organisms perform cellular respiration?

3. Where in an organism does cellular respiration take place? Be specific.

4. Compare and contrast the processes of photosynthesis and cellular respiration. (list similarities and differences)

5. Compare and contrast the processes of aerobic respiration and anaerobic respiration. (list similarities and differences)

6. Compare and contrast internal cellular respiration with external respiration (i.e. breathing). (list similarities and differences)

7. A student conducted an experiment by placing a fish in a bowl of water and observing. After several days, the fish died. Next, the student placed a fish and a plant in a bowl of water and put it near a window. After several days, both the fish and the plant were healthy. Explain these observations.

8. Plants perform photosynthesis in the presence of light. Do they also perform cellular respiration? Explain your reasoning.

9. Suppose you have a friend who lost weight. The kilograms of material, which had previously been part of his or her body, must have gone somewhere. Where did they go?

APPENDIX E

Table 1.6 Photosynthesis Pretest and Posttest Rubric (3 point scale)

	1	2	3
1. What is the purpose of photosynthesis in plants? Be specific.	Vague, inaccurate	Some detail (makes sugar, useable energy, food for plant)	Accurate description with examples (energy from sunlight converted to carbs, sugar, glucose used for energy or building materials)
2. Where in a plant does photosynthesis take place? Explain.	Vague, inaccurate (leaves, stem, chlorophyll, plant cells, roots)	Some detail (chloroplast, leaves with explanation)	Accurate description (inside chloroplast within leaves, light reactions—thylakoid membranes, Calvin Cycle—stroma)
3. Which gases does a plant exchange with the atmosphere during photosynthesis? Which ones are taken up, and which are given off?	Vague, inaccurate (CO_2 or O_2 no direction; neither correct: CO_2 out OR O_2 in; N_2, C_2, H_2O)	Some detail (one correct: CO_2 in OR O_2 out)	Accurate description (both correct: CO_2 in AND O_2 out)
4. Where in/on a plant does this gas exchange occur?	Vague, inaccurate (cells, roots, leaves)	Some detail (stomata, pores)	Accurate description (stomata on underside of leaves)
5. Why does a leaf on a plant appear green?	Vague, inaccurate (pigment, chloroplast, chlorophyll)	Some detail (leaves reflect green light)	Accurate description (chlorophyll, chloroplast pigment reflects green light, absorbs all other colors)
6. Explain why animals, such as humans, need photosynthesis.	Vague, inaccurate (answered “no”; no details)	Some detail (food for energy OR O_2 to breathe with explanation)	Accurate description (both correct or one with detailed explanation: source of O_2 to breathe, provides food used for energy in animals

Table 1.6 Continued

7. When a plant grows larger in size, where does the mass of the plant come from? Explain.	Vague, inaccurate (water, ground, stem, leaves, nutrients)	Some detail (cell division, mitosis; products of photosynthesis, sugar made)	Accurate description (CO_2 from atmosphere is used to build carbs)
8. Name some environmental factors that could affect the rate of photosynthesis in a plant. Predict the effect of each one.	Vague, inaccurate (1, 2, or 3 factors but lacking explanation; 1 factor with effect)	Some detail (2 factors with effects)	Accurate description (3 factors with effects)
9. Design a sample experiment to test the rate of photosynthesis in a plant.	Vague, inaccurate (contains 1 of the following: hypothesis, procedure summary, independent/ dependent variable, control/experi-mental group)	Some detail (contains 2 of the following: hypothesis, procedure summary, independent/ dependent variable, control/experi-mental group)	Accurate description (contains 3 of the following: hypothesis, procedure summary, independent/depende nt variable, control/experimental group)

Table 1.7 Cellular Respiration Pretest and Posttest Rubric (3 point scale)

	1	2	3
1. What is the purpose of cellular respiration in living things?	Vague, inaccurate (breathing, gas exchanges, i.e. CO_2, O_2)	Some detail (make ATP, energy)	Accurate description (breaks down food, fuel, glucose to supply energy, ATP to cells for life processes)
2. What types of organisms perform cellular respiration?	Vague, inaccurate (plants do not; only animals; only heterotrophs)	Some detail (only some organisms; only multicellular, only eukaryotic, only humans, animals)	Accurate description (all organisms, i.e. plants, animals, humans etc.)
3. Where in an organism does cellular respiration take place? Be specific.	Vague, inaccurate (lungs, bronchi, trachea)	Some detail (cells, mitochondria AND choroplasts, mitochondria AND respiratory system)	Accurate description (within the mitochondria inside cells)
4. Compare and contrast the processes of photosynthesis and cellular respiration. (list similarities and differences)	Vague, inaccurate (1 of the following with/without explanations: C.R.—all living things, burns glucose, releases energy, O_2 in/CO_2 out, no sunlight. PS—only plants, algae, autotrophs, makes glucose, stores energy, O_2 out/CO_2 in, requires sunlight)	Some detail (2 of the following with explanations: C.R.—all living things, burns glucose, releases energy, O_2 in/CO_2 out, no sunlight. PS—only plants, algae, autotrophs, makes glucose, stores energy, O_2 out/CO_2 in, requires sunlight)	Accurate description (3 of the following with explanations: C.R.—all living things, burns glucose, releases energy, O_2 in/CO_2 out, no sunlight. PS—only plants, algae, autotrophs, makes glucose, stores energy, O_2 out/CO_2 in, requires sunlight)

Table 1.7 Continued

5. Compare and contrast the processes of aerobic respiration and anaerobic respiration. (list similarities and differences)	Vague, inaccurate (0-1 of the following without explanation: both make energy for cells, both break down food. Aerobic—requires O_2, produces more ATP (38), details about particular stages. Anaerobic—absence of O_2, produces less ATP (2), only certain organisms/cell types.	Some detail (1 of the following with explanation: both make energy for cells, both break down food. Aerobic—requires O_2, produces more ATP (38), details about particular stages. Anaerobic—absence of O_2, produces less ATP (2), only certain organisms/cell types.	Accurate description (2 of the following with explanation: both make energy for cells, both break down food. Aerobic—requires O_2, produces more ATP (38), details about particular stages. Anaerobic—absence of O_2, produces less ATP (2), only certain organisms/cell types.
6. Compare and contrast internal cellular respiration with external respiration (i.e. breathing). (list similarities and differences)	Vague, inaccurate (internal—inside body, external—outside body)	Some detail (1 of the following with explanation: O_2 in/CO_2 out; cellular respiration within mitochondria (food → ATP), external respiration involves lungs (gas exchange))	Accurate description (2 of the following with explanation: O_2 in/CO_2 out; cellular respiration within mitochondria (food → ATP), external respiration involves lungs (gas exchange))

Table 1.7 Continued

7. A student conducted an experiment by placing a fish in a bowl of water and observing. After several days, the fish died. Next, the student placed a fish and a plant in a bowl of water and put it near a window. After several days, both the fish and the plant were healthy. Explain these observations.	Vague, inaccurate (fish uses CO_2, etc.)	Some detail (1 of the following with/without explanation: plant is food for fish, fish receives O_2 from plant, plant receives CO_2 from fish, plant needs energy from sunlight, etc.)	Accurate description (Sunlight provides energy for photosynthesis in the plant which produces glucose and O_2 that the fish utilizes during cellular respiration to produce ATP and CO_2, and the cycle continues)
8. Plants perform photosynthesis in the presence of light. Do they also perform cellular respiration? Explain your reasoning.	Vague, inaccurate (No; No with incorrect explanation)	Some detail (Yes; Yes with wrong/vague explanation, i.e. C.R. requires sunlight, C.R. is part of PS, etc.)	Accurate description (Yes with correct explanation: plants create sugar during PS and use it/break it down during C.R. to create energy for plant processes; ATP is necessary for plant processes)
9. Suppose you have a friend who lost weight. The kilograms of material, which had previously been part of his or her body, must have gone somewhere. Where did they go?	Vague, inaccurate (lost in sweat, burned off/up, flushed out, fat converted to muscle, lost in urine, died off, dissolved)	Some detail (burned/broken down body weight to make energy during C.R.)	Accurate description (sugars and fats are broken down through cellular respiration and released as CO_2 (waste) which is breathed out in the air)

Table 1.8 Critical Thinking Lab Report Conclusion Rubric

<table>
<tr><th rowspan="2">Component</th><th colspan="6">Level</th></tr>
<tr><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td>Claim
A conclusion that answers the original question</td><td colspan="2">Makes an inaccurate claim or does not make a claim.</td><td colspan="2">Makes an accurate but incomplete claim.</td><td colspan="2">Makes an accurate and complete claim.</td></tr>
<tr><td>Evidence
Information that supports the claim. The information needs to be appropriate and sufficient to support the claim</td><td colspan="2">Provides no evidence or only provides inappropriate evidence (i.e. evidence that does not support the claim).</td><td colspan="2">Provides appropriate, but insufficient evidence to support the claim. May include some inappropriate evidence.</td><td colspan="2">Provides appropriate and sufficient evidence to support claim.</td></tr>
<tr><td>Reasoning
A justification that connects the claim and evidence. It shows why the information counts as evidence by using appropriate and sufficient subject-specific principles.</td><td colspan="2">Provides no reasoning or only provides reasoning that does not link evidence to claim.</td><td colspan="2">Provides reasoning that connects the claim and the evidence. Repeats the evidence and/or includes some subject-specific principles, but not sufficient.</td><td colspan="2">Provides reasoning that connects evidence to claim. Includes appropriate and sufficient subject specific principles.</td></tr>
<tr><td>Reflection
Involves careful evaluation and consideration of at least one or more of the following:
- alternative arguments
- quality of evidence
- assumptions
- interpretations
- assessments of importance</td><td colspan="2">Demonstrates no careful evaluation and consideration or reflections are inconsequential.</td><td colspan="2">Demonstrates some level of careful evaluation and consideration, but reflections are superficial and/or limited.</td><td colspan="2">Demonstrates the ability to carefully evaluate and consider information. Reflections are well articulated and varied.</td></tr>
</table>

APPENDIX F

BIOLOGY A **Name**________________________ **Hr**___

Photosynthesis & Respiration Pre-Unit Survey
Circle the answer that describes you best.

1. My favorite class/subject is:

   Math　English　Science　History/Social Studies
   Foreign Language　Other (please list) ______________________

2. My least favorite class/subject is:

   Math　English　Science　History/Social Studies
   Foreign Language　Other (please list) ______________________

3. My typical grade in math classes is:

   A　B　C　D　E

4. My typical grade in science classes is:

   A　B　C　D　E

5. What do you feel is the **most helpful** part of science class with regard to learning?
   Lecture/class discussion　In-class work
   Labs　Homework
   Quizzes/Tests　Other (please describe)______________

6. What do you feel is the **least helpful** part of science class with regard to learning?
   Lecture/class discussion　In-class work
   Labs　Homework
   Quizzes/Tests　Other (please describe)______________

7. What is your **favorite** part of science class?
   Lecture/class discussion　In-class work
   Labs　Homework
   Quizzes/Tests　Other (please describe)______________

8. When you have trouble in science class, which of the following do you do? (Please number the choices 1-6, with 1 as the activity you are most likely to do, and 6 as the activity you are least likely to do.)
   ___ read the textbook　___ talk to the teacher
   ___ ask other students in class　___ talk to a friend who had the class
   ___ look at class notes　___ other (please describe) _____________

9. When you study for science class, which of the following do you do? (Please number the choices 1-6, with 1 as the activity you are most likely to do, and 6 as the activity you are least likely to do.)

___ listen to music	___ turn on the TV for background noise
___ go to a quiet room in the house	___ go to the school library or public library
___ go to a friend's house	___ other (please describe) ____________

10. Performing labs in science class helps me learn. (circle one)

Strongly Agree   Agree   Neutral   Disagree   Strongly Disagree

11. Tests and quizzes require that I learn concepts studied in the lab. (circle one)

Strongly Agree   Agree   Neutral   Disagree   Strongly Disagree

12. If I knew something in class or in the lab was going to be on a test or quiz I would work harder to learn that concept.

Strongly Agree   Agree   Neutral   Disagree   Strongly Disagree

13. Do you plan to take any more life science classes in high school (Anatomy/Physiology, AP Biology)?

Yes   No   Not Sure

14. Do you plan to continue your education after graduating from Hartland High School?

Yes   No   Not Sure

15. If you answered yes to the previous question, please indicate where you might like to continue your education:

16. Do you plan to have a career that is related to science?

Yes   No   Not Sure

17. If you answered yes to the previous question, please list which careers you are considering:

BIOLOGY A Name____________________________Hr__
Lab Survey

Circle the answer that describes you best.

1. When I work in the lab, I prefer to work in a group of ____ students.

   2 3 4 5 6

2. When I work in the lab, I believe I learn best in a group of ____ students.

   2 3 4 5 6

3. I think that doing labs in Biology class helps me to learn science concepts.

   Strongly Agree Agree Neutral Disagree Strongly Disagree

4. When I work in the lab, I prefer to perform a lab in which I just follow the written procedure.

   Strongly Agree Agree Neutral Disagree Strongly Disagree

5. When I work in the lab, I prefer to perform a lab in which I design my own procedure.

   Strongly Agree Agree Neutral Disagree Strongly Disagree

6. I think that designing my own lab procedure and performing my own experiment helps me to better understand science concepts, as compared to a traditional lab.

   Strongly Agree Agree Neutral Disagree Strongly Disagree

BIOLOGY Post-Survey **Name**________________________**Hr**___

Circle the ONE answer that describes you best.

1. The lab exercises helped me to learn.

   Strongly Agree Agree Neutral Disagree Strongly Disagree

2. The lab exercises were enjoyable and stimulated my interest.

   Strongly Agree Agree Neutral Disagree Strongly Disagree

3. I was stimulated to think and/or want to learn more during the lab exercises.

   Strongly Agree Agree Neutral Disagree Strongly Disagree

4. The lab exercises improved my technical skills as a scientist (technique, use of equipment, etc.).

   Strongly Agree Agree Neutral Disagree Strongly Disagree

5. The lab exercises improved my scientific reasoning (thinking) skills.

   Strongly Agree Agree Neutral Disagree Strongly Disagree

6. Tests and quizzes required that I learn concepts studied in the lab.

   Strongly Agree Agree Neutral Disagree Strongly Disagree

7. If I knew something in class or in the lab was going to be on a test or quiz I would work harder to learn that concept.

   Strongly Agree Agree Neutral Disagree Strongly Disagree

8. I had positive interactions with Ms. Tury during the lab exercises.

   Strongly Agree Agree Neutral Disagree Strongly Disagree

9. I prefer to learn by doing hands-on activities (labs, building molecules, group work, simulations) instead of lecture and notes format.

   Strongly Agree Agree Neutral Disagree Strongly Disagree

10. I was more focused and on task during the lab exercises if I knew I was receiving a daily lab grade (participation points).

    Strongly Agree   Agree   Neutral   Disagree   Strongly Disagree

11. Using white boards for sharing group lab results and conclusions as a class helped my understanding of lab concepts.

    Strongly Agree   Agree   Neutral   Disagree   Strongly Disagree

12. Using whiteboards individually for sharing ideas about labs helped me learn.

    Strongly Agree   Agree   Neutral   Disagree   Strongly Disagree

Peer Lab Group Evaluation Forms

Directions: In the space below, honestly evaluate the work of other students in your group by answering yes or no and by using a scale from 1 to 3, 1 being poor, 2 being average, 3 being above average.

Evaluator's Name:________________________________ Date:____________

Group Member 1:________________________

1. Did this group member complete his/her assigned tasks for the group? Yes No
2. How would you rate the quality of this person's work? 1 2 3
3. How would you rate the timeliness of the completion of the work? 1 2 3
4. How would you rate the accuracy of the work? 1 2 3
5. Overall, how would you rank this group member's performance in the group?1 2 3
6. Would you want to work with this person again? Yes No
   Explain why in the space below.

Group Member 2:________________________

1. Did this group member complete his/her assigned tasks for the group? Yes No
2. How would you rate the quality of this person's work? 1 2 3
3. How would you rate the timeliness of the completion of the work? 1 2 3
4. How would you rate the accuracy of the work? 1 2 3
5. Overall, how would you rank this group member's performance in the group?1 2 3
6. Would you want to work with this person again? Yes No
   Explain why in the space below.

Group Member 3:________________________

1. Did this group member complete his/her assigned tasks for the group? Yes No
2. How would you rate the quality of this person's work? 1 2 3
3. How would you rate the timeliness of the completion of the work? 1 2 3
4. How would you rate the accuracy of the work? 1 2 3
5. Overall, how would you rank this group member's performance in the group?1 2 3
6. Would you want to work with this person again? Yes No
   Explain why in the space below.

Group Member 4:________________________

1. Did this group member complete his/her assigned tasks for the group? Yes No
2. How would you rate the quality of this person's work? 1 2 3
3. How would you rate the timeliness of the completion of the work? 1 2 3
4. How would you rate the accuracy of the work? 1 2 3
5. Overall, how would you rank this group member's performance in the group?1 2 3
6. Would you want to work with this person again? Yes No
   Explain why in the space below.

APPENDIX G

BIOLOGY A Photosynthesis & Respiration Pre-Unit Survey RESULTS

1. My favorite class/subject is:
   Math—21%
   English—13%
   Science—25%
   History/Social Studies—15%
   Foreign Language—9%
   Other—17%

2. My least favorite class/subject is:
   Math—27%
   English—17%
   Science—10%
   History/Social Studies—26%
   Foreign Language—16%
   Other—4%

3. My typical grade in math classes is:
   A—37%
   B—46%
   C—15%
   D—2%
   E—0%

4. My typical grade in science classes is:
   A—33%
   B—34%
   C—25%
   D—7%
   E—1%

5. What do you feel is the **most helpful** part of science class with regard to learning?
   Lecture/class discussion—29%
   In-class work—22%
   Labs—30%
   Homework—2%
   Quizzes/Tests—1%
   Other—16%

6. What do you feel is the **least helpful** part of science class with regard to learning?
   Lecture/class discussion—15%
   In-class work—7%
   Labs—11%
   Homework—47%
   Quizzes/Tests—19%
   Other—1%

7. What is your **favorite** part of science class?
   Lecture/class discussion—19%
   In-class work—9%
   Labs—69%
   Homework—0%
   Quizzes/Tests—1%
   Other—2%

8. When you have trouble in science class, which of the following do you do?
   Read the textbook—9%
   Talk to the teacher—8%
   Ask other students in class—45%
   Talk to a friend who had the class—1%
   Look at class notes—32%
   Other—5%

9. When you study for science class, which of the following do you do?
   Listen to music—40%
   Turn on the TV for background noise—7%
   Go to a quiet room in the house—39%
   Go to the school library or public library—1%
   Go to a friend's house—4%
   Other—9%

10. Performing labs in science class helps me learn. (circle one)
    Strongly Agree—30%
    Agree—42%
    Neutral—18%
    Disagree—5%
    Strongly Disagree—5%

11. Tests and quizzes require that I learn concepts studied in the lab. (circle one)

    Strongly Agree—6%
    Agree—52%
    Neutral—33%
    Disagree—9%
    Strongly Disagree—0%

12. If I knew something in class or in the lab was going to be on a test or quiz I would work harder to learn that concept.

    Strongly Agree—37%
    Agree—47%
    Neutral—10%
    Disagree—6%
    Strongly Disagree—0%

13. Do you plan to take any more life science classes in high school (Anatomy/Physiology, AP Biology)?

    Yes—43%
    No—19%
    Not Sure—38%

14. Do you plan to continue your education after graduating from Hartland High School?

    Yes—95%
    No—1%
    Not Sure—4%

15. If you answered yes to the previous question, please indicate where you might like to continue your education:

    Most popular answers:

    Central Michigan University
    Grand Valley State University
    Eastern Michigan University
    Michigan Technological University
    University of Michigan
    Michigan State University

16. Do you plan to have a career that is related to science?

    Yes—29%
    No—38%
    Not Sure—33%

17. If you answered yes to the previous question, please list which careers you are considering:

    Most popular answers:

    Nursing
    Medical Doctor
    Neuroscientist
    Meteorologist
    Marine Biologist
    Sports Medicine
    Engineer

BIOLOGY A Lab Survey RESULTS

1. When I work in the lab, I prefer to work in a group of ____ students.
   - 2 students—11%
   - 3 students—34%
   - **4 students—50%**
   - 5 students—4%
   - 6 students—1%

2. When I work in the lab, I believe I learn best in a group of ____ students.
   - 2 students—16%
   - 3 students—36%
   - **4 students—43%**
   - 5 students—4%
   - 6 students—1%

3. I think that doing labs in Biology class helps me to learn science concepts.
   - Strongly Agree—26%
   - **Agree—44%**
   - Neutral—20%
   - Disagree—7%
   - Strongly Disagree—3%

4. When I work in the lab, I prefer to perform a lab in which I just follow the written procedure.
   - Strongly Agree—31%
   - **Agree—52%**
   - Neutral—14%
   - Disagree—2%
   - Strongly Disagree—1%

5. When I work in the lab, I prefer to perform a lab in which I design my own procedure.
   - Strongly Agree—0%
   - Agree—14%
   - **Neutral—32%**
   - **Disagree—32%**
   - Strongly Disagree—22%

6. I think that designing my own lab procedure and performing my own experiment helps me to better understand science concepts, as compared to a traditional lab.
   - Strongly Agree—1%
   - Agree—24%
   - **Neutral—33%**
   - Disagree—23%
   - Strongly Disagree—19%

BIOLOGY Post-Survey RESULTS

1. The lab exercises helped me to learn.
   Strongly Agree—21%
   Agree—52%
   Neutral—21%
   Disagree—6%
   Strongly Disagree—0%

2. The lab exercises were enjoyable and stimulated my interest.
   Strongly Agree—28%
   Agree—44%
   Neutral—24%
   Disagree—4%
   Strongly Disagree—0%

3. I was stimulated to think and/or want to learn more during the lab exercises.
   Strongly Agree—9%
   Agree—59%
   Neutral—22%
   Disagree—10%
   Strongly Disagree—0%

4. The lab exercises improved my technical skills as a scientist (technique, use of equipment, etc.).
   Strongly Agree—28%
   Agree—50%
   Neutral—16%
   Disagree—6%
   Strongly Disagree—0%

5. The lab exercises improved my scientific reasoning (thinking) skills.
   Strongly Agree—11%
   Agree—62%
   Neutral—22%
   Disagree—5%
   Strongly Disagree—0%

6. Tests and quizzes required that I learn concepts studied in the lab.
   Strongly Agree—15%
   Agree—48%
   Neutral—28%
   Disagree—8%
   Strongly Disagree—1%

7. If I knew something in class or in the lab was going to be on a test or quiz I would work harder to learn that concept.
   Strongly Agree—34%
   Agree—47%
   Neutral—13%
   Disagree—5%
   Strongly Disagree—1%

8. I had positive interactions with Ms. Tury during the lab exercises.
   Strongly Agree—41%
   Agree—50%
   Neutral—6%
   Disagree—3%
   Strongly Disagree—0%

9. I prefer to learn by doing hands-on activities (labs, building molecules, group work, simulations) instead of lecture and notes format.
   Strongly Agree—36%
   Agree—21%
   Neutral—22%
   Disagree—6%
   Strongly Disagree—15%

10. I was more focused and on task during the lab exercises if I knew I was receiving a daily lab grade (participation points).
   Strongly Agree—20%
   Agree—52%
   Neutral—16%
   Disagree—12%
   Strongly Disagree—0%

11. Using white boards for sharing group lab results and conclusions as a class helped my understanding of lab concepts.
   Strongly Agree—20%
   Agree—38%
   Neutral—35%
   Disagree—5%
   Strongly Disagree—2%

12. Using whiteboards individually for sharing ideas about labs helped me learn.
   Strongly Agree—13%
   Agree—46%
   Neutral—28%
   Disagree—8%
   Strongly Disagree—5%

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