Using the BioDatamation strategy to learn introductory college biology: value-added effects on selected students' conceptual understanding and conceptual integration of the processes of photosynthesis and celluar respiration

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USING THE BIODATAMATION™ STRATEGY TO LEARN INTRODUCTORY COLLEGE BIOLOGY: VALUE-ADDED EFFECTS ON SELECTED STUDENTS’ CONCEPTUAL UNDERSTANDING AND CONCEPTUAL INTEGRATION OF THE PROCESSES OF PHOTOSYNTHESIS AND CELLULAR RESPIRATION

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College
In partial fulfillment of the Requirements for the degree of Doctor of Philosophy

in

The Department of Curriculum and Instruction

by

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The purpose of this exploratory research was to study how students learn photosynthesis and cellular respiration and to determine the value added to the student's learning by each of the three technology-scaffolded learning strategy components (animated concept presentations and WebQuest-style activities, data collection, and student-constructed animations) of the BioDatamation™ (BDM) Program. BDM learning strategies utilized the Theory of Interacting Visual Fields™ (TIVF) (Reuter & Wandersee, 2002a, 2002b; 2003a, 2003b) which holds that meaningful knowledge is hierarchically constructed using the past, present, and future visual fields, with visual metacognitive components that are derived from the principles of Visual Behavior (Jones, 1995), Human Constructivist Theory (Mintzes & Wandersee, 1998a), and Visual Information Design Theory (Tufte, 1990, 1997, 2001). Student alternative conceptions of photosynthesis and cellular respiration were determined by the item analysis of 263,267 Biology Advanced Placement Examinations and were used to develop the BDM instructional strategy and interview questions. The subjects were 24 undergraduate students of high and low biology prior knowledge enrolled in an introductory-level General Biology course at a major research university in the Deep South. Fifteen participants received BDM instruction which included original and innovative learning materials and laboratories in 6 phases; 8 of the 15 participants were the subject of in depth, extended individual analysis. The other 9 participants received traditional, non-BDM instruction. Interviews which included participants’ creation of concept maps and visual field diagrams were conducted after each phase. Various content analyses, including Chi's Verbal Analysis and quantitizing/qualitizing were used for data analysis. The total value added to integrative knowledge during BDM instruction with the three visual fields was an average increase of 56% for cellular respiration and 62% increase for photosynthesis.
knowledge, improved long-term memory of concepts, and enhanced biological literacy to the multidimensional level, as determined by the BSCS literacy model. WebQuest-style activities and data collection provided for animated prior knowledge in the past visual field, and detailed content knowledge construction in the present visual field. During student construction of animated presentations, layering required participants to think by rearranging words and images for improved hierarchical organization of knowledge with real-life applications.
INTRODUCTION

Photosynthesis and cellular respiration are basic concepts in biology, but students across the world have difficulty learning these concepts. There needs to be reform in biology education because present instruction is not meeting the needs of most students. The BioDatamation™ (BDM) learning strategy components described here are offered as a possible solution to the current problems. BDM is an integrated instructional technology. Its strategy of scaffolded learning utilizes visual fields, memory theory, and animation to help students construct meaningful conceptual understanding of an integrated view of photosynthesis and cellular respiration. The effectiveness of BDM is analyzed in this exploratory research project.

Rationale

Difficulties with Learning Photosynthesis and Cellular Respiration

Students have difficulty understanding photosynthesis and cellular respiration, yet these concepts are basic to the understanding of many other biology concepts. “The breadth and complexity of biology, the interconnectedness of the knowledge at many different levels, and the invisible nature of many key processes make biology a particularly difficult subject to teach and to learn” (Wandersee, Fisher, & Moody, 2000, p. 30). In response to the difficulties of teaching and learning biology, BDM was developed. Although the current study is specific to problems with learning photosynthesis and cellular respiration, it may ultimately be useful in solving important problems with biology education in general. BDM is designed to address these problems. The current problems encountered in biology education and how BDM appears to have the potential to help remedy some of these problems is explained in the following section.
Need for Change in Instruction

*Bio 2010: Transforming Undergraduate Education for Future Research Biologists*

(National Research Council [NRC], 2003) notes that, over the last two decades, there have been significant changes in how biological research is conducted and shared. Unlike research, undergraduate biology education has changed little.

The ways in which most future research biologists are educated are geared to the biology of the past, rather than to the biology of the future. Like research in the life sciences, undergraduate education must be transformed to prepare students effectively for the biology that lies ahead. Life science majors must acquire a much stronger foundation in the physical sciences (chemistry and physics) and mathematics than they get now. Connections between biology and the other scientific disciplines need to be developed and reinforced so that interdisciplinary thinking and work becomes second nature. (NRC, 2003, p. 1)

The report described the need of undergraduates to gain "scientific knowledge, practice with experimental design, quantitative abilities, and communication skills" (NRC, 2003, p. 2) to successfully undertake careers in research after graduation. The Committee indicated that interdisciplinary coursework is beneficial for all students. The Committee recommended that faculties utilize teaching approaches that help students learn these skills and offer exciting courses, which will draw more students to enroll in biology courses, and thus increase the number and quality of students who would consider entering the biomedical field. The report also emphasizes the need for making concepts relevant to students' lives and surroundings, helping students understand where a specific research topic fits into the big picture.

BDM is designed to provide exciting strategies centered on real-world situations that increase student knowledge with integrated animations, to practice combining experimental
designs with digital data collection that utilizes computer technology, and to enhance quantitative mathematical analysis and communication skills with student-created animated Microsoft® PowerPoint® 2003 presentations.

**BDM Strategy Addresses Problems**

The Committee also recognized the importance of recent research on education that focuses on the ways that students are taught and the way they learn the concepts being taught. The Committee referred to the National Research Council’s Report, *How People Learn: Brain, Mind, Experience, and School* (NRC, 2000), written by a committee that included cognitive scientists, psychologists, and experts in research on education. The major findings of *How People Learn*, coupled with descriptions of how BDM addresses these critical findings, follow.

1. Students come to the classroom with preconceptions about the world they live in and, if these initial conceptions are not considered, they may fail to understand the new concepts. BDM is based upon both the alternative conceptions determined from results of the Biology Advanced Placement Exam and a set of studies on photosynthesis and cellular respiration-related student alternative conceptions.

2. A deep foundation of factual knowledge, an understanding of these facts within a contextual framework, and coherent organization of knowledge in ways that facilitate retrieval and application helps students to develop confidence doing inquiry activities. BDM utilizes heuristics such as hierarchical concept maps, Visual Field Perception Map Heuristic™, and animated layered diagrams to accomplish this goal. Also, BDM employs real-world problems and digital data collection to enhance ongoing activities.

3. Students need to have learning goals and a way to monitor their progress in accomplishing them, which is a metacognitive approach to learning. BDM has a set of activities
that identify the goals and utilize assessment tools like concept maps and a Visual Field Perception Map Heuristic™ to track their progress.

**BDM Learning Components are Congruent with Bio 2010 Recommendations**

All the BDM learning components are compatible with the recommended new curriculum in *Bio 2010* (NRC, 2003) described below.

1. Photosynthesis and cellular respiration are central themes of biology. "Living things are far from equilibrium. They utilize energy, largely derived from photosynthesis, which is stored in high-energy bonds or ionic concentration gradients. The release of this energy is coupled to thermodynamically unfavorable reactions to drive biological processes" (NRC, 2003, p. 32).

2. The students should be able to use computers to acquire, process, and graph data. Specifically, students need to use different types of graphic representations for visualizing and displaying data and models for conceptual understanding. Further, they should understand the process of abstracting certain aspects of reality to include the simplifications of reality in the form of a model, understand quantitative principles (such as rate of change, use of consistent units which measure a system, etc.), understand that there are diverse methods to display data (e.g. know that simple bar graphs are often more than sufficient to visualize data) and see that new insights can be derived from nonlinear transformations.

3. Computers can be used to deal with most types of analyses and modeling. "Computer use is a fact of life for all modern life scientists. Exposure during the early days of their undergraduate careers will help life science students use current computer methods and learn how to exploit emerging computer technologies" (NRC, 2003, p. 46). The Committee also recommended that students have experience operating computer-controlled lab equipment and that they try to modify settings to fit the needs of the experiment (NRC, 2003). The Committee
used the example of a physics laboratory at Dickinson College that uses microcomputer-based laboratories. There are very few examples of research on the use of microcomputer-based labs outside of physics. More work needs to be done to help effectively use microcomputer-based labs in biology. BDM develops such technology and applies it to photosynthesis and cellular respiration.

The Committee recommended that undergraduates experience the excitement of research and stressed the importance of establishing this element of research in biology education at an early stage in the educational process (NRC, 2003). Traditional undergraduate laboratories are restricted by time, materials, and space while the microcomputer based labs of BDM allow students to do independent inquiry.

Finally, the Committee recognized the need for new creative classroom materials and stated that dedicated scientists and educators need to develop and assess these new materials (NRC, 2003). BDM strategies are examples of new materials developed to help address the need for biology education reform.

**Concerns about Photosynthesis and Cellular Respiration Education**

There is a widespread recognition of the need for biology reform in general. Moreover, there is a need specifically for improvements in teaching photosynthesis and cellular respiration. Table 1 is a summary of research that illustrates the grave and widespread concerns for teaching these concepts.

**Research Questions**

The main research question was: What is the value added by each of the three instructional technology-based curriculum components comprising the BioDatamation™ Strategy to selected introductory college biology students’ conceptual understanding and conceptual integration of the processes of photosynthesis and cellular respiration?
Table 1

Sample Comments Concerning Photosynthesis and Cellular Respiration Education

<table>
<thead>
<tr>
<th>Author</th>
<th>Comment or Quotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Griffard &amp; Wandersee, 2001, pp. 1039-1040)</td>
<td>“Wandersee (1983) conducted a nationwide cross-age survey using multiple-choice and open-ended questions to reveal an alternative conception common from elementary to university level that plants obtain their nutrition from the soil.”</td>
</tr>
<tr>
<td>(Wandersee, 1986, p. 592)</td>
<td>“Students seem to have difficulty understanding what it would be like to live without eating (being an autotroph) and appeared to project their own needs onto the plant.”</td>
</tr>
<tr>
<td>(Wandersee, 1986, p. 593)</td>
<td>“Students at all grade levels studied may hold misconceptions about photosynthesis which are similar to those which occurred and are documented in the history of science.”</td>
</tr>
<tr>
<td>(Waheed &amp; Lucas, 1992)</td>
<td>The study showed there was a lack of understanding of interrelationships of photosynthesis.</td>
</tr>
<tr>
<td>(Clements &amp; Jackson, 1998, p. 601)</td>
<td>“The blank stares of student faces whenever the words, ‘our topic for today is photosynthesis’ are uttered are disturbingly predictable.”</td>
</tr>
<tr>
<td>(Clements &amp; Jackson, 1998)</td>
<td>There needs to be active learning and there is a lack of understanding of photosynthesis.</td>
</tr>
<tr>
<td>(Clements &amp; Jackson, 1998, p. 601)</td>
<td>“This process of actively learning photosynthesis has been encouraged by the National Science Foundation as an improvement of pedagogy over standard didactic lecture.”</td>
</tr>
<tr>
<td>(Clements &amp; Jackson, 1998)</td>
<td>There is a lack of understanding of the importance of the topic of photosynthesis.</td>
</tr>
<tr>
<td>(McLaughlin, 2001)</td>
<td>The lecture has dominated the college classroom for many years. It is based on taking notes and memorizing but not on understanding the concepts.</td>
</tr>
<tr>
<td>(Ozay &amp; Oztas, 2003, p. 68)</td>
<td>“Results show that students have conflicting, and often incorrect ideas about photosynthesis, respiration, and energy flow in plants, even after teaching them. This suggests that students’ initial ideas are deep-rooted and difficult to change. By developing science curricula and helping teachers become more aware of student misconceptions, a different approach to teaching this subject area may help to reduce students’ difficulties in understanding the concept of photosynthesis.”</td>
</tr>
</tbody>
</table>
Additional subquestions were: What value does each of the following curriculum components add to students’ existing conceptual understanding and integration of the processes of photosynthesis and cellular respiration:

1. WebQuest–style activities (Dodge, 1997; Watson, 1999) that use stories, animations, and carefully designed, hands-on live biological experiences that together serve to introduce and exemplify the constructs of photosynthesis and cellular respiration;

2. Real-time inquiry data collection experiences (Brasell, 1990) using living systems and electronic sensors, with real-time display and analysis with calculators/computers;

3. Scientifically valid, student-constructed, real-world based, photosynthesis and cellular respiration animations using commercially available animation programs, and demonstration of these animation products to peers?

Research Vee Diagram

The proposed BDM research study is shown as a research Vee Diagram (Gowin, 1981) in Figure 1. The main questions are located at the top of the figure. The left side states the theoretical and conceptual basis of the research. The right side includes the methods that are used. The bottom of the vee describes the research activities that are employed, along with the knowledge and value claims of this research.

Flow Chart of Research

The Flow Chart of Research indicates the major activities of this research study and is Figure 2. This diagram shows the historical development of the study, temporal sequence of activities, and data that were collected during the research.

Brief Description of BioDatamation™ Strategy

The BDM strategy consists of the past, present, and future visual fields. The past visual field utilizes WebQuest-style lessons (Dodge, 1997), which create animated prior knowledge
Figure 1. Research Vee Diagram.

**THOERY**
- Human Constructivist Theory
- Jones' Visual Behavior Theory
- Tufte's Theory of Graphic Design
- Salo's INFOPRO Model
- Bang's Visual Symbolism Primer
- Piavio's Dual Coding Theory
- Neilsen's Theory of Perception
- Reuter and Wandorsee's Theory of Interacting
- Visual Field
- Mayer's Principles of Multimedia

**PRINCIPLES**
- Understanding is achieved when animated past, present and future visual fields are present and are shared in an activity.
- Understandable and meaningful graphics have simple designs.
- Meaningful learning involves use of prior knowledge and connection to new concepts.
- Clinical interviews allow for data collection and qualitative analysis.
- Mixed model theory allows for strong inference.

**CONCEPTS**
- Concepts of energy, chemical recycling in ecosystem, metabolic pathways of photosynthesis and respiration, membrane morphology and physiology.
- Concepts of encoding, retrieval, metacognitive awareness process, graphical analysis, digital data collection and annotated animation development.
- Clinical interviews, biological literacy analysis, co-constructed concept maps, Visual Field Perception Map Heuristic, conceptual framework, verbal analysis, animation analysis.
- Concept mapping of knowledge can identify critical junctures.
- Visual Field Perception Map Heuristic can identify visual learning.
- Graphic and animation clarity can reduce cognitive overload.

**RESEARCH QUESTIONS**
- What is the value added by each of the three instructional technology-based curriculum components, comprising the BioDataMan strategy, to selected introductory college biology students' conceptual understanding and conceptual integration of the processes of photosynthesis and cellular respiration?

**SUBQUESTIONS**
- What value does each of the following curriculum components add to students' existing conceptual understanding and integration of the processes of photosynthesis and respiration?
  1. WebQuest-style activities that use stories, animations and carefully designed, hands-on and live biological experiences that together serve to introduce and exemplify the constructs of photosynthesis and respiration?
  2. Real-time inquiry data collection experiences using living systems and electronic sensors, coupled with real-time display and analysis with calculators/computers?
  3. Scientifically valid, student-constructed, real-world based, photosynthesis and respiration animations and demonstration of these animation products to peers?

**VALUE CLAIMS**
- Instructional activities that utilize animations and the past, present, and future visual fields increase the construction of meaningful understanding of photosynthesis and cellular respiration. Biological literacy is an effective means of assessing student conceptual understanding and integration of the process of photosynthesis and cellular respiration.

**KNOWLEDGE CLAIMS**
- Three instructional scaffolded technology-based curriculum components, the past visual field (animated prior knowledge), present visual field (animated content knowledge and data collection), and future visual field (animated knowledge construction for problem solving) are all REQUIRED for conceptual understanding and integration of the processes of photosynthesis and cellular respiration.

**TRANSFORMATIONS**
- Description of the value added of each animated visual field to show changes.
  - Profile of a BDM learner using BDM knowledge indices.
  - Transcription and analysis of audiotapes of student interviews.
  - Analysis of videotapes of activities/interviews/think aloud sessions.
  - Analysis of object and term sorting.
  - Analysis of concept maps.
  - Analysis of Visual Field Perception Map Heuristic.
  - Analysis of field notes and journal entries.
  - Descriptive statistical analysis of BDM Profile surveys (data are quantized).
  - Analysis using Biological Literacy Rubric.
  - Analysis of specially annotated student created animations.
  - Analysis of chloroplast and mitochondria study kit model interpretations.
  - Biology AP Exam analysis to determine alternative conceptions (quantizing).

**EVENTS/OBJECTS**
- Create animated content (video and animated PowerPoints).
- Create photosynthesis and cellular respiration survey and chloroplast and mitochondria study models.
- Use technology to record student think aloud processes while they use animations (including data collection and graphing software).
- Identify biology professor with whom to work, interview about photosynthesis and cellular respiration.
- Make short recruitment presentation to their class.
- Identify a total of 24 students-15 with BDM (6 high and 9 low) for BDM Group and 8 without BDM (4 high and 4 low) for Comparison Group.
- Pre-interview preparation (Biology AP Exam analysis) and meet with all participants (phase 1).
- Meet with all participants for baseline interview (phase 2).
- Meet with all participants for knowledge after class presentation (phase 3).
- Give BDM instruction and conduct interviews after past, present, and future visual fields to BDM EAS and traditional instruction for Comparison Group (phases 4-10) and delayed interview (phase 11). Comparison Group and BDM OAS had one interview after 6 hr. instruction.
- At proper phases conduct: object and term sorting, interviews, co-constructed concept maps, think aloud, field notes, BDM Biological Literacy Assessment, student constructed annotated animations, BDM survey, mitochondria and chloroplast models.

**RECORDS**
- Audiotapes of student interviews.
- Videotapes of selected activities/interviews.
- Videotapes of selected think aloud tasks.
- Co-constructed concept maps and Visual Field Perception Map Heuristic.
- Field notes and journal entries.
- Object and term sorting.
- BDM biological literacy assessment.
- Specially annotated student created animations.
- Surveys.
Figure 2. Flow Chart of Research.
with activities and presentations that help learners understand the value of the new concept and how it relates to everyday life. This field helps the student to build familiar knowledge about photosynthesis and cellular respiration by utilizing layered and animated presentations in the form of custom videos, basic data collection on the video, and animated Microsoft® PowerPoint® 2003 presentations created by the researcher.

The present visual field develops content knowledge and digital data collection in a case-based inquiry laboratory activity, which utilized scenarios. The scenarios utilize episodic memory (Tulving, 1985). Introductory labs challenge students to gather data to help solve a case problem. Special layered, annotated animations presented the concepts of photosynthesis and cellular respiration. The future visual field utilizes animated knowledge construction for problem solution with student-created, layered, and animated presentations that address the case problem studied in the present visual field. Students work in pairs, review each other’s presentations, and finish by editing. All three visual fields are required for integrating a conceptual understanding of the processes of photosynthesis and cellular respiration.

**Brief Description of Theory of Interacting Visual Fields™ (TIVF)**

An accurate description of the learning process had to be determined to allow for full development of the constructivist learning strategies. Indeed, as the researcher piloted the BDM learning strategy, a pattern was revealed that helped to explain how meaningful learning was achieved.

All BDM learning activities are derived from Human Constructivist Theory (Mintzes, Wandersee, & Novak, 1998a). The theory emphasizes the importance of prior knowledge, hierarchically structured knowledge, conceptual change, and the use of metacognitive tools for knowledge construction. Together these constitute fundamental components of all BDM learning activities.
Students' metacognition involves prior knowledge of a past situation, present knowledge of current study, and prospective knowledge of the future application. Insight and learning occur if there is interaction between or among past, present, and future visual fields Jones (1995). As students use BDM they become aware of the interaction of visual fields. Moreover, as they do activities in the present visual field, they can make meaning and once they use all three visual fields, they experience meaningful integration. The rote-mode learning that often characterizes the present visual field allows only accumulation of unorganized information. However, the addition of the past and future visual fields allow for organization of information to allow for meaningful knowledge. Significantly, as the researcher continued to develop BDM learning strategy, it became obvious that graphic design (Tufte, 1990, 1997, 2001) and visual cognition (Neisser, 1976) were important to establishing the visual fields.

The researcher and her major professor have formulated a theory that explains the special components necessary for meaningful knowledge. This Theory of Interacting Visual Fields™ (TIVF) (Reuter & Wandersee, 2002a, 2002b, 2003a, 2003b) states that meaningful knowledge is hierarchically constructed using the past, present, and future visual fields with visual metacognitive strategies that are derived from the principles of visual behavior (Jones, 1995), Human Constructivist Theory (Mintzes & Wandersee, 1998a), and Visual Information Design (Tufte, 1990, 1997, 2001). The TIVF use of “field” is similar to, but distinct from, Jones’ use of “space.” TIVF research is reviewed in the second section of the Literature Review.

Definitions of Terms

Alternative Conception – an understanding constructed by the learner which does not fully agree with current scientific thought; see misconception.
BioDatamation™ – an integrated instructional technology-scaffolded learning strategy that is specifically designed to improve students’ learning of photosynthesis and cellular respiration, and is based on the Theory of Interacting Visual Fields™.

Cellular Respiration – the metabolic process by which energy is released during the breakdown of food molecules in the presence of oxygen.

Concept Map – a graphic representation of the structure of a piece of knowledge in which concepts are semantically linked in a hierarchy to form propositions.

Conceptual Change – the restructuring of prior knowledge that occurs during meaningful learning.

Heuristic – a device that serves as an aid to learning, discovery, or problem-solving and can eventually be discarded.

Human Constructivism – a learning theory that states that meaningful knowledge is constructed from linking propositions into a hierarchical network by using metacognitive tools.

Meaningful Learning – the acquisition of integrated knowledge and the association of the new knowledge with existing knowledge.

Misconceptions – wrong or inaccurate conception.

Multimedia – the presentation of material using two or more delivery devices.

Photosynthesis – the process by which organisms use light energy to power chemical reactions that convert water and carbon dioxide into oxygen and high energy carbohydrates such as sugars, starches, and other organic compounds.

Simulation – a computer-based activity which places the learner in a virtual, simplified representation of an actual situation. Various components and variables can be manipulated to increase user knowledge.
The Theory of Interacting Visual Fields™ (TIVF) – states that meaningful knowledge is hierarchically constructed using the past, present, and future visual fields with visual metacognitive strategies that are derived from the principles of Visual Behavior (Jones, 1995), Human Constructivist Theory (Mintzes & Wandersee, 1998a), and Visual Information Design (Tufte, 1990, 1997, 2001).

Value-Added Theory – a way of comparing whether a student, subject, or group is performing better or worse over a period of time (Taylor, 1986).

Visual Fields – what is seen now or visualized from the past or the future.

**Summary**

Some of the major problems with contemporary undergraduate education in biology are explained in *Bio 2010* (2003). Photosynthesis and cellular respiration were highlighted as critical themes in biology education. Computer-based learning strategies, specifically the BDM learning strategy, were identified as potential solutions to the current problems of biology instructional methods.

In summary, this introduction has provided an overview and general explanation of the original research question which was first posed and then investigated in this exploratory study. It also offered a basic set of justifications, in harmony with calls from the literature of the field, for conducting this research project in order to advance theory and practice within the field of biology education.
LITERATURE REVIEW

This section reviews theoretic historical antecedents to the problems associated with photosynthesis and cellular respiration instruction as well as the theoretical background of BDM learning strategy. Major developments with respect to the principles of photosynthesis, cellular respiration, visual behavior, human constructivism, psychology and graphic design are described. These components form the foundation and support the TIVF, which is the basis for BDM learning strategy.

Photosynthesis and Cellular Respiration

The history of biology reveals much about how scientists over the centuries have developed the major scientific principles that support today’s constructs of photosynthesis and cellular respiration. According to Wandersee, Mintzes, and Novak (1994) alternative conceptions are often derived from previous generations’ ideas. Understanding of concept discovery helps educators identify the alternative conceptions, which is critical to helping others construct knowledge. An alternative conception is a piece of prior knowledge that interferes with the acquisition of meaningful knowledge. For example, Wandersee (1986) used history as a heuristic to teach photosynthesis. The historic approach allowed learners to identify their alternative conceptions as they traced the changes in scientific concepts over time. Similarly, an analysis of the 1990, 1994, 1999, and 2002 Biology Advanced Placement Exam questions on photosynthesis and cellular respiration identified many student alternative conceptions.

Photosynthesis History

Science transcends national barriers so communication between scientists in different countries is very important. Journal articles help scientists share knowledge and build on each other’s findings. A brief summary of the early history of photosynthesis research as abstracted from Asimov (1968; 1989) follows:
**Water.** John Baptista van Helmont, a Belgian scientist, is credited with discovering that water was needed for photosynthesis (Asimov, 1968). In his classic experiment, he watered a plant over the course of several years and measured the mass of the plant and the soil over time. He concluded that the change in mass of the plant was not from the soil because the soil’s mass had little change, and that the change in mass of the plant was a result of the water. This was an excellent example of the scientific process of an investigation. Also, the plant’s use of soil to increase its mass is an alternative conception among many people worldwide, and this investigation can help to correct that.

**Oxygen.** In 1774 Priestley, a British scientist, placed a mouse in a closed jar and the mouse died. He then placed a plant in a closed jar and it lived. Finally, if he placed a mouse in the closed jar with the plant; both the mouse and the plant lived. When he placed a lit candle in a jar with the plant, the candle remained lit, when the lit candle was alone in the closed jar the flame died. Although Lavoisier had not yet discovered oxygen, Priestley had described the need for it. Even today, many students are confused about the relation of plants and animals with the carbon cycle, and this experiment provides a good introduction.

Engenhousz from Germany built on Priestley’s research and conducted many experiments on plants. In 1779, he discovered that plants produce oxygen in the presence of light, but not in the dark (Asimov, 1989). In 1804, de Saussure, a Swiss plant physiologist, carefully measured the amount of carbon dioxide and water used by plants and measured the change in weight of the plant. He concluded that both carbon dioxide and water were needed for photosynthesis (Asimov, 1989).

**Glucose.** In 1872 von Sachs of Germany hypothesized that glucose was created in small green bodies (later to be called chloroplasts) and that some of the glucose was then converted to
starch (Asimov, 1989). A simple experiment using fumes of iodine (which turns starch black) can reproduce this finding. If a leaf is exposed to light, the fumes of iodine will cause the leaf to turn black. If a leaf is kept in the dark, the fumes do not cause a color change because photosynthesis and the accompanied starch accumulation are light dependent. He also showed that plants require oxygen to use the glucose that they produce. There are many alternative conceptions related to von Sachs’ work that could help identify them. Only 42% of the students that took the 1999 Biology AP Exam correctly identified the mitochondria and chloroplast as locations of ATP production.

In 1887, a German scientist, Engelmann, performed an elegant experiment with green algae, *Spirogyra*, and motile bacteria under a microscope using scattered light from a prism (Lehninger, 1970). Bacteria migrated toward the algal cell near the single chloroplast, only when light was present. The bacteria were attracted to areas where oxygen is dense; Engelmann concluded that oxygen was produced in the chloroplast. This was a very visual experiment and it used an interesting genus of algae.

**Two Reactions.** In 1905 Blackman determined that photosynthesis had two reactions, the light and the dark, now known to be the Calvin cycle (BSCS, 1980). Many students still have the alternative conception that the Calvin cycle must occur in the dark and some call it the dark reaction.

**Hydrogen Donor.** In 1935 Van Niel from the United States discovered that bacteria can use hydrogen sulfide as a hydrogen donor in photosynthesis (Lehninger, 1970). Hill in 1942 determined that oxygen is produced in photosynthesis (Lehninger, 1970). Kamen, of Canada, used the O$^{18}$ isotope to show that oxygen that was released from photosynthesis originated in water (Nelson & Cox, 2000). Most students do not know that the oxygen comes from water.
The 1999 Biology AP Exam item analysis revealed that many students think it comes from the carbon dioxide. As discoveries are studied, students begin to see that science is a process and knowledge is gained step-by-step.

**Calvin Cycle.** In 1948 Melvin Calvin from the United States described the step-by-step cycle and found that carbon dioxide, RuBP, and rubisco are used to form glucose and that RuBP is continuously generated (Lawler, 2001). He used C\(^{14}\) to trace the carbon atoms in carbon dioxide. This cyclical process was named the Calvin cycle. Cycles are difficult for students to understand and the tracing of C\(^{14}\) is an excellent method to help them follow the diagram.

**Photosystems I and II.** In 1957 Emerson from the United States showed that Photosystems I and II are needed for photosynthesis (Nelson & Cox, 2000). Racker in 1960, also from the United States, identified the structure of ATP synthase (Lehninger, 1970). In 1961 Peter Mitchell from the United Kingdom discovered chemiosmosis (Mitchell, 1978; Nelson & Cox, 2000). He described how hydrogen must be concentrated between the membranes in the chloro plast and mitochondria in association with electron transport. When the proton passes across ATP synthase, ATP is created. In 1973 Paul D. Boyer from the United States discovered that it is the conformational change that occurs in the ATP synthase that allows the energy necessary to phosphorylate the ADP to ATP (Boyer, Walker, & Skou, 1997; Nelson & Cox, 2000).

**Cellular Respiration History**

**Anaerobic Respiration.** Most students do not understand when oxygen is, or is not required in the process of cellular respiration. In particular most students are confused about the concept of anaerobic respiration. The French scientist, Louis Pasteur is credited with discovering in 1860 that yeast has the ability to conduct fermentation. In 1897, Buchner
discovered that the entire yeast cell is not needed for fermentation and extracts from yeast could be used (Lehninger, 1970). Songer and Mintzes (1994) had research results that showed that many students are confused about whether yeast is living and this history might be part of the reason.

**Electron Transport.** In 1900 Warburg of Germany discovered that cyanide, even in very small concentrations, prevented oxygen consumption (Lehninger, 1970). Between 1900 to 1920, Thunberg discovered dehydrogenases and showed that oxidation is a critical step in the process (Lehninger, 1970). Contrary to Thunberg, Wieland thought that hydrogen was critical for dehydrogenase and respiratory enzymes. Warburg in 1913 thought that oxygen was critical for the respiratory enzymes that contained iron. Then, in 1925, Englehardt from Russia discovered oxidative phosphorylation. With all the previous information, Keilin, from Cambridge, in 1928 elucidated the electron transport chain (Keilin, 1966).

**Glycolysis and Krebs Cycle.** The following is an explanation of the discovery of glycolysis and its function in cellular respiration. In the 1930’s Embden and Meyerhof described the pathway from glucose to pyruvate, now called the Embden-Meyerhof pathway or glycolysis (Lehninger, 1970). Warberg and Meyerhof, in 1930, showed that ATP was produced by fermentation. Hans A. Krebs, in 1937, a German scientist working in England discovered the citric acid cycle (Krebs cycle). He demonstrated that pyruvic acid is converted to acetyl CoA and that acetyl CoA reacts with a four carbon compound to create a six carbon compound called citric acid.

**Oxidative Phosphorylation.** Oxidative phosphorylation was discovered by Lipmann in 1942 (Lehninger, 1970). In 1948, Lehninger from the United States showed that oxidative phosphorylation occurred in the mitochondria. The fact that these discoveries are important to
both photosynthesis and cellular respiration helped to show how the processes are chemically similar. They also helped to explain the structure and function of the mitochondrion and chloroplast.

**Studying with New Technologies**

Photosynthesis and cellular respiration can be studied by students with new technologies. For example students can rapidly gather data with the digital sensors and the Lab Pro® computer interface (Vernier, 2004). The data are displayed as numbers and as points on the graph as the data are collected. The software Vernier Logger Pro® 3.2 (Vernier, 2004) allows for instant analysis of slope and other statistics. Many variations can be tested in a short time due to the rapid data collection. The students can also predict the expected graph by drawing with the mouse on the computer screen. Brasell’s (1990) research indicated that students learn better with graphing tools.

**Oxygen.** Gaseous oxygen can be assayed with a gaseous oxygen sensor. The dissolved oxygen concentration in an algae solution is determined with the dissolved oxygen sensor. A mixing bar and mixing machine is needed to agitate the water for this membranous sensor. Studying oxygen concentrations allows the study of the light reaction and cellular respiration.

**Carbon Dioxide.** Gaseous carbon dioxide can be determined with a carbon dioxide sensor. Also, the pH of the water can be monitored with a pH sensor to track the formation of carbonic acid. As carbon dioxide reacts with the water, it produces carbonic acid. Thus, when there is a high carbon dioxide concentration, the pH of the water decreases. Tracking carbon dioxide can be used to study the Calvin cycle, cellular respiration, and the relationship of oxygen and carbon dioxide. Vernier Logger Pro® 3.2 software (Vernier, 2004) allows the collection of up to four sets of data simultaneously and so the inverse relationship by volume of oxygen and carbon dioxide during photosynthesis or cellular respiration can be seen on the graph.
**Temperature.** The temperature sensor can be used for temperature measurement. It can be used to reproduce Blackman’s experiment (BSCS, 1980) where light intensity and temperature are modified to see the effect on photosynthesis. The light sensor assays the light level, and the moisture level is determined with the humidity sensor.

**Reduction of NADP⁺.** The reduction of NADP⁺ to NADPH can be determined with a DPIP solution. DPIP is blue, and it replaces NADP⁺ in the photosynthetic reaction. The solution turns clear as a result of the reduction of DPIP to DPIPH (College Entrance Examination Board [CEEB], 2001). The colorimeter sensor can be used to determine the color of the DPIP solution. DPIP helps to track the light reaction. The colorimeter sensor also determines the turbidity of the algae solution to determine its growth.

**Concentration of Glucose.** The gas pressure sensor in association with pressure related to osmosis can help determine the concentration of glucose and starch in the plant (e.g. roots and stems) to indicate the products of the Calvin cycle. The nitrate sensor can be used with the algae solution to study the effects of nitrates on photosynthesis and cellular respiration.

In order to simulate Priestley’s (Asimov, 1989) closed bell jar experiment, the researcher has developed a very large Sensosphere™, a large closed container with an inserted sensor. A closed container is important to data collection with both gaseous oxygen and carbon dioxide. Also, Calvin and Engelmann (Lehninger, 1970) used algae in their studies and algae allows for very diverse experiments in BDM activities.

The previous analysis indicates that the BDM method utilizes the history of photosynthesis and respiration. Also, it has been shown that knowledge of the history of science is instrumental in students’ attainment of science literacy (Champagne, Klopfer, Desena, & Squires, 1981; Wandersee, 1986).
Photosynthesis and Cellular Respiration Are Critical to Biology Literacy

Photosynthesis and cellular respiration are essential to understanding the metabolic activities of organisms and energy flow in ecosystems. They are an important component in many different biology courses, nevertheless they are poorly understood by many students (Songer & Mintzes, 1994).

Anderson and associates (1990) focused their research on the related processes of photosynthesis and cellular respiration because they play a central role in biologists’ understanding many concepts of living systems. Biological Sciences Curriculum Study (BSCS, 1993) considers photosynthesis and cellular respiration as essential energy concepts to be taught.

Educational research has identified the failure of many students to recognize: the complexity and the reciprocal relationships of photosynthesis and cellular respiration; an inability to use everyday language in reference to photosynthesis and cellular respiration; and a failure to comprehend the overall picture (Songer & Mintzes, 1994).

Photosynthesis and Cellular Respiration Concepts in College Courses

Figure 3 is a concept map that shows how photosynthesis and cellular respiration are related and how a college biology course could teach the concepts. The map is a summary of the content that would be taught, in a hierarchical format. BDM instruction uses concept maps as part of instruction and assessment. This master concept map was used to compare the progress of the students’ conceptual change and the value added by BDM components.

Research-Based Science Education

“Research work in science education is a special area of scholarship within the scientific enterprise” (Novak, 1963, p. 3). Further, research in science education has the same goals as other fields of science, “to advance the conceptual schemes which have been developed to
Figure 3. A concept map for introductory college photosynthesis and cellular respiration.
explain events in the universe about us” (Novak, 1963, p. 3). Another influential work, *Teaching on Solid Ground: Using Scholarship to Improve Practice*, also emphasized the need for research-based education studies. “We are convinced that when work on teaching and learning is truly scholarly, the knowledge it contains has the power to positively affect the practice of instruction” (Weimer, 1996, p. 11).

**Science Literacy and History of Phases of Science Literacy**

The term scientific literacy is widely used in the popular press. The National Science Foundation defines scientific literacy as

…the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. It also includes specific types of abilities. In the National Science Education Standards, the content standards define scientific literacy. (NRC, 1996, p. 22)

A large amount of money and effort has been invested by the American Association for the Advancement of Science (AAAS), The National Research Council (NRC), and the National Science Teachers Association (NSTA) (NRC, 1996) on the scope, sequence, and coordination of *National Science Education Standards* (NRC, 1996). The science content standards considered standards for science literacy and technology literacy. An early attempt to emphasize the importance of technological ideas and skills was by the AAAS in their Project 2061 which explained science literacy (AAAS, 1989). The *Atlas of Science Literacy: Project 2061* (AAAS, 2001) gives specific examples of knowledge integration of science and technology by means of “strand maps.” Literacy programs in science and technology are designed to help students learn about “design, the interaction between science and technology, and the limits and strengths of technology” (Cajas, 2001, p. 715).
The Journal of Research on Science Teaching dedicated an entire issue to the interdependence of scientific and technological literacy, because of the complex relationship between science and technology (Cajas, 2001). There needs to be a reevaluation of science education and technology education. Technology-centered activities, ideas, and skills must be included in science education and are essential for scientific literacy. A robust relationship between science and technology needs to be established (Cajas, 2001).

Science and technology share two similar dimensions, “(a) the production and transformation of representations and (b) the action-oriented language describing the two domains” (Roth, 2001, p.768). Roth’s research suggests that curricula should use and investigate “science-through technology” (Roth, 2001, p. 768).

Biological Literacy and Stages of Biological Literacy Development

The goal of all curriculum reform efforts is scientific literacy for all citizens (BSCS, 1993). Biological literacy is a critical component of overall science literacy and has been described by the BSCS (1993) as levels of development in Developing Biological Literacy (BSCS, 1993). The levels of biological literacy were described in the BSCS Biological Literacy Model as follows:

Nominal biological literacy – At this level students are able to identify terms or concepts as biological or other science, have alternative conceptions, and provide a most basic explanation of biological concepts.

Functional biological literacy – At this level students can use biology vocabulary, define terms correctly, and repeat memorized responses.

Structural biological literacy – At this level students understand different conceptual schemes of biology, have procedural knowledge and skills, and can explain biological concepts in their own words.
Multidimensional biological literacy – This is the topmost level of biological literacy where students understand the role of biology with the other disciplines, understand the nature and history of biology, and understand biology’s place in society.

Because the BSCS analyzed how biological knowledge is built, the biological literacy model provides an infrastructure in which to analyze growth. The researcher selected levels of biological literacy instead of standardized test scores for student assessment so that meaningful knowledge construction could be analyzed.

The BSCS developed a 5E Model (refer to Table 2) as an effective way to help students construct knowledge. Developed in the 1980s, the BSCS 5E Instructional Model is a hallmark of the BSCS programs. The 5E Model is a way to teach and learn using the Human Constructivist Theory; it is a modification of the classic learning cycle.

First, students are Engaged in the concepts through a short activity or relevant discussion to help students make connections between past and present learning experiences and to help the student organize their thinking to the goals of the activity. Next, students Explore the concepts with others to develop a common set of experiences. In the Explain stage, the teacher guides the students as they develop an explanation for the concepts they have been exploring. The instructor has the opportunity to introduce the concepts, processes, and skills. In the Elaborate stage, the students extend their understanding or apply what they have learned in a new setting and broaden their knowledge and investigation skills. In the Evaluate stage, the students and the teacher have an opportunity to evaluate the student’s understanding of the concepts.

Upon analysis, the 5E Model and the levels of biological literacy have a correlation. The 5E Model is an instructional strategy to accomplish the levels of biological literacy. If the upper level 5E Model activities are accomplished there is a greater chance of achieving the higher
Table 2

BSCS Literacy Levels Correlated to 5E Model and BDM Principles

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<tr>
<td>Nominal-recognize terms related to biology</td>
<td>Engage</td>
<td>Activities to help students make connections</td>
<td>Setting the Context</td>
<td>-past visual field</td>
<td>WebQuests and real world style video</td>
</tr>
<tr>
<td>Functional-define terms correctly</td>
<td>Explore</td>
<td>Explore concepts with others to develop a common set of experiences</td>
<td>Setting the Context</td>
<td>-past visual field</td>
<td>layered animations</td>
</tr>
<tr>
<td>Conceptual and Procedural-explain biological principles and use processes of scientific inquiry</td>
<td>Explain</td>
<td>Provide opportunities to develop concepts they have been exploring</td>
<td>Experimenting and Investigating</td>
<td>-present visual field</td>
<td>set up laboratory and digital data collections</td>
</tr>
<tr>
<td>No equivalent</td>
<td>Elaborate</td>
<td>Develop deeper conceptual understanding and offer application of new skills and behaviors.</td>
<td>Processing for Meaning</td>
<td>-future visual field</td>
<td>digital data analysis</td>
</tr>
<tr>
<td>Multidimensional-evaluate complex scientific and social issues</td>
<td>Evaluate</td>
<td>Assess students understanding with a tool for evaluation</td>
<td>Applying</td>
<td>-future visual field</td>
<td>student MS PowerPoint® creations</td>
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levels of biological literacy. For example, multidimensional literacy will not be attained unless the 5E Model activity of Engagement is achieved. BDM learning strategy and principles also correlate to the 5Es and the levels of biological literacy. BDM learning strategy was embedded within specific activities which allow for biological literacy development. Table 2 shows the analysis of the 5E Model, Levels of Biological Literacy, BDM Principles, and BDM learning strategy. The table also includes Dougherty and Miller’s (1998) curriculum components which are considered in the Theory of Interacting Visual Fields™ section. Figure 4 is a graphic that the researcher developed to relate biological literacy, the 5E Model and BDM learning strategy. The levels of literacy were shown on the arrow to indicate the direction of development. The 5E Model is included below the arrow, and related to the levels of biological literacy. The BDM learning strategy is identified with the definitions of the levels of literacy. Figure 4 shows how BDM learning strategy components could help to advance the levels of literacy because the strategy components are congruent with the 5E Model.

Biology literacy is a qualitative method of measuring a students’ level of knowledge of biology and the BSCS sequential 5E Model framework supports conceptual development. BDM learning strategy offers specific instructional activities that fit the framework. In Developing Biological Literacy (1993) the BSCS designated photosynthesis and aerobic and anaerobic respiration as essential topics to be taught in high school and college level courses.

**History of Research on Science Education**

**Overview of Science Educational Research Focus of Last 50 Years.** A general review of science education shows that there are three eras of science education research over the last 50 years: Practicalist, Academist, and Human Constructivist (Mintzes et al., 1998a). Each of these eras had specific goals and the process and knowledge of science were a source of continued
debate over time. There has also been a trend towards more research to back classroom practices. The following is a summary of the research foci:

**Practicalist (1917-1957).** John Dewey was one theorist of this era and his major concern was scientific research related to teaching. The concerns of this era were management, efficiency, and practical concerns of science education. An example of a research question of
this era is, What is the impact of lecture instruction versus demonstration versus lab instruction (Mintzes & Wandersee, 1998a)? Simple surveys would be an example of the research methods and the data were survey responses that were analyzed with descriptive statistics (Mintzes & Wandersee, 1998a).

Academist (1958-1977). Much happened in this era due to the launch of the Russian satellite, Sputnik. America was in shock over Russia being ahead of the US in the space race. The National Science Foundation supported many educational reform efforts so that America’s students could catch up with Russian students. For example, the BSCS was highly funded for 20 years to help reform the out-of-date biology curriculum. There was emphasis on textbooks, inquiry labs, and ancillary materials for teaching (DeBoer, 1991).

The theorists of this era prepared the way for the human constructivists. Bruner’s major focus in 1960 was the “spiral curriculum” which emphasized the need to revisit concepts at various grade levels and to build the information (DeBoer, 1991). His major concern was transfer of information. Schwab was more concerned with fluid enquiry. He believed that students had to fill the gaps with what they learned and keep up with scientific development. Piaget had a significant impact on the use of psychological development on the teaching of science. He believed that the developmental stages controlled what could be taught and learned. In contrast to this Ausubel developed the Reception Theory. He believed that new knowledge had to be added to old knowledge, and this became a critical aspect of human constructivism. By 1970 Gagne’s major concern was the hierarchical nature of concepts (DeBoer, 1991). He thought that the learning of new concepts was a matter of combining prerequisite skills, which had been previously learned, with new knowledge. Hurd believed in ‘scientific literacy.’ Content was important to the citizens because science had become a dominant force in society.
and it was difficult to separate social, political, and economic problems or objectives without consideration for the role played by science (DeBoer, 1991). The major research questions of this time were concerned with the curriculum and methods of teaching. The research tools were very often standardized tests and the data was analyzed using inferential statistics (Mintzes & Wandersee, 1998a).

**Human Constructivist (1978-Present).** The work of David Ausubel in the early 1960’s was novel and not well understood by curriculum developers and education researchers, and in 1968 he wrote a book titled *Educational Psychology: A Cognitive View.* Mintzes and Wandersee selected the following quote from Ausubel to help describe assimilation theory, “The single most important factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly” (Mintzes & Wandersee, 1998b, p. 39). Ausubel explained that meaningful learning is the nonarbitrary, nonverbatim incorporation of new concepts and ideas into a learner’s framework of knowledge. For learning to occur, three conditions must be met: the material must have meaning; the learner must already understand relevant concepts to which to attach the new ideas; and the learner must willingly want to incorporate the new knowledge in a nonarbitrary, nonmemorized fashion (Mintzes & Wandersee, 1998b). This sequence of meaningful learning is related to the past, present, and future visual fields of BDM. The past visual field must be present to establish meaning of photosynthesis and cellular respiration for the student. The future visual field is the potential meaning of the knowledge.

**A Review of Human Constructivist Theory**

**Ausubel’s Assimilation Theory of Meaningful Learning**

The goal of education is the understanding of concepts. Since concepts are what are used in thinking and concepts are learned, if the learner consciously attempts to relate new knowledge
in a meaningful way to concepts which previously existed (i.e. prior knowledge) (Wandersee, 1986). Meaningful learning was first explored by Ausubel about 40 years ago. According to Ausubel, (2000) “At the core of assimilation theory, therefore, is the idea that new meanings are acquired by the interaction of the new potentially meaningful ideas (knowledge) with previously learned concepts and propositions” (p. 102). Many problems with meaningful learning center around understanding and conceptual change (Songer & Mintzes, 1994).

**Prior Knowledge.** According to Ausubel rote learning is incorporated into the learner’s cognitive structure in isolation and there is a lack of integration. Prior knowledge is the linking point for new knowledge (Ausubel, 1968; Mintzes & Wandersee, 1998b; Ward & Wandersee, 2002). Comprehension is based on schema theory. Prior knowledge forms the learner’s template, his or her schema. Assimilation of new material occurs when new information enters the schema. The learner may accept or reject the information based on how it fits into the schema. Meaningful learning occurs when the new information has been represented and connected well (Ward & Wandersee, 2002). The more connections, the greater the understanding (Stocklmayer & Gilbert, 2002). Encoding and organization are critical to learning. Visualization with graphic organizers helps learners to organize, abstract, and reflect upon concepts (Trowbridge & Wandersee, 2000).

**Cognitive Structure.** The four cognitive processes all function in meaningful learning and aid in eliminating alternative conceptions. Although the book does not clearly identify a theory of learning or a specific process involved, these cognitive processes are consistent with concepts described by Bransford and others in *How People Learn* (NRC, 2000). Also, Ausubel “described the instructional strategy of advanced organizers, or preliminary learning tasks, that help to activate relevant aspects of the learners’ existing cognitive structure and guide their
observation of specific aspects of relevant events or objects” (Novak, 2002, p. 559). Elements that are central to conceptual change are required for meaningful learning to occur. In principle it is known why learning in sciences and mathematics is not effective for most students and how to correct this problem (Novak, 2002). Meaningful learning involves higher cortical centers that include interconnected networks of neurons (Anderson, 1997). To eliminate rote memorization of science concepts, prior knowledge, and disciplinary knowledge need to be connected (Novak & Gowin, 1984). Student motivation and sense making are greatly influenced by the ways students explore and interact with objects (NRC, 1996).

**Meaningful Learning Theory: A Human Constructivist View**

**Description.** Joseph Novak (1977) along with Mintzes and Wandersee (1998b) used David Ausubel’s idea about the importance of prior knowledge to develop the Human Constructivist Theory. The Human Constructivist Theory states that meaningful knowledge is constructed from linking propositions into a hierarchical network by using metacognitive tools. As Ausubel described the significance of prior knowledge, Novak integrated this idea with the need to form a hierarchical representation of knowledge by using heuristics such as concept maps (Mintzes & Wandersee, 1998a). Human constructivism is the only successful effort that unites cognitive theory of learning and epistemology with useful tools to aid classroom teachers to allow for knowledge building. Human Constructivist Theory unifies the processes of meaningful learning, knowledge reconstruction, and conceptual change. Rote learning is an evil of the classroom caused by not linking new information with prior knowledge because retrieval is restricted by the lack of links to relevant information and memory. On the other hand meaningful learning occurs when the learner uses propositions they already know to relate prior information to relevant prior knowledge (Novak, 1984).
Hierarchical Organization. The structure of knowledge is hierarchical with meaningful links occurring between the concepts. Heuristic devices, such as concept maps and Gowin’s Vee Diagrams (Gowin, 1981), are metacognitive tools that explicitly represent the knowledge structure that aid the learner in structuring their knowledge. Concept maps have been shown to be reliable instruments for classroom work with students and researchers in clinical interviews (Mintzes & Wandersee, 1998a). Concept maps are powerful cognitive tools that aid in thinking, problem solving, and learning.

A constructivist model serves as a theoretical organizer for many science educators who are trying to understand cognition in science, which holds that learners construct their ideas and understanding on the basis of personal experiences. Learning is an active, interpretive, and iterative experience (Tobin, Tippins, & Gallard, 1994). There is a growing sense that learning is contextualized and that learners construct knowledge by solving significant real world problems (Brown, 1989).

Integration of Prior Knowledge. The following research explored meaningful learning which was centered on constructing knowledge. An individual’s PAST, “personal awareness of science and technology,” uses prior experience to produce understanding in informal settings (Stocklmayer & Gilbert, 2002). The quality of the present experience and the nature of the PAST were important to the consequence of the interaction that will take place. They proposed a model for PAST, which concerned remindings. Remindings were the ideas generated from the exhibit which are related or linked to the PAST and the PAST is related to the target or the outcome. The more PAST experiences the more possibilities for links and the more experiences allow for more links. These links are critical for understanding and individual engagement in experience is critical for the creation of the links. This study showed the significance of prior knowledge in learning.
“Existing schemata are used to construct additional network links among ideas, serving as a context for adding new information and partially constraining the kind of information that is incorporated into networks” (Anderson, 1997, p. 86). Students’ dissatisfaction with their own existing conceptions is one of the conditions for students to want to replace or reorganize their central concepts. Alternative conceptions are not easily given up and changed by the students. Many teaching approaches externalize the cognitive structure of students, and the students are then confronted with discrepancies or opposing views (Wandersee et al., 1994).

Active Engagement. Also, constructivist learning examples emphasize active engagement of the learner by having them investigate events and create explanations from their own knowledge and, in dialogue with others, offer the opportunity to examine significant relationships between neurocognitive theory and the human educational experience.

An example of human constructivism is learning-centered instruction that helps students construct knowledge with the following principles, which were summarized by Uno (1999): (a) the material must appear to be important to the student, (b) the information must be acted on by the students in a deep way, (c) the students must relate the new material to what they already know, (d) based on the new experiences students must update their knowledge, (e) transfer of new learning to new relevant contexts does not automatically occur, and (f) if students become aware of the learning process they will become autonomous learners. Learner-centered instruction research in college science and mathematics classes has shown that when students are active participants, learning can be “deep, enduring and enjoyable” (Walczyk & Ramsey, 2003, p. 566). The study of Walczyk and Ramsey revealed that students are dissatisfied with the traditional lecture instruction and that the number of students in science and mathematics programs is half of what it was 20 years ago.
Computers as Aids in Constructing Knowledge. Learners can use new technology tools to gather data across multiple trials and across long time intervals. By using associated software students can examine graphs of relationships generated in real-time as the investigation progresses, and examine the same data by various visual means. In addition the graphics offer visualization that can improve students’ understanding (Hofstein & Lunetta, 2004). “New computer tools are available to facilitate teaching activities targeted at modifying limited or inappropriate propositional hierarchies, and aiding meaningful learning in general” (Novak, 2002, p. 549).

Students’ alternative conceptions form obstacles that are contrary to the scientific view. The obstacles to learning do not disappear unless science instruction allows for construction of reasonable and accessible alternatives to students’ ideas (DePosada, 1997), and concepts can help with the construction of reasonable alternative ideas.

**Conceptual Change and Construction of Knowledge**

**Conditions for Conceptual Change.** Four conditions have been identified for students to have successful conceptual change: there must be dissatisfaction with existing conditions, new concepts must be comprehensible, new concepts must be initially reasonable and worthy of belief and new concepts must be shown to be productive in explaining many observable facts or events (Posner, Strike, Hewson, & Gertzog, 1982).

In an intentionally broad and ambiguous sense, learning can be described as the action of applying and reorganizing knowledge in order to achieve a better understanding of the world…however in order to be useful, a description of learning must incorporate a description of the structure of a learner’s knowledge. (Southerland, Abrams, Cummins, & Anzelmo, 2001, p. 329)
The process of describing the structure of a learner’s knowledge involves examining what and how a student is thinking and BDM also includes visual perception in the learning structure. Studies that consider the knowledge of a student before and after instruction have shown that there is no one best way to structure information and the knowledge can be structured in many ways (Champagne et al., 1981). Concept maps helped to reveal the structure of the knowledge.

**Knowledge Construction Process.** Anderson and Demetrius (1993) provided a theoretical model for the dynamic construction of knowledge which integrates information with memory and recall. It is illustrated in Figure 5 and applied to BDM strategy. Reconstruction is included as an essential component to knowledge construction and recall. Conceptual reorganization is necessary for learning to occur according to the cognitive view of learning (Ward & Wandersee, 2002), and Figure 5 shows the reorganization in relation to BDM strategy. The visual fields help to organize the stages of the process of learning.

**Interrelated Conceptions.** Learners have interrelated conceptions for some science concepts (Taber, 2000). It is possible for a learner to have several versions of a concept. This theoretical perspective aims to characterize the interrelationships among diverse knowledge elements rather than identify particular flawed conceptions; it emphasizes knowledge refinement and reorganization, rather than replacement, as primary metaphors for learning; and it provides a framework for understanding misconceptions as both flawed and productive. (Smith, diSessa, & Roschelle, 1993, p. 116)

Research (Thompson & Mintzes, 2002) showed that attitudes are influenced by knowledge structure variables; Taber considers alternative conceptions as part of a “mental toolkit” (Taber, 2000, p. 414). Instructors can use knowledge of alternative conceptions to help students learn and to help keep a positive attitude. Conceptual change that involves the strongest restructuring occurs during the first six weeks of the course, and weak knowledge restructuring
Figure 5. Process of knowledge construction and memory recall related to BDM strategy. Adapted from Anderson and Demetrius (1993).
occurs after this (Martin, Mintzes, & Clavijo, 2000). Since photosynthesis and cellular respiration require strong restructuring, its placement in the course may be critical to successful learning. This research indicates that there is much information load at the beginning of the course. The knowledge may be added faster than students are able to integrate it and that this suggests that there is much rote memorization. The rote memory restricts the learners’ ability to use knowledge in various settings. It might be worth considering teaching photosynthesis and cellular respiration during the first six weeks. Also, the research findings of Martin, Mintzes, & Clavijo (2000) are consistent with Mintzes (2000) that many students do not have the basic learning skills and metacognitive ability to be successful in today’s society, a society that has an overabundance of information, and this adds to the problem.

**Alternative Conceptions**

*Causes.* Wandersee, Mintzes, and Novak (1994, pp. 181-191) analyzed hundreds of key studies and determined 8 major causes of students not developing the correct conception, and they are as follows:

1) Learners come to formal science instruction with a diverse set of alternative conceptions concerning natural objects and events.

2) The alternative conceptions that learners bring to formal science instruction cut across age, ability, gender, and cultural boundaries.

3) Alternative conceptions are tenacious and resistant to extinction by conventional teaching strategies.

4) Alternative conceptions often parallel explanations of natural phenomena offered by previous generations of scientists and philosophers.
5) Alternative conceptions have their origins in a set of personal experiences including
direct observation and perception, peer culture, and language, as well as in teachers’
explanations and instructional materials.

6) Teachers often subscribe to the same alternative conceptions as their students.

7) Learners’ prior knowledge interacts with knowledge presented in formal instruction,
resulting in a diverse set of unintended learning outcomes.

8) Instructional approaches that facilitate conceptual change are effective classroom
tools.

This research is very useful for science instruction because teachers and learners need to
assess prior knowledge before a lesson begins and all must be aware of the possible alternative
conceptions (formerly called misconceptions). Because part of this dissertation research
concerns photosynthesis and cellular respiration, the researcher identified the alternative
conceptions that learners could possibly have before she began developing lessons for the
project.

The research of She (2002) lists three reasons that students’ alternative conceptions in
science are resistant to change: (a) students’ natural concepts are derived from everyday
experiences, (b) abstract concepts are difficult to understand, (c) invisible molecules are difficult
to perceive. Nicoll, Francisco, and Nakhleh (2001) determined that alternative conceptions
related to bonding were resistant to change despite increased chemistry education.

Classification. Research has identified a four-level framework for identifying and
classifying student’s conceptual reasoning problems and reasoning difficulties. Level 1 is
unanticipated by researchers; level 2 researchers suspect the alternative conception; level 3 the
alternative conception has been partially established in limited contexts; and level 4, the
alternative conceptions has been established in many contexts (Grayson, Anderson, & Crossley, 2001). This framework is a tool for identifying and classifying student alternative conceptions and it helps to explore the alternative conception in research.

Research on chemical thermodynamics and chemical bonding alternative conceptions has been effective dealing with alternative conceptions that relate to context-based material that is presented slowly over time. However, some alternative conceptions were resistant (Barker & Millar, 2000). From the previous research the researcher noticed that there appears to be a common alternative conception with energy transfer for thermochemistry and electrochemistry in the physical sciences, and with photosynthesis and cellular respiration in the biological sciences.

**Alternative Conceptions about Photosynthesis and Cellular Respiration**

“‘Misconceptions’ are used to describe an unacceptable (although not necessarily ‘incorrect’) interpretation of a concept by the learner” (Wandersee, 1986, p. 581). Wandersee’s research showed that the history of photosynthesis is an indicator of possible alternative conceptions and can help educators anticipate instructional difficulties. The research indicated that the history of science can be used to expose students’ alternative conceptions and thus allow for the correction of them.

Alternative conceptions are present in undergraduate introductory-level students regardless of academic ability and continue to persist into upper-level biology even with experienced students despite well developed instruction. Students have difficulty relating to the cellular level and quality instruction helps students establish meaningful connections between the cellular and organismal levels (Songer & Mintzes, 1994). They state the importance of cellular respiration and the need to engage students in active meaning making with the use of applications such as yogurt making and jogging.
Students fail to recognize the complexity and the reciprocal relationships of photosynthesis and cellular respiration, and novices maintain more alternative conceptions than experts (Songer & Mintzes, 1994). Exercise activities helped students to be active in giving meaning to cellular respiration. The activities suggest the use of computer-aided teaching. They also indicate that students will not engage in much effort to understand complex topics like cellular respiration unless there are alternative forms of evaluation that reward meaningful learning.

**Resistance to Change.** The alternative conceptions about photosynthesis and cellular respiration are difficult to change. Research has shown that students with previous college biology instruction did not improve their performance on pretest and posttest concerning photosynthesis and cellular respiration (Anderson, Sheldon, & Dubay, 1990). Anderson and associates (1990) indicated that these results raise questions about the helpfulness of current high school and college courses. They claim that their 1990 article was the first attempt to consider students’ conceptions of cellular respiration. Their analysis of alternative conceptions is centered on previous courses and the alternative conceptions could be a result of the students’ everyday life encounters with the concepts and the words.

**Lack of Links.** Griffard and Wandersee (2001) have done research on photosynthesis alternative conceptions by using a two-tier instrument to study the alternative conceptions. They found that advanced students, such as college biology majors, have a developing conceptual framework that is becoming more complex with more links between their concepts and thus more research on links and gaps would be useful. Determining where links have failed to form can be helpful and Think Aloud procedures were useful at identifying gaps (Griffard, 1999).

**Language Sources.** Misinterpretation of language causes confusion according to the research of Carlsson (2002). There are four categories that describe photosynthesis in
relationship to ecological understanding and they are concerned with consumption and transformation. Inclusion of this idea could help students understand photosynthesis (Carlsson, 2002). Photosynthesis and cellular respiration are misconceived as opposites (Amir & Tamir, 1995) and analysis of propositions can track this alternative conception, which is language-related. Also, in Hebrew there is only one word for breathing and respiration (Amir & Tamir, 1995), which is an extreme example of the types of language problems which must be addressed in teaching this subject. Canal (1999) has specifically done research on photosynthesis and ‘inverse respiration’ in plants and recommends the use of cartoon maps in instruction, which could help with language difficulties.

Textbook Sources. Most textbooks refer to both the light reactions and the dark reactions of photosynthesis. Textbooks often incorrectly state the products of photosynthesis (Storey, 1989). That the Calvin cycle occurs during the “dark reaction” and is independent of light for its activity is erroneous (Lonergan, 2000). Since Calvin cycle reactions do not occur in the dark, the statement that these reactions are “light-independent” is not correct. That the Calvin cycle reactions occur at various levels of light is more accurate. Most textbook accounts of cellular respiratory processes are misleading or incomplete. “A teaching strategy using flow diagrams is suggested to help understand the complex relationship between aerobic and anaerobic respiration by visual associations” (Yip, 2000, p. 37). There has been much more research on other photosynthesis and cellular respiration alternative conceptions, and Table 3 summarizes this research, and Table 4 shows it is an international concern.

Research Example. The research studies support the work of Hazel and Prosser (1994) on learning photosynthesis and how it is being taught at all levels of the educational system. Their study shows that few students understand the concepts of: energy transfer, the roles of
<table>
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<th>Reference</th>
<th>Alternative Conception</th>
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<td>(Seymour &amp; Longden, 1991, p. 177)</td>
<td>“The results of this study show that the cellular basis of respiration, the nature of respiration in plants, and the application of the concepts of physical science to biology, are all areas of knowledge which are poorly understood by pupils.”</td>
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<td>(Seymour &amp; Longden, 1991)</td>
<td>Learning failures can be explained by Gagne (1970) and Ausubel (1968). For students to understand that respiration occurs in cells, subordinate concepts, such as the division of organisms into cells, must be mastered first before meaningful learning can occur.</td>
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<td>(Alparslan, Tekkaya, &amp; Geban, 2003)</td>
<td>Sanders and Cramer (1992) suggest that misconceptions about cellular respiration might be caused by students’ inability to link new information about respiration.</td>
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<td>(Alparslan, Tekkaya, &amp; Geban, 2003)</td>
<td>The two modes of treatment of conceptual change instruction and traditional construction were studied for students’ understanding of cellular respiration. The results indicate that conceptual change instruction caused better acquisition than traditional instruction.</td>
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<td>(Waheed &amp; Lucas, 1992)</td>
<td>The study showed there was a lack of understanding of interrelationships of photosynthesis.</td>
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<td>(Boyes &amp; Stanisstreet, 1991, p. 209)</td>
<td>“These misconceptions, that living organisms obtain energy other than by photosynthesis or food intake, may be due to an inability to distinguish between energy supply (which is essential) and other requirements, which are essential but which do not supply energy.”</td>
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<td>(Ozay &amp; Oztas, 2003, p. 68)</td>
<td>“Results show that students have conflicting, and often incorrect ideas about photosynthesis, respiration, and energy flow in plants, even after teaching them. This suggests that students’ initial ideas are deep-rooted and difficult to change. By developing science curricula and helping teachers become more aware of student misconceptions, a different approach to teaching this subject area may help to reduce students’ difficulties in understanding the concept of photosynthesis.”</td>
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<td>(Alparslan et al., 2003)</td>
<td>Teachers should be aware of students’ prior knowledge and misconceptions, because they are strong predictors of student achievement. Teachers can plan their instruction activities to address these misconceptions.</td>
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<td>(Haslam &amp; Treagust, 1987)</td>
<td>Photosynthesis and cellular respiration tests help determine misconceptions. Students do not understand the relationship between photosynthesis and respiration in plants. Also, they do not have an understanding of the nature and function of cellular respiration.</td>
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carbon dioxide and oxygen, and the linkage of photosynthesis to other chemical processes such as cellular respiration (Hazel & Prosser, 1994). “Energy is one of the most important topics in science education” (Boytes & Stanisstreet, 1991, p. 209) and research shows that most students do not understand how plants get energy. First-year undergraduate students’ alternative conceptions occur in their understanding whereby other essential, but nonenergy supplying conditions are thought to provide energy. The following summarizes the distribution of alternative conceptions: 31% - plants get energy from the soil; 28% - plants get energy from the water; and 20% - plants get energy from the air (Boytes & Stanisstreet, 1991).

**International Concern.** BDM addresses the identified alternative conceptions concerning photosynthesis and cellular respiration and these alternative conceptions are international educational concerns. Table 4 supports this assertion. This BDM research project determined the quality of biology education is increased with use of BDM learning strategy.

**Are Gaps Alternative Conceptions?**

Phyllis Griffard (1999) carried out a dissertation study about college biology students’ understanding of photosynthesis. In particular she identified gaps in understanding that were revealed using photosynthesis multimedia software. A case study was conducted with students of different biological literacy levels within a first-year undergraduate biology course. Griffard’s study showed that all students had various gaps in their graphic decoding ability for biochemical simulations, indicating that both direct and explicit experience are required for students to learn with graphics-based instruction of concepts. She speculated that these gaps might be associated with the formation of alternative conceptions of photosynthesis.

**Experts and Novices**

The research of Ault (1994) in teaching earth science has shown the importance of prior knowledge. He has done much research on domain knowledge by working with experts and
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<th>Country</th>
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<tr>
<td>NC, USA</td>
<td>Respiration: Relation of photosynthesis and cellular respiration</td>
<td>(Songer &amp; Mintzes, 1994)</td>
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<td>LA, USA</td>
<td>Photosynthesis: Two-tier instruction and diagnosis</td>
<td>(Griffard &amp; Wandersee, 2001)</td>
<td>IJSE</td>
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<td>LA, USA</td>
<td>Photosynthesis: Reaction in the dark</td>
<td>(Lonergan, 2000)</td>
<td>ABT</td>
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<td>MI, USA</td>
<td>Photosynthesis: Instruction in high school</td>
<td>(Anderson et al., 1990)</td>
<td>JRST</td>
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<td>MN, USA</td>
<td>Photosynthesis: History of misconceptions</td>
<td>(Wandersee, 1986)</td>
<td>JRST</td>
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<td>Taiwan</td>
<td>Cellular respiration: Concepts</td>
<td>(Kao &amp; Su, 2004)</td>
<td>NARST</td>
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<td>Sweden</td>
<td>Photosynthesis: Ecological understanding</td>
<td>(Carlsson, 2002)</td>
<td>IJSE</td>
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<td>Spain</td>
<td>Photosynthesis and respiration: Inverse respiration misconceptions</td>
<td>(Canal, 1999)</td>
<td>IJSE</td>
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<td>Israel</td>
<td>Photosynthesis and respiration: PGT meaningful learning</td>
<td>(Amir &amp; Tamir, 1995)</td>
<td>IJSE</td>
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<td>Greece</td>
<td>Greenhouse effect</td>
<td>(Koulaidis &amp; Christidou, 1999)</td>
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<td>Australia</td>
<td>Photosynthesis and respiration: Diagnosis of misconceptions</td>
<td>(Haslam &amp; Treagust, 1987)</td>
<td>JBE</td>
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<td>Scotland</td>
<td>Photosynthesis and respiration: Learning difficulties in biology</td>
<td>(Bahar, Johnstone, &amp; Hansell, 1999)</td>
<td>JBE</td>
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<td>Hong Kong</td>
<td>Respiration (lactic acid fermentation)</td>
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<td>Japan</td>
<td>Photosynthesis: Extracting pigments</td>
<td>(Katayama, Kanaizuka, Sudarmi, &amp; Yokohama, 2003)</td>
<td>JBE</td>
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<tr>
<td>Turkey</td>
<td>Photosynthesis: Interpretation and plant nutrients</td>
<td>(Ozay &amp; Oztas, 2003)</td>
<td>JBE</td>
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<td>UK</td>
<td>Photosynthesis: Plant science module</td>
<td>(Sneddon, Settle, &amp; Triggs, 2001)</td>
<td>JBE</td>
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<td>UK</td>
<td>Photosynthesis: At age 14</td>
<td>(Waheed &amp; Lucas, 1992)</td>
<td>JBE</td>
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<td>UK</td>
<td>Photosynthesis: Girls with plants and animals</td>
<td>(Kinchin, 2000)</td>
<td>JBE</td>
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<tr>
<td>Canada</td>
<td>Respiration: Bacteria and micro-organisms</td>
<td>(Trevors, England, Beaudette, &amp; Cassidy, 2000)</td>
<td>JBE</td>
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<tr>
<td>Canada</td>
<td>Photosynthesis: Flow diagram</td>
<td>(Holliday, Brunner, &amp; Donias, 1977)</td>
<td>JRST</td>
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Table Legend defining journal abbreviations:
JRST – *Journal of Research in Science Teaching*
ABT – *The American Biology Teacher*
JBE – *Journal of Biological Education*
SE – *Science Education*
IJSE – *International Journal of Science Education*
novices. He found that format is not very important for experts, but it is for novices. It is important to keep the presentation clear and simple with novices so that they will learn the basics and then be able to solve problems.

For novices more time needs to be given to breaking down instruction into smaller and clearer pieces. Most text books include advanced information mixed with the basic information and there needs to be editing of these books to help clarify the presentation (Mintzes & Wandersee, 1998b).

**Heuristics**

Scientific advancement does not rely solely on empirical data, but it is the heuristic principle (organization of the mind) that leads scientists to look for relevant data (Schwab, 1978). Heuristics serve as a device to help in understanding. They are the equivalent to a brace or temporary support (scaffold) for a structure. When the framework of a building is complete, the temporary support is no longer needed, but played a vital role in the building of the structure. In the same way, heuristics are introduced in the explanation of a concept and play a vital role in understanding. Examples of heuristics include concept maps, vee diagrams, timelines, and flow diagrams. Heuristics are educational tools to help learners understand difficult concepts. Heuristics can also aid in identifying alternative conceptions and learning difficulties by revealing problems in the cognitive process.

**Knowledge Integration**

**Definition.** Knowledge integration is critical to the understanding of science (Wilson, 1998). Linn and Hsi (2000, p. 362) define “knowledge integration as the process of making sense of science that includes adding new ideas to the mix of views about a topic, linking and connecting new and existing ideas, sorting out the ideas available, reflecting on the ideas while
solving problems, and restructuring views to achieve more coherence.” They explained that
students link and connect the ideas they bring to science class to experiments, everyday
examples, firsthand experiences, ideas of other students, prototypes, and principles. Students
progress in knowledge integration by gaining more robust and coherent perspectives on a science
topic.

**Examples of Knowledge Integration.** The research of Kali, Orion and Eylon (2003) used
knowledge interrelation in relationship to systems thinking to achieve understanding of concepts.
They used a “systems thinking continuum” to interpret the progress of the students’
understanding. Low systems thinking is a static view of the system; as there is an increase of
chunking of the information high systems thinking is achieved. Their research concerned the
rock cycle which can be compared to the carbon cycle of photosynthesis and cellular respiration.
The knowledge integration activities of this research included a postinstructional activity that
required students to apply knowledge. This study did not consider prior knowledge in the
knowledge integration. BDM strategy considers both prior and prospective knowledge. Their
research showed that the inclusion of the prospective knowledge activity significantly helped
knowledge integration and understanding and the activity only took 2 hours of instruction time.
BDM strategy allows for full knowledge integration and the value-added measures can help to
determine the value of each phase of knowledge integration. Also, the task of fully
understanding the greenhouse effect is a good example of the need for knowledge integration
(Andersson & Wallin, 2000).

Thompson and Mintzes (2002) determined that the amount of branching in concept maps
indicates knowledge differentiation in the concept map. Also, the frequency of cross links is a
measure of degree of integration and cohesiveness of knowledge framework.
Need for Balance. For many years, knowledge growth was mostly vertical in more specialized directions, but now there is an increase in the growth of horizontal knowledge which is interdisciplinary (Duggan & Gott, 2002). E.O. Wilson (1998) also has explained the need for knowledge integration in his book, *Consilience*. He stated, “A balanced perspective cannot be acquired by studying disciplines in pieces but through pursuit of the consilience among them” (Wilson, 1998, p. 14).

**Psychology**

Visual Aspects of Cognition

Meaningful learning theory can provide the infrastructure for most education research. Adding to it, the following are lessons from research on thinking and memory that apply to using visual cognition to enhance learning.

Cognitive psychology is concerned with gathering, organizing, processing, storing, and using knowledge. Knowledge is the organized mental representation of external information. Perception involves construction of a model of the world rather than passive reception of it.

Information can be gathered from the environment. People use their sensory perception. For example, light enters the eye and hits the retina. Then perception data are processed to envision the object (Solso, 1996). Perception requires the use of prior knowledge so the person is helped in perceiving the image by using previous experiences. Perception is the construction of models from external information and it is an important unconscious process. Since no two people have the same prior knowledge and experiences, no two people are going to perceive an object in exactly the same way. Students do not have identical copies of the mental images based on prior knowledge that they are visualizing. Educators need to be aware of perception and to help students understand perception and to assess students’ perceptual development of images used in class.
Neisser’s Perception Model

Neisser’s Model (1976) for visual perception is adapted for presentation in Figure 6. This diagram quickly describes perception, in particular visual perception. This diagram could be used with students to help them become more metacognitive about perception. The key ingredients and actions relate to perception. The learner has prior knowledge from previous experiences and this forms a schema which is a structural representation of the prior knowledge. The prior knowledge is also hierarchically arranged. The schema directs the perceptual exploration. Then the learner samples the present environment. This indicates that perception is selective and will vary between learners. A picture may be worth a thousand words, but not necessarily the same thousand words between learners (Mayer & Sims, 1994). Then the samples of the environment are used to modify the schema. The aforementioned usually occurs implicitly, without the conscious knowledge of the learner. The direction of the flow indicates whether there is bottom-up or top-down processing. The foregoing was a description of bottom up processing.

Figure 6 makes it obvious that perception is a process that is individualized for each person because of each person’s unique schema. Neisser’s research helped to identify the alternative conceptions that a student could get from an image early along in the use of the image. Perception alone is a complex process. BDM research uses the Neisser diagram as a metacognitive tool, which helps students better understand their perception and how it relates to their knowledge building. The Neisser Model makes it clear that knowledge is being constructed and the Human Constructivist Theory supports this. The Neisser Model also helped to explain the need to have the past, present, and future visual fields in the Theory of Interacting Visual Fields™, which is explained in the Theory of Interacting Visual Fields™ section.
Solso (1996) presented a theory of visual cognition which describes how the eye and the mind see and understand visual art. According to Solso visual cognition involves three stages: First, an individual will see and analyze basic shapes, colors, forms, textures, movement, and contrasts. The person will send this information to the visual cortex of the brain for processing. Second, the basic information is organized into fundamental forms. These forms are the basis for higher order processing. These images are processed with prior learning or experience. Third, the fundamental forms are given meaning through association of prior knowledge and stored in long-term memory. Prior knowledge is critical to the process.

Figure 6. Neisser’s Model of Perception. Adapted from Neisser’s Model of Perception (Neisser, 1976, p. 21).

**Solso’s INFOPRO Model**

Solso (1996) presented a theory of visual cognition which describes how the eye and the mind see and understand visual art. According to Solso visual cognition involves three stages: First, an individual will see and analyze basic shapes, colors, forms, textures, movement, and contrasts. The person will send this information to the visual cortex of the brain for processing. Second, the basic information is organized into fundamental forms. These forms are the basis for higher order processing. These images are processed with prior learning or experience. Third, the fundamental forms are given meaning through association of prior knowledge and stored in long-term memory. Prior knowledge is critical to the process.
The first two stages are associated initiation of the process of visual awareness and are called the bottom-up process. The third stage is known as the top-down process because the cognitive processes produce visual cognition. Both bottom-up and top-down processes are needed for visual cognition and understanding (Solso, 1996). Solso (1996) and Neisser (1976) have helped to explain that perception is an individual experience and it is important to be aware of this when working with images.

**Jones’ Visual Behavior Theory**

The principles of visual behavior were published by Jones in a book called *Visual Behavior* (1995). Jones described the importance of perception and said that vision was much more than just getting the light to hit the retina of the eye.

Jones defined visual space as space that can be shared by others in the same space at the same time. It involves what we see now and what we have seen (visual memory) and what we anticipate visually in the future and in our imagination.

Jones defined behavior as our actions in that space. Jones also used the phrase “meaningful seeing” which uses our past experiences (past visual space), what individuals presently see (present visual space), and visualization of our future actions (future visual space). The combination of past, present, and future visual spaces create insight. Another way Jones related it was that hindsight and foresight create insight. Figure 7 is the Visual Field Diagram which is a graphic representation of how the visual spaces or fields intersect to form insight.

The Visual Field Diagram is used as a heuristic in the TIVF to get the learner to focus on the three visual fields. The Visual Field Diagram has been adapted into a metacognitive worksheet, Visual Field Perception Map Heuristic™. The Visual Field Diagram has lines and the learner fills in information about each field. This diagram is more than just a metacognitive
heuristic. It also summarizes the importance of linking the present experience to the past (prior knowledge) and also to the future (prospective knowledge). The diagram also helps the learner better understand that perception is a part of the learning process. “Seeing involves our past experience and our future actions projected onto the present visual identification,” (Jones, 1995, p. 69).

BDM strategy uses the following three steps with the Visual Field Perception Map Heuristic™. Jones (1995, p. 70) explained that for students to become independent problem solvers, they must be able to: “Identify the problem (from recognition), select from visual memory, and develop the appropriate solution for the problem (visualize the future).”
Bang’s Visual Symbolism Primer

Bang’s book *Picture This: Perception and Composition* (2000) described the use of simple graphic displays for effective presentations. In her book she encouraged experimentation of moving individual elements for exploring picture structure. BDM also encourages moving of elements in concept maps and animated presentations for knowledge construction.

Neisser (1976), Solso (1996), Bang (2000), and Jones (1995) have helped to explain that perception is an individual experience and that it is important to be aware of this when working with images. These theories are foundational to BDM learning strategy.

Memory Theory Related to Multimedia Applications

Memory is a critical component of learning, and memory models help to analyze the process. There are long-term and short-term memory components in most memory models, but there is a lack of consensus as to how the two memories fit into the overall memory model.

Comparing Atkinson and Shiffrin and Martindale Models. Comparing Martindale’s Model (Matthews, 2002) to the Atkinson and Shiffrin Model (Bower, 2000) reveals the lack of consensus. Martindale’s Model does not have a separate short-term and long-term memory as do the Atkinson and Shiffrin Model (1971), which is shown in Figures 8 and 9.

In comparing the two models, the largest difference is the separation of short-term and long-term memory. Schematizing requires prior knowledge and prior knowledge is part of long-term memory in the Martindale Model (Bower, 2000). It is logical to want to include perception in long-term memory and to eliminate short-term memory. The fact that short-term memory is not durable and long-term memory is durable makes it necessary to have two separate locations as indicated in the Atkinson and Shiffrin Model (Bower, 2000). Review of these models helped to reveal the complex nature of memory and the current debates about its structure.
Notice the separation of long-term and short-term memory.

Figure 8. Atkinson and Shiffrin Memory Model. Adapted from Atkinson and Shiffrin Memory Model (Atkinson & Shiffrin, 1971; Bower, 2000, p 21).
Notice there is no separate short-term memory.

Figure 9. Systems in Martindale’s Theory. Adapted from (Mathews, 2002).
Paivio’s Dual Coding Theory Related to Mayer’s Cognition Model. Since multimedia is popular in education today, many studies have been done to determine how multimedia fits into memory models. Richard Mayer, a psychologist from the University of California, Santa Barbara, has done much work in this field. The Handbook on Educational Communication and Technology (2004) offered much for improving biology education in general with visual learning-related research studies. The researcher used this handbook to help identify Mayer as one of the leading researchers in multimedia applications.

Mayer (2001) developed a Cognition Model based on Paivio’s (1990) Dual Coding Theory, which is shown in Figure 10. It applies the Dual Coding Theory that was proposed by Paivio (1990). The Dual Coding Theory states that there are two distinct channels for verbal and nonverbal processing that are independent but the two channels can exchange information. Paivio’s Dual Coding Theory is the most accepted theory among those who do communication and technology research (Paivio, 1990). Mayer’s Cognition Model showed how words can enter either the audio or video channel depending whether they are printed or spoken and it showed how the image and sound coding can travel between channels. The perception aspect of the working memory is indicated with the label that shows when the sounds and images are selected. This diagram integrates the need for perception, since all of what is taken in by the sensory systems does not make it into cognitive processing, and need for the corresponding visual fields.

The hierarchical nature of processing is indicated by the organized label. This indicated a high level of human constructivist learning. Also, there is the integration of the sounds and the images with prior knowledge. The diagram clearly showed that prior knowledge is in long-term memory and that access to prior knowledge helps working memory to access long-term memory.

This diagram helps to explain cognitive overload. Mayer’s research has helped to establish the processes that are necessary for successful design of multimedia applications, and
Figure 10. Mayer’s Cognition Model. Adapted from Mayer’s Cognition Model. (Mayer, 2001)
offers much to the improvement of biology education. The diagram can help an instructor select better multimedia and these criteria that are used to select the multimedia should also be used in everyday classroom traditional teaching approaches. Both auditory and visual channels need to be used for processing so instructors and multimedia presentations need to effectively use each channel, and the associated BDM visual fields.

**Cognitive Load.** Cognitive overload was a large concern. Cognitive load is defined as the total processing occurring at a given time. Mayer and Massa (2003) had a classical controlled study that showed that animations are best described with audio narration. When text was included on the screen, there was less understanding than when there was audio narration. They also found that if the animation could be understood alone, then narrative should not be added. His studies support the Dual Coding Model. They concluded that it is best to use both channels than to overload one. There is also the issue of divided attention and this supports the omission of narration if the animation is self-explaining. Viewers have attention diversion and cognitive overload when there is unneeded audio and video.

This dissertation research study informs the design and selection of multimedia. What is known about multimedia is true also for classroom instruction. Lecture is not good alone because it only uses one channel. Time should be given to the student to process the information. When good graphics are used in a lesson, an elaborate explanation may not be necessary, for example, a diagram that is self-explanatory. It is best to select self-explanatory diagrams to help reduce cognitive load. Biology instruction has a wealth of graphics to use (maps, charts, graphs, diagrams, photographs) and efforts should be made to integrate them into classroom lessons.

**Learning styles.** Mayer and Massa (2003) did a study on learning styles related to successful learning with multimedia and again the Mayer Cognition Model is useful for this
analysis. The study evaluated a battery of 14 learning style assessments that helped to determine cognitive ability, learning preference, spatial orientation, and general knowledge. The results showed that a simple survey was a good indicator for learning preference and that a simple paper folding assessment helped to quickly determine spatial ability. The ACT and SAT appeared to be good indicators of knowledge on some things. Cognitive ability could be assessed with a few simple tests and more work needs to be done on this. Establishing a dependable battery of tests to determine the learning style of a student is significant to both multimedia and classroom instruction in general. The research confirmed previous research that showed that presentation format was not an issue to learning if the learner was an expert. Novice learners need to have compatible formats for successful knowledge building. Also, some learners were identified as verbalizers and others were identified as visualizers. There may be dual coding, but there may be a preference of channel. Mayer recommended giving students the option of having audio or text so that they could select according to their learning preference and learning style.

Learning styles need to be known by both the instructor and the learner so that the best methods can be implemented to allow for successful learning. Identifying learning styles is an important metacognitive process that is a critical component to helping learners build meaning that will improve biology education and multimedia education (Mayer & Massa, 2003).

Effects of Segmentation. Mayer and Chandler (2001) examined when information was “just a click away” (Mayer & Chandler, 2001, p 390). The study looked at the effect of having a multimedia presentation in parts (segments) or a whole or as a whole and then parts. The study showed that there was better transfer when the presentation was in parts and then whole, but retention was not affected. Another study showed that a part and part presentation was better than two full presentations for promoting transfer (Mayer & Chandler, 2001). The parts allowed
for the creation of prior knowledge that could be used to understand the next section of the presentation.

**Use of Graphics.** ChanLin (2001) did a study that compared the learning of experts with novices. It indicated that the novices did best with text or still graphics. Still graphics were better than text for descriptive learning, and still graphics were better than text for procedural learning. Among expert (experienced) students there were no significant differences found among still graphics, animation, or text. Again, prior knowledge is an important factor in linking new knowledge. Biology instruction needs to consider the use of animations with novice learners. If the learners are novice, then still graphics should be done prior to using the animation.

**Audio Visual.** Paivio showed that the images enter the visual channel and words can enter the visual channel if they are written or the auditory channel if they are spoken. Since the model was based on his Dual Coding Theory (1990), the visual and auditory channels are independent but can exchange information. He showed prior knowledge as part of long-term memory and that it interacts with perceptions of working memory.

Much of Mayer’s research focused on the best use of the channels. Mayer has found that when an image was self-explaining, captions should not be added because they cause cognitive overload (Mayer & Sims, 1994). He also found that if a description of an image or animation is needed, it is best to include it in audio to reduce cognitive load (Mayer, 2001). Most of his research is centered on multimedia design that will prevent cognitive overload and allow for effective learning.

Multimedia studies consider the effective use of the audio and video channels because it is easy to have cognitive overload. Mayer’s work is valuable to educators because he uses
research to explain the best design methods for images in multimedia settings. The results derived from multimedia research are also helpful with real life situations. His research helps instructors to better deal with explaining images to students. The voice of the instructor in a classroom is equivalent to the audio of the multimedia.

Mayer and Massa (2003) indicated that it is best to give the student the choice of activating or not activating the audio during a multimedia presentation. Most often students are not given that option in a traditional classroom situation. Multimedia learning situations allow for diverse delivery of content, which is not easily accomplished in the traditional classroom. Mayer and Massa (2003) indicated that learning style and preference should be considered. Some students do not have as much spatial ability as others and those students usually do better with audio presentation. Mayer’s consideration of learning styles and preferences has much to say about visual cognition in the classroom. Educators need to know their students’ learning style to better understand how to help them construct knowledge.

**Arousal Levels.** Martindale (1981; 1991) explained much about arousal and its relationship to short-term memory. This researcher recognized that studies about arousal help to explain the cognitive load theory that has been described by various sources (Mayer, 2001; Mayer & Chandler, 2001; Mayer & Massa, 2003; Mayer, Moreno, Boire, & Vagge, 1999; Mayer & Sims, 1994; Moreno & Mayer, 2000). Studies show that there is an inverse relationship between arousal level and short-term memory effectiveness. High arousal can be used if the task is simple (to help capture attention), but a complex task needs low arousal to provide adequate short-term memory to deal with the task. Yerkes and Dodson (1908) determined that a medium amount of arousal is usually best. These studies help to show that short-term memory is limited. Miller (1956) has indicated that short term memory is limited to 7 items. Some studies show this
is not exactly true, and that arousal must be considered. If there is high arousal, the limit is less than 7. Vogel and Machizawa (2004) found that according to electrophysiological evidence, visual short-term memory can maintain representations of only 3 or 4 objects at one time.

As images are used, care needs to be taken to consider arousal. Studies of Tufte (1990; 1997; 2001) have indicated that information display is critical and that graphics should be clear and not cluttered. He recommended as little ink as possible to get the job done and that is congruent with the arousal research.

BDM research uses layers of images to create the final image to help build to a more complex image. Multimedia makes this a viable alternative to presentations with only graphically overloaded images.

Implicit Images. Lewicki (1986) did research on the implicit use of images. He found that people do not consciously recognize implicit cues given from images. For example, if the good guy is usually depicted with short, black hair, the audience will think all good guys are of this appearance even though this was never stated. This is useful information for learning. If the answers are always coded in green, students will know this implicitly and not have to waste efforts on finding the answer. Also, icons can be used to help lead students and to reduce the amount of text needed to accomplish the task.

Encoding and Rehearsal Theory

Encoding is considered a very important step in memory and if done well allows for better retrieval (Craik & Tulving, 1975). Craik and Tulving considered deep and shallow processing and they determined that deep semantic processing helped lay a more durable memory trace and allowed for better retrieval. Images alone are not going to allow for better learning. There needs to be deep processing and having activities and stories associated with the
graphics will help to allow for deeper processing and a more durable trace. BDM research has activities associated with most graphics to allow for deep processing that helps the learner analyze images for meaning.

Rehearsal is also important in memory. Craik and Lockhart (1972) did research that compared maintenance rehearsal to elaboration rehearsal. Maintenance rehearsal is just repeating information to keep it in short term memory longer. They found that elaboration rehearsal allowed for better memory because it accessed long-term memory.

Images for Elaboration. Images are excellent for elaboration and can enhance learning. BDM research uses image elaboration as part of the lesson design. Semantic and episodic memories are hierarchically arranged and elaboration is an example of a hierarchical application. Human Constructivist Theory is congruent with this structure and encourages students to build hierarchical representation of knowledge.

Images as Cues. Images are also good cues (Beck, 1987). Images are best used for encoding and modality is a consideration. The more common uses of multimedia and e-learning allow for the use of images as cues and this research supports the use of them. BDM research uses image cues in the presentations to help the students build knowledge and answers to assessments.

Stories and Mental Images. Stories are also good for elaboration (Langer, 1989). The stories help to include episodic memory. Tulving (1985) has found that episodic memory is very helpful when combined with semantic memory. BDM uses stories about the character agents Adele and Pierre and scientists’ discoveries to help make some of the learning episodic. The students are instructed to take the role of one of the characters and then they are asked questions
at the end of the activity that require the students to take on the role of the character or the scientist.

Also the stories can help with top-down processing at retrieval. With the information as a story, the student can more easily create mental images. Baddeley (1982) indicates the effective use of mental imagery and mnemonics. There must be good encoding to have successful retrieval and mnemonics can be useful.

Hierarchical organization is important to memory and stories; elaboration and mnemonics can help to build hierarchical knowledge with ease of encoding and good retrieval. Creating concept maps is a metacognitive tool to follow the thought process effectively (Mintzes & Wandersee, 1998a). Concept maps help to track the building of knowledge and are useful for both research and teaching. BDM uses concept maps in both instruction and research data collection.

Mental images are also useful for prospective thinking. Using a mental image to envision a future event helps to build it as if it were a painting in the mind. Sketching images is also useful for retrieval and prospective memory. Sketching and using mental images are examples of top-down processing. BDM research includes lessons where the students use Microsoft® PowerPoint® 2003 and a tool box of images to create animations that requires prospective thinking.

**Video Research.** BDM teaching strategy utilizes the Principle of Congruity, in which memory performance is enhanced to the extent that the context of encoding forms an integrated unit (Schulman, 1974). Video helps to form an integrated unit more so than text. According to Craik and Tulving (1975) congruous encoding yields better memory performance because a more elaborate trace is laid and their levels of processing research determined that retention
depends on the number of “features checked” during encoding. They determined that a large number of features in the encoding implies a more elaborate trace. If video encoding allows for a greater number of features, then it should allow for superior encoding that would result in greater recollection and comprehension. If video helps to lay a more elaborate trace, as did the sentences in the levels of processing research of Craik and Tulving’s 1975 research, then BDM research expands their findings. They also determined that the encoding unit is integrated on the basis of past experience, rich encoding implies greater compatibility with the organization of semantic memory, and the structure is used during retrieval. If encoding the stimulus is interpreted in terms of the system’s structured record of past learning or semantic memory, and BDM utilizes the past visual field to give the students past experience, then students profits disproportionately more from video encoding conditions than the student with traditional learning strategies that do not use the past visual field in the lessons.

**Encoding Theory**

**Encoding Specificity.** Tulving and Thomson (1973) described how encoding specificity, which is a specific encoding operation performed on what is perceived, determines what retrieval cues are effective in providing access to what is being stored. They defined cognitive environment as the totality of conditions determining the encoding of the perceived item. Their research suggested that the effectiveness of a cue depends on how the to-be-retrieved item was encoded at input. They related recognition failure to the general principle that encoding determines the trace and that the trace determines the effectiveness of the retrieval cues and that the trace is a link between the encoding conditions and the retrieval environment. Rajaram (1993) indicated that results of studies have been mixed as to the effect of modality (visual and auditory presentation and testing) on remember and know judgments. Rajaram’s research
showed that modality (visual and auditory) manipulation produced little effect on overall recognition data. The encoding of the trace in BDM utilizes these findings that modality has little overall effect on recognition and thus uses text assessments instead of video assessments in part of the study.

Representation of information is an important factor in memory. The method of presentation is important to the representation that is created. Narrative is better than expository text. BDM utilizes narrative presentations in most activities whereas traditional teaching strategies rarely utilize narrative presentations. Also, if there is better representation of the knowledge with video, then there should be better recognition.

**Propositional Theory and Visuals.** Proposition Theory indicated that how a person relates to the information (how the person puts themselves into it) makes a difference as to how they represent the information (Jahnke & Nowaczyk, 1998). Video allows for better construction and thus better encoding. Video easily activates multiple contextual components and clues. BDM utilizes the effects of video dual processing on recognition and comprehension associated with elaborate encoding and possession of prior knowledge while traditional learning strategies do not.

There has been little formal research to determine how video impacts basic memory. Chan and Schmitt (1997) have found that video-based retrieval is more realistic and concrete than text retrieval for situation judgment tests. Lang’s (1995) research review indicated that multi-channel redundant presentations are better than single-channel presentations at every level of processing (encoding, storage and retrieval), and that there is a superiority of visual information both for recognition and recall, but Lang’s review lacked studies that analyzed the fundamental impact of video on memory. BDM extends the current studies on video and memory.
Computers and calculators are useful for data collection and help students to understand biology concepts. The interactive nature of microcomputer-based laboratories (MBLs) links the concrete experience of data gathering with a symbolic representation in real-time and enhances the learning of science concepts, science process skills, graphing skills, and problem solving abilities for a broad range of science students (Krajcik & Layman, 1993). Brasell (1990) also emphasized the effective use of MBLs to helps students develop a cognitive link between the data and the real world and is considered in detail in the Graphics section.

BDM research is based upon well documented cognitive psychology research, and the previous is a sample of the psychology that is included in BDM research. Including strong psychology theory across disciplines provides a greater assurance of optimum development of BDM learning strategy components.

**Graphics**

**Tufte's Theory of Visual Information Design**

Excellent information design is critical for learning with visuals. Edward Tufte’s three books described not only information design but also learning using graphics. His first book, *The Visual Display of Quantitative Information* (Tufte, 2001), is concerned with describing numbers well and in that book he establishes the need for clear and consistent graphics that describe what is being compared. This is critical for good encoding in the present visual field. The use of consistent graphics prevents the learner from having to waste effort figuring out the format of the graphic. Tufte warned against distorting the data with graphics and recommended that the data should be revealed in multiple layers. He encouraged the use of closely integrated statistical and verbal data sets to reduce distortion of the data. Tufte encouraged the comparison of data by using graphs that reveal variations in the data and not variation in the design of the
graphs. Tufte stated that the purpose of the graph is to get the viewer to think about the substance of the graph rather than the methodology. His second book, *Envisioning Information* (Tufte, 1990), was about displaying nouns. In this book he described the need to use multiples with variations to successfully represent multivariant visuals on paper. This need is critical for the metacognition of graphics. In the envisioning process using multiples can help learners better perceive visual information and is a component to TIVF. He encouraged escaping the flatland of the paper by using small multiples, color, stereo illustrations, multiple layers, and graphical timelines. In his example of $1+1 = 3$, where two horizontal lines form three spaces (=), Tufte warned against the use of illustrations which may cause confusion or interpretation errors. Tufte’s guidelines can help students interpret visual displays properly.

In his last book, *Visualizing Explanations* (Tufte, 1997), Tufte’s goal was to describe design strategies for presenting information about process, mechanism, and cause and effect. The book addressed the proper display of pictures of verbs. He provided examples of how to properly arrange images and numbers. “When the principles of design replicate principles of thought, the act of arranging information becomes an act of insight” (Tufte, 1997, p 9). He stated that data should be placed in appropriate context for assessing cause and effect. Graphic design should quantify information by answering questions of: How many? How often? At what rate? The act of arranging information is critical to the use of the concept maps and flow diagrams. The arrangement of the propositions is similar to what Tufte described, and quality graphics that are given to the learner requires the learner to create other graphics which is a critical component to the TIVF. The TIVF uses graphic input, output, and learning devices to increase knowledge.
The Role of Graphics in the Study of Science

Analysis of science and technology studies show the “almost obsessive preoccupation of scientists and engineers with inscriptions—that is, visual re-presentations of nature that are extracted from the laboratory, cleaned, redrawn, transformed, and finally displayed in scientific articles to support the text” (Roth & McGinn, 1998, p. 216). They also note that inscriptions may be fruitful to science educators’ work.

Representation with Graphs

Importance. Graphs are critical to the practice of professional science and are the most important way to present data pictorially. They defined graphing as “producing, reading and critiquing graphs” (Bowen, Roth, & McGinn, 1999). They also indicated that graphing was one of the most important skills of a professional biologist; graphs should be an important part of a university biology program. They indicated that context is lost as the representation moves from the individual data point to the analysis. The study recommended that there needs to be authentic graphing practices in learning activities. BDM digital data collection is an example of this. Students have the opportunity to see the data points appear as they watch the experiment and to immediately analyze the data with Vernier Logger Pro® 3.2 (Vernier, 2004) data analysis tools. Tufte agreed that graphic representation is an important tool in learning (Tufte, 1990, 1997).

Communication. Information is transformed when students summarize it into lists, tables and graphs. “The graph and description are in reflective relationship and one draws on the other to be meaningful” (Roth & McGinn, 1997, p.99). Roth referred to the reflective relationship to form meaning as “conscription” (Roth & McGinn, 1997, p. 100).

Once graphs become a part of students’ daily communication, they become increasingly real and are no longer abstract meaningless pictures. When graphs are created by a group effort,
they promote communication between the students by providing a common interest to promote shared understanding (Roth & McGinn, 1997). “Enhancing visual abilities or using graphics to teach a concept is equivalent to using language. The experience creates the shapes, the inherent capacity, into an ability to handle increasingly complex tasks” (Mathewson, 1999, p. 42).

Students need to learn communication with graphs because it is a complex skill. Also, students need help interpreting graphs (Testa, Monroy, & Sassi, 2002).

**Visual Language.** Visual language is the use of images and representations to convey meaning analogous to the verbal language. The use of visual language allows communication and acquisition of new knowledge (Pinto, 2002). Real world elements appear in images. Elements in the image are intended to be metaphors. Students often lack the ability to incorporate abstract elements into their interpretation of the images. It is often difficult for students to establish the relationship between verbal and graphical elements (Pinto & Ametller, 2002). Images are not easily understood. Special care needs to be given to graphical design (Stylanidou, Ormerod, & Ogborn, 2002). On-screen graphs use elements of traditional graphs and the specific characteristics of the graphs are related to real-time experiments (Pinto & Ametller, 2002).

**Student Multimedia Authoring**

Research of Gobert and Clement (1999) has shown that student-generated diagrams facilitate inference making. Diagrams allow students to form inferences based on perceptual cues such as spatial adjacency (Larkin & Simon, 1987). Making their own diagram was more effective for concept formation than writing summaries. Drawing diagrams, which represented what they understood from the test, helped the students do deeper processing and is congruent with other research (Craik & Lockhart, 1972; Craik & Tulving, 1975; Lockhart & Craik, 1990).
Their research also suggested that “having students construct drawings of events and processes rather than static pictures may be significant to understanding causal and dynamic processes” (Gobert & Clement, 1999, p. 50), and BDM utilizes the use of student-created graphics.

Most children begin their education with a visual-spatial orientation. According to Mathewson (1999) this should be encouraged and utilized in later learning rather than discontinued in order to promote the traditional alphanumeric skills of reading and learning numbers. “Visual-spatial learning can begin with the development of visual-spatial self-awareness and metacognitive visual skills though some direct experience with physiological visual processes such as focus, resolution, peripheral vision, color, and optical illusions” (Mathewson, 1999, p. 42). Children should be encouraged to represent their concepts of natural objects and events with drawings. Students can develop their visual abilities in ways similar to verbal abilities (Mathewson, 1999). BDM students create Microsoft® PowerPoint® 2003 animation presentations that test this suggestion.

**Overall Visual Representation in Learning**

“The presence of visual images will increase rapidly in the future” (Testa et al., 2002, p. 253) and today’s students are part of a visual culture. Educators need to be prepared to properly utilize images in instruction, and BDM attempts to successfully utilize them. The following is research background for image utilization.

Research shows the importance of providing the learner with diagrams that show the concept in a single glance instead of separate parts (Hollliday, Brunner, & Donias, 1977). Picture-word diagrams that integrated images with essential words and just word diagrams were tested. It depended on the learning preference of the student as to which type of diagram was more effective at helping the student learn.
Beeth (1998) suggested that teachers should provide metacognitive tools as part of the instruction so that students can apply these tools to science concepts (Beeth, 1998). An example of such tools is BDM Visual Perception Map Heuristic™.

Prior knowledge requires a means for encoding previous experiences. Multiple perceptual pathways or modalities include our linguistic storage for audio and words, and an image bank for visual information (Mathewson, 1999). Not only is it important for teachers to understand the nature of prior conceptions, but they need to understand that these conceptions are strongly determined by the context being used in the instructional setting (Ebenezer & Erickson, 1996).

**Meaningful Learning with Visuals**

Meaningful learning occurs when the new information has been represented and connected well (Ward & Wandersee, 2002). The more connections, the greater the understanding (Stocklmayer & Gilbert, 2002). Encoding and organization are critical to learning. Visualization with graphic organizers helps learners to organize, abstract, and reflect upon concepts (Trowbridge & Wandersee, 1998).

Solso (1996) uses the word ‘Pragnänz’ which means ‘pregnant with meaning’ and this term can be used with simple figures such as circles. He indicates that how people perceive simple forms is an important component to the full knowledge structure (Ward & Wandersee, 2002). Visual processing does not just occur in the eye, and perception is a critical component to finding meaning from seeing.

Research has shown the effectiveness of using molecular-level pictorial presentation of matter to students (Noh & Scharmann, 1997). The research indicated that instruction that included molecular pictorial materials “helped students construct more scientifically correct
conceptions than traditional instruction” (Noh & Scharmann, 1997, p. 199). BDM addresses graphical representations of real-time events and this research supports the use of them with many molecular images to help explain photosynthesis and cellular respiration.

Mayer stated that cognitive overload can occur when too much information is included with graphical and visual information (e.g., verbal explanations on a graphical illustration) and BDM instructional strategy attempts to avoid cognitive overload.

**Visual Instructional Technology in Science Education**

“Past and present reform efforts have been limited to updating traditional subject matter, which is not adequate for life and living in today’s world. A new framework is required for general education in science, one that is student centered and up-to-date on the nature of technology” (Hurd, 2002, p. 380).

“The virtual complements the real labs” (Pedretti, Mayer-Smith, & Woodrow, 1998, p. 580). Integrated science and technology studies have shown that technology can provide investigation tools in the form of visualization and analysis capabilities, but technology also provides an infrastructure for artifact construction, expression, and record keeping. Technology plays an important role in knowledge application activities. “Because knowledge application requires meaningful, goal-directed tasks, the technologies that can support knowledge application are the technologies that will allow learners to conduct meaningful tasks” (Edelson, 2001, p. 380). With respect to BDM, students are given the opportunity to conduct experiments and to create animations that help them visualize their knowledge and share it with peers.

Studies have shown that technology encourages students to reassess their approach to learning (Pedretti et al., 1998) and that the teacher is important in the learning process. “Chalk and talk was identified as being annoyingly unproductive (Pedretti et al., 1998, p. 582)…. but
technology is not a substitute for a teacher” (Pedretti et al., 1998, p. 579). Also, students preferred to learn science with technology.

**Animation Research**

One method to help students understand dynamic processes is to incorporate the processes into a short animation that can be viewed on the Internet (Slish, 2000). The effectiveness of computer animations may be based on Paivio’s (1990) Dual Coding Theory which assumes that learners store incoming information in working memory as either verbal or visual mental representations. The instructional superiority of pictures is a result of the fact that images are coded visually and verbally. Dual coding has been applied to animated situations (Mayer et al., 1999) even though the original research was done on static images. Several chemical education researchers have shown the effectiveness of animations to help students think about chemical processes (Sanger, Brecheisen, & Hynek, 2001). Animations are most effective in situations that require the student to visualize a process (Sanger & Greenbowe, 2000).

The results of Sanger and Greenbowe (2001) suggest that using computer animations at their particular developmental level can help students understand chemistry and biology concepts (Sanger, Brecheisen, & Hynek, 2001).

Computer-based drawings can be used effectively in the classroom. Mayer and Gallini (1990) and Mayer and Anderson (1991) suggest that computer animations can be used most effectively when words and pictures are presented simultaneously, as opposed to being separated in time and space. Most previous research has centered on the instructor’s use of animation. BDM strategy includes instructor use of animations with presentations, but it extends the use of animations to student-created animations. Students that use BDM learning strategies construct animations with Microsoft® PowerPoint® 2003 in order to benefit from the previously noted effects.
Multimedia Research

In response to video segments, graphs, animations, and equations, experts formed large inclusive groups of concepts, whereas the novices had many small groups with surface features (Kozma, Chin, Russell, & Marx, 2000). Novices were particularly good in providing alternative representations especially in the verbal representations. The research shows that special concern should be given to surface features. Also, special consideration must be given to developing representational competence in chemistry students. The roles of representations and tools in the chemistry lab are significant, and BDM provides and infrastructure for bridging the gaps between the disciplines of biology and chemistry.

Construction Models. Research has shown that technology applications which allow students to build and translate representations help students to understand chemical representations with the use of visualization tools such as eChem (Wu, Krajcik, & Soloway, 2001). They explained that students have difficulty with symbolic representations that rely heavily on sensory information that is invisible or abstract within the symbolic representations. The research suggested that the technology tools that allowed students to build molecular models and to view multiple representations simultaneously helped to create referential linkages between visual and conceptual aspects of representations. BDM includes the creation of molecular animations with Microsoft® PowerPoint® 2003, and this BDM activity is similar to this research which supports it.

Students should be able to generate interpretations and make translations and mental representations when they understand the representation (Kozma & Russell, 1997). Wu, Krajcik and Soloway (2001) emphasize the importance of Paivio’s Dual Coding Theory. They utilized the theory in their research, and they mapped the connection between the outside sources and the
representation of the individual. They showed the necessity of students making changes and creating representations to meet their needs for successful learning to occur. BDM uses Microsoft® PowerPoint® 2003 creations and curve prediction with Vernier Logger Pro® 3.2 (Vernier, 2004) to help the students create representations, and the BDM research has similarities to the Wu, Krajcik and Soloway (2001) research.

Collecting Data. Kozma (2003) showed that microcomputers are effective at allowing students to develop a global perspective and he also suggested the use of 3-D models in association with the computer models to help students understand how different models show different information.

The TIVF considers surface features as described by Tufte’s principles and development of representational competence with the use of visual fields and Neisser’s (1976) Perception Model. The study of Monaghan and Clement (1999) showed that computer simulations helped students visualize posttest problems when they used the predict-observe-explain activity. Recollection from the computer simulation was transferred to the real problem. Data collection with Vernier Logger Pro® 3.2 is a “real simulation” and simulation research findings support the BDM applications of MBLs. BDM research is an indicator of the successful use of MBLs.

Utilizing Constructivist Theory. A constructivist theory of learning utilizes authentic environments where the learner is able to manipulate and synthesize information to allow for knowledge construction (Hsu & Thomas, 2002). Multiple interactive representations in an authentic environment allow learners to actively change and build information to construct knowledge allowing for constructivist learning. The simulations support metacognition. BDM’s digital data collection is an excellent example of a “real simulation.” The multiple representations are good, but weak learners may have difficulty. The research indicated that
instructors need to help familiarize the students with a technology situation so that they recognize when and how to apply it since there is a change in learning environments and transfer between them must be enabled (Hsu & Thomas, 2002).

Mental models influence perceptions of phenomena and understanding of representations in a way similar to prior knowledge. The mental model is influenced by thoughts on phenomena (Buckley, 2000). The researcher explained that it is difficult to understand living things and there are problems related to creating and interpreting representations of phenomena over a large range of physical and temporal scales. Also, it is difficult to observe biological phenomena directly (Buckley, 2000). As students work with multimedia simulation models, revisions occur while they interact with the simulation and the model building is effective at providing a foundation to develop experience.

Research showed that novice knowledge hierarchies are composed of mostly model-based attributes and not theories, in contrast to experts. Since novices are acting at the most basic levels, they group the models with the most visual similarities together. The research showed that novices focused on similarities of the models and were not able to extract more than the basic lesson. The novices needed not only knowledge about the model, but also how to connect the models into sound theories (Snyder, 2000), and BDM allows for this integration.

**Scaffolding Knowledge.** Research showed that guiding students to encourage their planning for and reflection on activities allows for knowledge integration by differentiating, integrating, and restructuring ideas. Expanding their ideas does not allow for knowledge integration unless the ideas are linked and reconciled to current ideas through reflection (Davis & Linn, 2000). The researchers recommended a "scaffold knowledge integration framework" which contains the following instructions: how to think visually to help students see how the
links are made; how to make science accessible by helping students to identify models; how to provide these social supports so students learn links and connections from their peers; and how to encourage students to be autonomous learners so that they revisit ideas to continue their knowledge integration. Also, the study of meaning-making requires that both verbal and nonverbal interactions be considered simultaneously (Rahm, 2004).

“Multimedia allows for learning to be distributed both spatially and temporally” (Rahm, 2004, p. 241). A case study using multimedia showed that students’ scores on a plant science module significantly improved due to the effects of multimedia delivery and continual assessment (Sneddon et al., 2001). In addition Lovell (2000) concluded that the Internet access can serve as a supplemental instructional tool.

At all levels students learn best when they are given multiple opportunities to exercise and demonstrate skills. Also, it is important to select the appropriate materials and integrate them into the curricula (Peat & Fernandez, 2000), and BDM can help instructors accomplish this goal.

**Learning with Student Multimedia Authoring**

Research has shown that writing forces interaction with prior knowledge (Fellows, 1994) and the learner’s manipulation of the data allows for diagnosis of misconceptions (Glynn & Muth, 1994). The writing also allowed communication via constructed inscriptions: graphics tables, photographs, equations, and diagrams (Latour & Woolgar, 1979). Campbell, Kaunda, Allie, Buffler and Lubben (2000) indicated that laboratory report writing is an important component of university level science education. Campbell suggested that teaching laboratory writing should include not just the structure of writing, but also how to communicate cognitive concepts, investigative procedures, and data analysis. BDM facilitates better understanding of
concepts and graphics and helps in the process. The inclusion of student-created animations in student laboratory reports brings laboratory reports and research communication into the new millennium.

**Computer Simulations**

Research has shown that many learners do not recognize the role of theoretical models in the interpretation of data (Ryder & Leach, 2000). BDM attempts to help to make that connection. Simulation applications help students interpret data.

Process simulations can be used to practice both inquiry skills (such as hypothesis formulation, manipulation of variables, and inference) and more general critical thinking skills such as understanding relationships, cause and effect, identifying complex patterns, and creating models (Windschitl & Andre, 1998).

Employing simulations in instruction is important. They can help students integrate knowledge into associations after basic conceptual understanding has been achieved, but after a simulation has been selected, the method of its introduction to the students is important (Windschitl & Andre, 1998).

**Conditions for Successful Learning.** Windschitl and Andre (1998) identified four conditions necessary for successful use of computer based simulations in science instruction:

1. Determine how simulations fit in the “big picture” of science instruction.
2. Develop written guides for students to use during use of simulation.
3. Use strategies for student accountability.
4. Manage the logistics of using simulations in a computer lab.

The aforementioned conditions are useful in integrating simulations into BDM instructional strategy.
Scaffolding Knowledge. Research has shown that computer visualizations can help to scaffold the revising student ideas rather than disrupting their ideas (Clark & Jorde, 2004), as well as help them to create and integrate mental models (Davis & Linn, 2000). Effective visualizations are embedded in instruction in a way that focuses students on the connection of ideas within the visualization, as Clark and Jorde (2004) stress. Their research also indicated the importance of tactile information in the simulations, and it should be noted that MBL activities include the tactile.

BDM embeds visualization and helps students to revise their ideas. BDM builds on the current literature of visualization and it includes the learner’s experiences related to visualization.

The constructivist approach to using computer simulations allows the learner to choose the mode of information representation and does not present a step-by-step “cookbook” approach, as do traditional objectivist approaches (Windschitl & Andre, 1998). BDM, with the use of real-time data collection, allows for a “hands-on simulation” that allows students to watch the real situation.

Data Collection and Microcomputer-Based Laboratories

Technology has been identified as a useful teaching tool according to the review of many studies. It helps students to have interactive learning process. Technology can enhance the learning environment for a diverse range of students. The appropriate learning environment needs to be determined for each student (Berger, Lu, Belzer, & Voss, 1994).

Interpreting Data. One study in particular was done by Brasell (1990) with data collection via graphing calculator. According to Brasell there is evidence that developing visuospatial competence has positive effects on both understanding and motivation. Her study showed
the difference between novice and expert graphers and what novices are lacking and in what areas they would need help.

She concluded that data collection with the graphing calculator allowed students time to interpret the data and that interpretation is very often missing due to the lack of time in lessons that plot the data by hand. The graphs are quickly displayed as the data are collected and the slope and statistics are quickly obtained. The students can also predict curves with the data collection system. Additionally, students can alter graphs for the study of cause and effect. Students are able to use graphs as a starting point of inquiry instead of the end point of the investigation.

This research helps educators with the decision of whether to use this expensive data collection technology. The research also indicated the issues that need to be closely considered. BDM research utilizes data collection and Brasell’s research findings add confidence to the research design of the project and it also helps to describe how to help a novice better deal with the data and graphs.

**Conceptual Change.** Digital data collection and analysis and other BDM strategy activities help students to construct knowledge by allowing for conceptual change. The following showed the effectiveness of digital data collection and analysis in relationship to the conditions needed for conceptual change that were identified by Posner and associates (1982) and Boo and Watson (2001):

1) With BDM the use of a case-based problem creates dissatisfaction so that the students make a prediction and activate prior knowledge. Vernier Logger Pro® 3.2 allows the drawing of the predicted graph that will occur during data collection.
2) Intelligibility is the next step and may be accomplished with a strong theme or storyline that extends around the activity. BDM uses WebQuest style activities and case-based situations to help establish the idea of contextually bound knowledge.

3) Plausibility is accomplished when the learner is able to quickly test their hypothesis with rapid digital data collection with Vernier Logger Pro® 3.2. The learner can set up the conditions in the system, determine if their prediction is correct, and the learner can refine their understanding (Windschitl & Andre, 1998).

4) The new conception is fruitful because it is solving a real-world problem. BDM fits all of these with the BDM Past, Present, and Future Visual Fields.

Predict, Observe, and Explain. It may be helpful to use audio-visual technologies to develop modeling skills (Boo & Watson, 2001). Technologies that allow students to observe patterns in the data visualization and to collect and evaluate evidence for hypotheses that relate to the data help students learn science (Edelson, 2001). BDM uses digital data collection in conjunction with making alterations and predictions in the experimental design, and the previous research offers support to its success. Also, digital data collection provides for output that is similar to simulations. Instead of generating data from the simulation program, the computer gathers data from the actual real-time experience. Thus the findings on the use of simulations and learning should apply to digital data collection.

Microcomputer-based laboratory (MBL) activities have much value for instruction because of the ease of data collection and storage, the ability to rapidly collect data over long and short intervals, and the ability to instantly analyze data which allows learners more time to manipulate variables, test hypotheses, and explore various relationships. MBLs allow for real time data collection which exceeds multimedia simulations.
Despite the positive attributes of MBLs, they are used little in instruction because many instructors are not aware of their ability to transform laboratory activities (Russel, Lucas, & McRobbie, 2004). They found that using predict, observe, and explain (POE) strategies helped guide the MBL activities. POE strategies were linked to MBL technological strategies to help the students construct knowledge while allowing teachers to feel comfortable with something familiar while they used unfamiliar technologies. Predicting results and setting up the sensor apparatus naturally lead to the observation of the data collection on the computer screen and then to the explanation related to the data analysis.

Much of the activity of students with MBLs was similar to interaction with multimedia dry simulations (Russell et al., 2004) but indicated the advantage of using live specimens. The easy use of live specimens with MBLs is an advantage over dry simulations. Also, the MBLs helped the student to connect the displayed data to the physical set up. The MBL activities allowed for a deep thinking process which was enhanced by POE. Other research indicated that deep processing allowed for better learning (Chin & Brown, 2000; Tulving, 1985). The MBL display was proven to be important to the students creating mental models that were consistent with the new information. Selecting and analyzing data became part of the students’ modeling process.

Research on Laboratory Instruction. Lazarowitz and Tamir (1994) identified the lack of laboratory instruction in most teaching situations and that the laboratory is needed to help integrate content with problem solving. They found that the textbook content related to lab was important. Science laboratory activities can be used by teachers to augment intended learning outcomes (Hofstein & Lunetta, 2004).

Many of the activities currently presented for student laboratory guides continue to offer “cookbook” procedures for students to follow. They do not motivate students to think about the
overall purpose of the investigation and of the sequence of tasks needed to reach those goals. BDM MBL activities address this problem with interactive labs.

Standardized tests are designed to assess science standards, but lack assessment of students’ practical knowledge and laboratory activities (Hofstein & Lunetta, 2004). BDM uses student-created animated Microsoft® PowerPoint® 2003 presentations to ensure that these areas of learning are addressed.

**Theory of Interacting Visual Fields™: Literature-Based Support**

**Defining the Theory of Interacting Visual Fields™**

The Theory of Interacting Visual Fields™ (TIVF), developed by the researcher with Dr. James Wandersee (Reuter & Wandersee, 2002a, 2002b, 2003a, 2003b), states that meaningful knowledge is hierarchically constructed using the past, present, and future visual fields with visual metacognitive strategies that are derived from the principles of Visual Behavior (Jones, 1995), Human Constructivist Theory (Mintzes & Wandersee, 1998b; Mintzes et al., 1998a), Information Design (Tufte, 1990, 1997, 2001) and Psychology of Visual Memory (Neisser, 1976). TIVF is the integration of Novak, Mintzes and Wandersee’s theory of knowledge construction, Jones’ theory of insightful perception, and Tufte’s theory of effective visual display. The TIVF was revealed through the researchers’ development and exploration of BDM learning strategy. The TIVF is the foundation of BDM learning strategy and the theory is unitized and actualized in the BDM teaching strategy.

**Literature-Based Support for TIVF: Principles Behind TIVF**

Jones’ Principles of Visual Behavior. Jones’ principles of Visual Behavior (1995) established the importance of perception and that vision was much more than just getting the light to hit the retina of the eye. With their perception the learners create the visual space of
what they see now (present visual field) and what they have seen (visual memory of the past visual field), and what they anticipate visually in the future (the future visual field) in their imagination, to accomplish insight, “meaningful seeing.” Research recently completed by Vogel and Machizawa (2004) shows that the average individual has the capacity to hold three to four objects in visual short-term memory. BDM only uses three objects, three visual fields, and it appears that BDM strategy protects against cognitive overload for students using TIVF.

Jones stated that “visual space is that space that can be shared by those in the same space at the same time” (Jones, 1995, p. 54). It involves what we see now, what we have seen (visual memory), and what we anticipate visually in the future and in our imagination. Figure 7, Visual Field Diagram, shows how the interaction of the visual fields allows for insight. The TIVF extends the use of that diagram to more than the display of a summary of the interaction of the fields. The Visual Field Diagram is used as a heuristic with the TIVF to help the learner focus on the three visual fields. The Visual Field Diagram has been adapted into a metacognitive Visual Field Perception Map Heuristic™ (Visual Field Worksheet; see Figure 11).

Lines are drawn in the Visual Field Diagram and the learner fills in the information about the fields. The lobes of the fields of Jones’ original diagram have been separated and arrows have been added to show possible interaction of the fields to allow for insight. This diagram is more than just a metacognitive heuristic it also summarizes the importance of linking the present experience to the past (prior knowledge) and also to the future (prospective knowledge). The diagram also helps the learner better understand that perception is a part of the learning process. “Seeing involves our past experience and our future actions projected onto the present visual identification” (Jones, 1995, p 69).

Neisser’s Perception Model. Also, Neisser (1976) described a perception cycle that involves the use of schema of the past. The schema of the past directs the visual exploration of
Figure 11. Visual Field Perception Map Heuristic™, Visual Field Worksheet. Adapted from Jones (1995).
the present surroundings and then the schema is modified as a result of the visual exploration. Using the schema (past visual field) helps to get the information out of short term memory and into long term memory, which is more durable.

**Human Constructivist Theory.** The TIVF utilizes the construction of knowledge of Human Constructivist Theory of Mintzes and Wandersee (1998b) with linking propositions into a hierarchical network by using metacognitive tools. TIVF is based on human constructivist tools such as prior knowledge, hierarchical arrangement of propositions, and the use of metacognitive heuristics, such as concept maps and the BDM Visual Perception Map Heuristic™. Also, TIVF incorporates the “systems thinking continuum” used by Kali, Orion, and Eylon (2003) in conjunction with the previously mentioned constructivist metacognitive tools. The concept maps are critical for tracking the construction of insight and concepts. As the students find the links to knowledge, they see how their insights have changed, and the heuristics help the learner have insightful and meaningful learning.

Also, prior knowledge is part of long-term memory, is organized hierarchically, and is critical to human constructivist learning. The congruent use of both hierarchical organization of knowledge with the present visual field helps to access prior knowledge. Also, the hierarchical organization is good for retrieval. The use of strong encoding with metacognitive tools allows for a better memory trace and thus better retrieval (Tulving & Thomson, 1973). Encoding is critical to memory.

The future visual field is similar to a traditional concept application, but it also has a special real-world scenario application. Learners are given the opportunity to trigger and use recently constructed knowledge. “The application process creates and reinforces links to those knowledge structures and restructures them, if necessary, to support use” (Edelson, 2001, p. 380).
Tufte’s Theory of Information Design. Tufte’s theory of information design (Tufte, 1990, 1997, 2001) is a major foundation of TIVF. Excellent information design is critical for learning with visuals. His theory directs the instructor and the learner to the best visual displays of number description and to clear and consistent graphics that describe what is being compared, which is critical for good encoding in the present visual field. The use of consistent graphics prevents the learner from having to waste effort figuring out the format of the graphic. His recommendation to use multiples with variations is critical for the metacognition of graphics. In the envisioning process, using multiples can help learners better perceive visual information and is a component of TIVF. His theory also indicates that the construction of a graphic indicates the thought process and the process of arranging the elements in the graphic leads to insight. This idea is critical to the use of concept maps and the Visual Field Perception Map Heuristic™ diagrams. The arrangement of propositions in concept maps is an example of the use of graphic construction to indicate the thought process. And so, quality graphics that are presented to the learner require the learner to create graphics, and quality graphics are critical to TIVF. The TIVF uses graphical input, output and learning devices to increase knowledge. Figure 12 is a concept map of the Theory of Interacting Visual Fields™.

BDM Teaching Strategies Utilize TIVF to Enhance Understanding

With BDM learning strategy students construct knowledge by utilizing perception and interaction of the past, present, and future visual fields to achieve insight with carefully designed visual displays. BDM learning strategies are the “threads” that unify the individual principles of human constructivism, visual theory, and visual displays.

BDM Learning Strategy Unitizes the TIVF. Visual fields must be established during the learning activity. The past visual field utilizes special annotated animated presentations of real-life applications of the concepts, which are layered to help to present the concepts. Videos and
Figure 12. Theory of Interacting Visual Fields™.
other multimedia are centered on real-life situations related to instructional activities and lack large amounts of detail.

**Past Visual Field.** The purpose of the videos and other multimedia presentations is to access the learners’ past visual field and to actually create part of a past visual field that all learners can identify with. The past visual field also utilizes WebQuest-style activities, which are specially crafted situation-based lessons that help students understand the value of the new concept and how it relates to everyday life, and help students to build familiar knowledge about photosynthesis and cellular respiration. The past visual field is built with Tufte’s principles of excellent graphics and the constructivist component of prior knowledge.

**Present Visual Field.** The present visual field utilizes multimedia and data collection with graphing calculators (CBL) or computers (MBLs) which is used to help relate the real world to the chemical equations of photosynthesis and cellular respiration. They are presented with a case study situation (present visual field) that requires them to gather data to help solve a problem. Students do introductory labs that allow them to set up a condition and witness data collection. Live data collections (present visual field) are viewed by the students on their computer screens. The students view the change in oxygen or carbon dioxide level graphically as the data points appear on the screen of the computer. The set-up and analysis of the data allow for constructing knowledge, and graphic displays are built with Tufte’s principles of excellent graphic design.

**Future Visual Field.** The future visual field utilizes student-created annotated animated presentations to address the case study problem from the present visual field. The animated Microsoft® PowerPoint® 2003 presentation is a modified lab report that contains information layered from the basic to the complex concepts and at least one annotated animation in each of
the following sections: a brief introduction about the biology background of the problem, methods of how the students did their investigation, results that include some sort of living graph image and quantitative data, and recommendations about the problem’s solution. The students are given a toolbox of images and labels to use in the construction of the animation and a rubric that defines the information layering that must be used to construct the animation. The students use a software similar to Microsoft® PowerPoint® 2003, Camstudio™, or Microsoft Producer® 2003 to create the presentation, and to add narrations and annotations.

The future visual field is utilized because the students have to think ahead about how the problem will be resolved and to determine their recommendation for solving the problem. Predicting how things will change is a result of the students’ utilization of the future visual field and requires the construction of knowledge while using Tufte’s excellent graphic principles. The TIVF makes obvious the tasks that need to be done with graphics to construct meaningful learning and is helpful to educators and students.

**Curriculum Components.** Dougherty and Miller (1998) identified four key curriculum components that allowed for development of conceptual understanding and connections to encourage development of process and critical thinking skills. BDM also utilizes these components and Table 5 relates the curriculum components, BDM’s learning strategy and the TIVF. BSCS has no equivalent for insight.

**Explanation of Interacting Visual Fields and the BDM Logo**

The researcher-created the BDM logo shown in Figure 13 by applying the graphical principles of Bang (2000). It shows the integration of the visual fields with BDM learning strategy. This is the project logo for the BDM Project Website, http://www.biodatamation.com, (Reuter, 2004) that was built by the researcher for administration of the project. The simple
Table 5

Key Curriculum Components of BDM

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<tbody>
<tr>
<td>Setting the Context</td>
<td>Real-Life Style Video WebQuests</td>
<td>Past</td>
<td>Prior knowledge</td>
<td>simple displays with little detail</td>
</tr>
<tr>
<td>Experimenting and Investigating</td>
<td>Digital Data Collection</td>
<td>Present</td>
<td>Learning by doing</td>
<td>visual organization of data</td>
</tr>
<tr>
<td>Processing for Meaning</td>
<td>Digital Data Analysis</td>
<td>Present</td>
<td>Linking concepts</td>
<td>analysis of numbers using graphic principles</td>
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<tr>
<td>Applying</td>
<td>Student-Created Animations</td>
<td>Future</td>
<td>Constructing meaning</td>
<td>use of layers</td>
</tr>
<tr>
<td>No equivalent</td>
<td>Successful Knowledge Integration with problem solving</td>
<td>Insight</td>
<td>Meaningful Understanding</td>
<td>visual display reflects understanding</td>
</tr>
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Figure 13. BDM logo™ (Reuter, 2004).
graphics of the logo help to focus the viewer’s attention on the BDM learning strategies. A sample of the project materials are provided on the BDM Web site and in the appendices.

**Literature Review Update**

BioDatamation™ strategies require that the information used in their implementation be up to date at all times. Constant monitoring of academic news, and scientific publications is required to ensure relevancy and vitality in the future visual field. The following publications relevant to BioDatamation™ and TIVF have come to the researchers attention following the initial submission of her prospectus and are included below for completeness.

In recent months, many publications reinforce the strategies organized and integrated into BioDatamation™ and TIVF. One article found in the *U.S. Naval Institute’s Proceedings* is concerned with the appropriate use of technology to aid in information transfer, and shows that technology applications are not only a concern of the scientific community, or even academia as a whole, but also a matter of interest to government and industry. While BioDatamation™ deals exclusively with the appropriate use of technology in teaching biology, the underlying Theory of Interacting Visual Fields™ can be applied to almost any document intended to convey information. A recent article illustrated the importance of appropriate information design in PowerPoint® presentations for no less than the United States Navy (Wooldridge, 2004).

In the article “Order a PowerPoint® Stand-down” Captain E. Wooldridge, USN (Ret.) illustrates the dangers facing the military through the overuse of PowerPoint® in briefings without due concern for the information conveyed (Wooldridge, 2004). He warns that focusing excessively on style of slides and what he terms “slide-ology” very often has become a common substitute for real planning, thoughtful discussion, and logical analysis. Wooldridge’s concerns are in fact two, though he does not himself state them explicitly. One is the specific military
concern with the use of the PowerPoint® program itself as an opportunity to mindlessly publish meaningless details without regard for substance; his other concern is the tendency of the stereotypical PowerPoint® presentation to inhibit rather than increase the ability to transfer information. An equivalent effect was observed in the comparison group in this study, which experienced a feeling of being “jumbled” after a traditional presentation.

Wooldridge feels that “PowerPoint® does not allow an audience to assimilate the information presented (Wooldridge, 2004). BDM is explicitly geared towards combating this tendency. PowerPoint® is a tool which can be used to increase the flexibility and scope of presentations but this can only be done with a cogent strategy. The BDM meta-strategy is designed to give coherent direction to both advanced technological and traditional information transfer tools in such a way that these dangers extant in any presentation are avoided and the full potentialities of the information media are exploited.

Also, another recent finding reinforces TIVF in real life. In order to ensure that TIVF remains a dynamic strategy, it is necessary to ensure that the future visual field is at all times current in order to maximize the ability of the subject’s imagination to contribute to the accomplishment of “meaningful seeing”. As an example of this, a new potential breakthrough in tuberculosis medication has just been discovered which functions by means of interfering with the ability of \textit{M. tuberculosis} to generate ATP via cellular respiration, one of the two scientific knowledge areas upon which BDM and TIVF were tested in this research (Cole & Alzari, 2005).

In all fields of study, TIVF can be applied into learning. In his plans for reorganizing the British Science Museum its head, Jon Tucker, inadvertently launched an initiative to reorganize the museum’s exhibits, focusing on the Industrial Revolution, to utilize the principles embodied
by TIVF. Tucker wishes to create a feeling of excitement in visitors for the past, present, and future of science and technology (Russell, 2005). While unsupported by the research and theoretical development undertaken to evolve TIVF, the museum’s focus on binding together the three visual fields composing TIVF into one unit indicates another opportunity for generalizing the TIVF beyond the university classroom (Russell, 2005).

Finally, J. Jose Bonner (2004) recommends a strategy similar to that used in the BDM lab, “The Falling Bread: Effects of Temperature on Cellular Respiration and the Rising of Bread” by Jewel Reuter. He teaches a course entitled The Biology of Food intended to interest nonbiology majors in the subject by illustrating to them the way in which biology is tied in with everyday life. By beginning with everyday, directly observable biological phenomena such as bread or cattle breeding, Bonner has found it easier to convince students to change their alternative conceptions to match the currently accepted scientifically correct conception. All the articles of recent months give BioDatamation™ and TIVF greater importance in appreciating and retaining knowledge in everyday life.

Mixed Methods Research Methodology

Essentiality of Mixed Model Design

A mixed model typology was essential because the research was focused on answering both confirmatory and expository questions at the same time and the answers of the questions are interrelated to determine the metainference of the study. The mixed model study also provided for better inferences since the best of qualitative and quantitative methods were combined to best accomplish the research. As Johnson and Turner indicated "methods should be mixed in a way that has complementary strengths and nonoverlapping weaknesses" (Johnson & Turner, 2003, p. 299).
The relationship of the inferences draw from all the data analysis in mixed methods studies form a metainference. These inferences confirm or refute each other and then allow for more triangulation and complementarity. The metainference of the study were various profiles of the value-added to learning with BDM, which indicated the effectiveness of the program for various levels of achievers.

Mixed methods in general allow for the discovery of the divergent elements of a phenomenon. The mixed model study allowed for the presentation of a greater diversity of divergent views about BDM in the form of profiles and maps of knowledge. It allowed for the inclusion of different voices and perspectives. Also, extended analysis of data transformed into different types of data (quantitative $\rightarrow$ qualitative) allowed this research to establish internal validity audits and identified the need of a new study for further investigation as indicated by Johnson and Turner (2003).

Purely qualitative research would have limited the study to a small set of students with limited data collection. A purely quantitative study would have lacked the depth of the interviews, which helped to explain and confirm quantitative data. Many studies that have used interviews with the quantitative data have been surprised as to the underlying meaning of the quantitative data. This BDM research used mixed methods to avoid these sorts of problems.

**Philosophical Orientation**

The research was a mixed model that blended qualitative and quantitative approaches with the questions, research methods, data collection and analysis, and inference process. The philosophical orientation was dialectic. BDM research was designed "to invite juxtaposition of opposed or contradictory ideas, to interact with the tensions invoked by these contesting arguments, or to engage the play of ideas" (Greene & Caracelli, 2003, p. 96-97). The dialectic
mixed methods inquiry allowed for a better way to understand the impact of BDM instructional strategy on student learning. It allowed for exposure of contradictions and tension so that "truth" was uncovered. The dialectic paradigm was congruent with the mixed models approach used in this research. It was through differences that the research revealed ideas.

**Design Sequence**

The design was the sequential mixed method design of Tashakkori and Teddlie (2003). The sequential mixed model incorporated Cresswell’s (Creswell, Clark, Gutmann, & Hanson, 2003) explanatory mixed methods design and exploratory mixed methods. The first strand of the research included data collection, analysis and inferences in one approach which was quantitative. The second strand of the research involved new data and was qualitative. Confirmation or disconfirmation of the inferences of the two strands of the research contributed to the final metainference (Tashakkori & Teddlie, 2003). The qualitative and quantitative components informed each other and were each critical for the formation of the metainference. It appeared that the qualitative component was dominant because more time was devoted to case studies, but the quantitative data was significant for the data analysis due to the large population size (N= 263,267). It was important information for composing the interview questions. The data collection was sequential with the quantitative data collection and analysis of multiple-choice items of the Biology Advanced Placement Examination and was followed by the qualitative components of the case studies of the learners. The case studies were repeated ten times.

**Techniques to Determine Trustworthiness of Qualitative Conclusions**

According to Tashakkori and Teddlie (2003), "there is a need to separate the standards for evaluating quality of data and observations from those that are required for evaluating the
quality of inferences” (p. 692-693). Data quality must first be considered before inference quality is considered.

The methods were appropriate for this project, and the research design aligned the methods, data collection and data analysis. There was a need for both qualitative and quantitative data collection and analysis to draw the necessary conclusions. The quantitative data established breadth and the qualitative data established depth. Integrating the results of the two data sets by qualitizing and quantitizing the data increased the inference quality, multiple qualitative and quantitative analysis methods on the same data allowed for triangulation and increased inference quality. Both qualitative and quantitative data quality were considered in the following sections.

**Qualitative Data Quality**

From the qualitative data perspective of Lincoln and Guba (1985), credibility, transferability, dependability and confirmability were considered to establish trustworthiness, the fact that this study was worth paying attention. First, the probability of credible findings was increased by using activities of prolonged engagement, persistent observation, triangulation, peer debriefing, referential adequacy, and member checks with the BDM research.

**Credibility**

Prolonged Engagement. The study was extensive and there was prolonged engagement. The researcher observed the classes from the beginning of the semester for 2 months prior to the start of the BioDatamation™ project and for a month after the major part of the study was complete. The researcher observed the entire semester, which was the most observation possible in this classroom situation. Prolonged engagement helped the researcher to become oriented into the culture of the classroom and allowed the researcher to better determine the possibility of
misinformation in the research. The researcher was able to determine possible distortions that might have entered the data. The extended observation and repeated interviews also allowed the building of trust. The participants fully understood that the researcher did not use their confidences against them and that promises of anonymity was honored. The researcher was careful to remain detached and open to multiple influences (Lincoln & Guba, 1985).

**Persistent Observation.** Persistent observation and repeated interviews established an extended depth. Since BDM was a sequential series study, the researcher had at least ten phases to the case studies. The researcher was able to find deep and authentic data (Lincoln & Guba, 1985).

**Triangulation.** Triangulation also increased credibility. The study was both confirmatory and exploratory which triangulate the purpose of the study. Qualitative and quantitative data collection and analysis methods were used with the qualitative components informing the quantitative components and vise versa. Also, there were multiple qualitative and quantitative data analysis techniques used on the same data. The qualitative and quantitative data increased credibility. The metainferences provided an additional layer of triangulation.

**Peer Debriefing.** A fourth technique of establishing credibility was peer debriefing. The researcher had frequent discussions with experts in the field in the form of conversations, e-mail, and various professional conferences. The researcher had presented the pilot BDM research multiple times to various professional organizations and there was a question and comment section at each presentation. Also, discussion boards and e-mail were continued with interested members of the convention groups. The researcher had contacts with experts in the various areas that have importance to the research, and sought their opinion at the various stages of the research. All of these activities were significant to the formulation of research questions and hypotheses, data collection and analysis, and the ultimate metainference.
Referential Adequacy. A fifth technique used to establish credibility was referential adequacy. Videotapes of the interviews were created to capture data and allowed for archiving and were reviewed in more detail during the data analysis. According to Lincoln and Guba (1985, p. 313), "The recorded material, provide a kind of benchmark against which later data analyses and interpretations (the critiques) could be tested for adequacy." Also, various forms of raw data from this research were stored in the form of notes and original surveys (Lincoln & Guba, 1985).

Member Checks. A sixth technique to establish credibility was member checks. The analysis was checked via what the researcher terms a member postproject interview. The analyzed data and metainferences were presented for discussion and "approval" to the participants. After the postproject conference, changes were made to the analyses as needed, then individual participants checked the analyses (Lincoln & Guba, 1985).

Transferability. The second component to trustworthiness was transferability. The thick description of the study allowed the audience to responsibly transfer judgments to other situations. According to Lincoln and Guba the audience is responsible for making the transfer, which is different from the quantitative counterpart of external validity (Lincoln & Guba, 1985). The researcher kept a reflexive journal with thick description, all research thoughts, activities, data, data analyses, and all associated research activities (Lincoln & Guba, 1985).

Dependability. The third component of trustworthiness was dependability. An inquiry audit was done to strengthen the dependability of the study. The inquiry audit had two steps. First the researcher satisfied the personal requirements that all the data gathered were accurate. The researcher sampled entries to the reflexive journal to determine that the journal entries supported and agreed with the various data. Second, the researcher assessed that the data and
interpretations supported the metainference. The researcher had an auditor repeat the process as an external audit, and this also increased the dependability of the study because it checked for possible bias. The research needs to fairly and accurately represent the data (Lincoln & Guba, 1985).

**Confirmability.** The fourth component of trustworthiness is confirmability and was established in this study with a confirmability audit, which integrated the use of triangulation of reflexive journaling. The following are components of the confirmability audit. The auditor is secured after the study is complete. There is an audit trail, which is composed of raw data of videotapes, field notes and documents, data reduction and analysis products, data reconstruction products, process notes of methods, and instrument development information. Trustworthiness is determined with confirmability. The auditor determines if the findings are grounded in data with the audit trail, that the inferences are logical based on the data, if there is researcher bias and the extent to which the researcher attempted to ensure confirmability (Lincoln & Guba, 1985).

The auditor also examined the research for dependability which included the appropriateness of research methodologies, researcher bias, early closure of research, the extent to which all data were accounted for, all reasonable areas explored, the possibility of the presence of the Pygmalion and Hawthorne effects, sampling decisions and triangulation process, the emergence of the overall design, and presence of possible instability. The auditor also views the peer debriefing and member checks (Lincoln & Guba, 1985).

**Quantitative Data Quality**

Simple descriptive statistics provided by Educational Testing Service (ETS) were used to analyze the data of all the students who took the Biology Advanced Placement Examinations in 1990 (ETS, 1992), 1994, (ETS, 1994) 1999 (ETS, 1999), and 2002 (CEEB, 2004).
Qualitized and Quantitized Data Quality

Qualitized and quantitized data were considered threats to quantitative and qualitative data as indicated previously. The researcher was cautious with quantitized data in particular so that the proper statistical considerations were taken to ensure validity.

Inference Quality

Concurrent with issues of qualitative and quantitative data quality was the issues of inference quality. If there is high data quality, then there will be the possibility of high inference quality. Tashakkori and Teddlie (2003, p. 709) defined inference quality as "the degree to which the interpretation and conclusions made on the basis of the results meet professional standards of rigor, trustworthiness, and acceptability as well as the degree to which alternative plausible explanations for the obtained result can be ruled out.” They also relate design quality. “Inference quality consists of design quality (within-design consistency) and interpretive rigor (conceptual [or inferential] consistency, interpretive agreement [or inferential] consistency, interpretive agreement [or interpretive consistency], and interpretive distinctiveness)” (Tashakkori & Teddlie, 2003, p. 709). The following is a discussion of inference quality.

Design Quality

First design quality of this research was considered. There was with-in design consistency because the various design components were consistent with the research questions and the inferences consistently emerged from the design. A thorough analysis of research method plans prior to performing research allows for effective data collection.

The design was consistent with the research questions. The Biology Advanced Placement item analysis data helped to indicate student alternative conceptions of photosynthesis and cellular respiration in preparation for answering the exploratory question of what is the value...
added to high and low achievers’ knowledge representation as a result of the use of BDM to supplement traditional strategies.

The case study interviews mostly allowed for answering the expository question of how the learner’s knowledge representation changed with the use of the learning strategy of BDM. But the qualitizing and quantitizing of data allowed the qualitative and quantitative components to inform each other and a mix model design was achieved and utilized to answer the research questions. The observations and measures demonstrated quality and are explained in the qualitative and quantitative data quality sections. The data analysis techniques were sufficient for providing answers to the research questions. Also, the methods of qualitizing and quantitizing data helped to expand and confirm the answers obtained for the questions. The audits established that the results are as the researcher has claimed.

There were the necessary strength, demonstrated results, and magnitude of effects to warrant the conclusion. The inferences strongly emerged from the results and again the qualitized and quantitized data strengthened the inferences. The metainferences were profiles and knowledge representation of students who used BDM and traditional strategies and were consistent with the research questions. The metainferences were qualitative and quantitative and the two informed each other. The researcher's reflexive journaling with thick description was critical for increasing all four criteria of trustworthiness: credibility, transferability, dependability and confirmability.

**Interpretative Rigor.** Interpretative rigor is another component to inference quality (Tashakkori & Teddlie, 2003). Conceptual consistency, interpretive agreement (interpretive consistency), and interpretive distinctiveness were items used to determine interpretive rigor. The conceptual consistency dimension consisted of the degree which the inferences of the BDM
research were consistent with each other and with the known state of knowledge. For example, some studies have shown an increased knowledge of multimedia applications such as TV and graphing calculator studies have resulted in an increase in learning.

BDM is cutting-edge research that combined the various technology strategies with the specific topic of photosynthesis and cellular respiration. The individual results of video and graphing calculator were compared with previous findings and consistency of inference with each other within the study were considered. The qualitative data were compared to the quantitative, they were then quantitized, and the quantitative and quantitized data extended the depth of the consistency. The answers to the different aspects of the research questions were analyzed for agreement with each other. For example, the qualitative case studies might reveal that the participants were not always getting the correct answers to closed-ended questions for the proper reasons. This helped to identify other alternative conceptions.

Also, there was interpretive rigor because various methods of analysis were used on the same data. The researcher looked to find inconsistencies at each level of analysis by performing various data analyses on the same data. Also, the researcher has a degree in biochemistry and was qualified to do the data analysis on the concepts. The researcher has been trained at LSU to understand mixed methods research and has the skills to successfully complete the project.

The inferences took the current literature into consideration, in particular the work of Mintzes, Wandersee, and Novak (2000). This BDM research helped to answer some of the questions that they were not able to solve. The inferences extended the current state of knowledge.

Interpretive Agreement. Interpretive agreement or consistency was another dimension of interpretative rigor. The study used peer debriefing because other scholars need to agree that the
metainferences of this study were the most defensible interpretation of the results. Also, the researcher made many conference presentations of the inferences for multiple analyses of the inferences. The participants’ construction of knowledge was important and member checks helped to establish that the participants were in agreement with the inferences. Interpretive distinctiveness was another dimension of interpretive rigor. The inferences were distinctively superior to other interpretations of the same findings according to the literature review. BDM considered the psychological, technological, and the educational analysis while using rigorous research methods. Also, the mixed model approach allowed for superior inferences because the qualitative and quantitative components were stronger together than they were alone. Other plausible explanations to the findings were considered and eliminated.

Transferability

Tashakkori and Teddlie defined inference transferability as “an umbrella term that refers to both the quantitative term external validity and the qualitative term transferability” (Tashakkori & Teddlie, 2003, p. 37). They suggested that mixed methods inferences are “more transferable than inference of either qualitative or quantitative components. This assumption is based on the gestalt principle that the whole is bigger than the sum of the parts” (Tashakkori & Teddlie, 2003, p. 42). Using the sequential mixed model design of Tashakkori and Teddlie (2003) for the BDM research increased the inference quality of the study. The following is an analysis of the various types of transferability (Tashakkori & Teddlie, 2003) related to the BDM study.

Ecological Transferability. Ecological transferability “refers to the generalizability or applicability of inferences obtained in a study to other settings or contexts. It subsumes the quantitative terms ecological validity and ecological external validity as well as the qualitative
term transferability” (Tashakkori & Teddlie, 2003, p.707). BDM has ecological transferability to other science units that have molecular applications. Many other chemistry and biology units has concepts similar to photosynthesis and cellular respiration. Also, the use of the 3 types of technology makes it transfer to most other learning situations. The interviews helped to establish this.

Operational Transferability. Operational transferability is “the degree to which the inferences that were made on the basis of the results of the study are generalizable to the other methods of observing/measuring the entities or attributes that the inference is about. It subsumes the quantitative, terms external validity of operations, and operational external validity” (Tashakkori & Teddlie, 2003, p. 712). The comparison of students who use BDM to those who use traditional methods increased this transferability.

Population Transferability. Population transferability “refers to generalizablity or applicability of the inferences obtained in a study to other individuals or entities. It subsumes the quantitative terms population validity and population external validity as well as the qualitative term transferability” (Tashakkori & Teddlie, 2003, p. 713). Since there were various strata of samples, there was an increase in population transferability. The tracking of high and low biology knowledge was very helpful for this.

Temporal Transferability. Temporal transferability “refers to generalizbility or applicability of inferences obtained in a study to other time periods. It subsumes the quantitative terms temporal validity and temporal external validity” (Tashakkori & Teddlie, 2003, p. 716). Time periods could be a threat to transferability of BDM findings since technology rapidly changes and the attitude of people toward technology changes. BDM technological learning strategy have been carefully designed to include only technologies that are not trendy.
Qualitative Data Analysis Using Concept Mapping as a Research Tool

Concept maps have been shown to be useful tools for evaluating conceptual understanding (Markham, Mintzes, & Jones, 1994; Martin et al., 2000; Novak, 1990; Thompson & Mintzes, 2002; Wallace & Mintzes, 1990). Concept maps support Ausubel’s theory of meaningful learning (Novak, 2002) which underlies the hierarchical structure of the concept map (Hoz, Bowman, & Chacham, 1997). The students showed their ideas as a concept map which is a spatial arrangement of concepts and their mutual relationships in a layout that may have a similarity to the semantic network. Concept maps help to reveal cognitive structure and its validity has been validated with much research (Hoz et al., 1997).

History. Ausubel, Novak and Gowin began to develop concept maps in the early 1970’s and concept maps have become vital tools in education research. One of the 1990 issues of the Journal of Research in Science Teaching had a special issue devoted to concept maps and one article included 100 references related to concept maps (Alkunifed & Wandersee, 1990). Concept maps have been referred to as “alternative assessments” (Ruiz-Primo, Schultz, Li, & Shavelson, 2001). Much research has shown that concept maps are a potent psychometric tool that assesses conceptual change in the classroom and in experimental situations (Markham et al., 1994).

Probing Knowledge Structure. Concept mapping is a strategy that probes knowledge structures of learners and is used to represent and assess students’ conceptual knowledge, structural knowledge, or cognitive structure (Rye & Rubba, 1998). Novak and Gowin (1984) and Novak, Gowin, and Johansen (1983) recommend the use of concept maps with clinical research interviews to help evaluate the students’ understanding by allowing the development of interview questions and assessing student understanding as indicated in the transcripts. Concept
mapping is commonly used in education research (Hoz et al., 1997). The comparison of consecutive student concept maps examines the changes in content and organization of knowledge by emphasizing construction and uniqueness of student maps and is consistent with Human Constructivist Theory.

Concept maps have been used for research (McClure, Sonak, & Suen, 1999) and strike a balance between objectivity and sensitivity to the structure cited as the students’ knowledge structure is revealed (McClure et al., 1999). Concept maps are useful for diagnosis of students’ misunderstandings because the maps are sensitive to structure of student knowledge, distortions of knowledge, and errors of omission (McClure et al., 1999). They indicated that open-ended concept mapping provides an opportunity to assess students’ knowledge. They recommended keeping the mapping task simple and using a master map in the scoring (McClure et al., 1999).

**Complementary to Traditional Assessment.** Concept maps are complementary to traditional assessment. Concept maps assess abilities that are measured by conventional course assessments (Novak et al., 1983). Unlike conventional measure, concept maps are able to measure meaningful learning modes and the relationship among concepts (Markham et al., 1994). Markham, Mintzes and Jones (1994, p. 100) explained that “there appears to be general agreement among cognitive scientists and developmental psychologists that structural representations (such as concept maps) capture this configural property of knowledge better than any other presently available technique.”

**Analysis of Concept Maps.** Research on comparison of various types of mapping has compared filling a map vs. constructing a map from a blank page and showed that constructing a map from a blank page provided the more accurate data about the students’ knowledge and connected understanding. Scoring the map based on the proportion of correct propositions to
the total possible propositions seemed to be the most efficient indicator of knowledge. Talk Aloud protocols provided information about the cognitive activities that occurred while creating the map (Ruiz-Primo et al., 2001). Scoring can be done with the Novak and Gowin method (Markham et al., 1994) for scoring structural complexity and structural validity and the newer method of scoring structural change (Martin et al., 2000; Pearsall, Skipper, & Mintzes, 1997).

Concept maps are useful research tools and the following are statements that summarize their use:

1. Meaningful learning attaches new thoughts and concepts to prior knowledge in a specific way (Novak, 1977).

2. Concept maps are thought to be a valuable instructional vehicle for providing meaningful learning described by Ausubel (Horton et al., 1993).

3. Previous studies show that there is little difference in the effectiveness of teacher-prepared concept maps when compared to student-prepared concept maps in providing student achievement (Horton et al., 1993).

Concept maps were central to this BDM research because the concept map is a graphic metacognitive tool (Rye & Rubba, 1998; Wandersee, 1990) that facilitates the externalization of students’ understanding. Concept maps with interviews allow for more reflection than without interviews (Rye & Rubba, 1998). Concept maps are used to analyze the restructuring of learners’ knowledge (Martin et al., 2000) and concept maps are effective at determining how students integrate knowledge into their present structure (Nicoll et al., 2001).

**Cognitive Significance of Protocols, Including Wait Time**

Wait time may be particularly important to allow students to fully access their knowledge domains (Anderson & Demetrious 1993). The researcher consciously included wait time after each question was posed to the participant.
Summary

Although the focus of the research is on learning photosynthesis and cellular respiration, BDM has broad application throughout the sciences. BDM is an integrated instructional technology-scaffolded learning strategy that utilizes visual fields and animation to help students construct meaningful conceptual understanding of an integrated view of photosynthesis and cellular respiration. BDM learning strategy has a complex and diverse theoretical foundation, which is supported by well-established learning theories. BDM is a unique learning strategy supported by the TIVF. The TIVF states that meaningful knowledge is hieratically constructed using the past present and future visual fields, with visual metacognitive strategies that are derived from the principles of Visual Behavior (Jones, 1995), Human Constructivist Theory (Mintzes & Wandersee, 1998a), Visual Information Design Theory (Tufte, 1990, 1997, 2001) and Neisser’s Perception Model (Neisser, 1976).

The following is a summary of the major theories and principles. The Principles of Visual Behavior of Jones (1995), which state that with their perception the learner creates the visual space of what they see now in the present visual field and what they have seen in the past visual field, and what they anticipate seeing in the future visual field. Visual perception involves past experience and future actions projected onto the present visual space. The Human Constructivist Theory learning methods of Novak, Mintzes, and Wandersee (1998a) hold that meaningful learning is constructed by linking propositions into a hierarchical network by using metacognitive tools. The communicative and instructive Visual Information Design of Tufte (1990, 1997 and 2001) suggests that the construction of a graphic indicates the thought process and the process of arranging the elements in the graphic leads to insight. The Perception Model of Neisser (1976) explains that the learner has prior knowledge, which is hierarchically arranged
and forms a schema. The schema directs perceptual exploration. Everyone's schema is unique due to different prior experiences, and, therefore, their individual perceptions are not the same.

The TIVF is the foundation of BDM and BDM learning strategy allows for the actualization of the TIVF. A number and variety of theories support the fundamental design of BDM, and strengthen its foundation.
METHOD

This section considers the research design. The research design was mixed methods which allows for the strengths of qualitative and quantitative methods. The qualitative component of twenty-four students allowed for depth of understanding beyond just one word or phrase of words answers for analysis. The quantitative component was based on the analysis of multiple-choice item analysis of 263,267 examinations from the 1990, 1994, 1999, and 2002 Biology Advanced Placement Examinations (CEEB, 2004; ETS, 1992; 1994; 1999). The information derived from the quantitative analysis was used to prepare for the qualitative component. The qualitative component was based on data collection composed of case studies that include co-concept mapping and visual field mapping, surveys, and observations. An *a priori* and emergent approach was used during the data collection. The data analysis included Chi’s (1997) qualitative and quantitative verbal analysis, the constant comparative method, and Spradely's Developmental Research Sequence (1980). Also, analysis software was used. There were 11 phases to the data collection to determine the value added from each BDM instructional strategy to the students' understanding of photosynthesis and cellular respiration. This exploratory study gathered 160 hours of qualitative data and provided a deep analysis of BDM learning strategies.

Overall Research Design

This research study was an exploratory investigation to determine the value added to students’ knowledge of photosynthesis and cellular respiration by each of the three BDM learning strategy components that form a unit of study on this topic. The study had one confirmatory component. The alternative conceptions of the Biology Advanced Placement students were compared to the selected students of the case study. The research was applied
research since the research was to add knowledge that helped people understand the problem of teaching and learning photosynthesis and cellular respiration and help resolve it (Patton, 2002).

The research question was best answered using a Multiple Case Study/Sequential Mixed Model Design (Tashakkori & Teddlie, 2003), which employed elements of both qualitative and quantitative methodologies during data collection and analyses. The research design is shown in Figure 14.

The units of analysis were the individual students’ conceptual framework for photosynthesis and cellular respiration of students who participated in the study. Instructional components included the professor’s lectures/visuals, assignments, exams, and the six BDM instructional phases. Subordinate units of analysis were: instruction learning skills, prior knowledge, and motivation. Decisions about research design were determined with respect to the unit of analysis (Yin, 2003).

The focus of the study was to identify the knowledge representation maps, Visual Field Perception Maps™, and learner profiles of high and low achievers with and without BDM learning strategy to determine the value added from each strategy; biological literacy levels (Bybee, 1993) were used to analyze the value added. Therefore, this study was a comparative case study with multiple cases. Case study methods of Yin (2003) were used. The case studies focused on knowledge construction and the interviewer and participant co-constructed concept maps and the participant did object sorting as part of the interview (Griffard, 1999). The Think Aloud Procedure (Chi, 1997) was used with those portions of the interview that concerned the concept map. The Think Aloud Procedure has shown that it does not change the status of the participants' knowledge with additional learning. The participants said what they thought as they constructed the maps and no explanations were requested. Chi's Verbal Analysis (1997) was
**Hypothesis:**
* Biology AP Exam item analysis of multiple choice questions are indicators of student alternative conceptions of photosynthesis and cellular respiration.

**Data Collection (Testing):**
- multiple choice item analysis from 1990, 1994 1999 and 2002 Biology AP Exams \((N=263,267)\)

**Data Analysis:**
- Descriptive Statistics

**Inferences:**
- Profile of alternative conceptions/knowledge representation of students.

**Questions:**
* What is the value added to high and low achieving students’ knowledge representations and visual fields as each of the 3 instructional strategies of BDM is included in instruction?  
* What is the student’s knowledge representation and visual field with BDM instruction compared to those without BDM instructional strategies?

**Data Collection:**
- Case studies- Interviews (Think Aloud with co-concept mapping, visual field mapping), *surveys, *observations \((a\ priori\ and\ emergent)\)  
  \(n=6\) high achiever with BDM (AP)  
  \(n=9\) low achiever with BDM (nonAP)  
  \(n=4\) high achiever without BDM (AP)  
  \(n=5\) low achiever without BDM (nonAP)

**Data Analysis:**
Chi’s qualitative and quantitative verbal analysis, constant comparative and Spradley’s DRS.

**Inferences:**
Learning profile of:
- high and low achievers with and without BDM strategies.

**Knowledge representation maps and visual field map with interpretation for high and low achievers with and without BDM strategy.**

**Metainferences:**
Various profiles of the value added to learning with BDM strategies indicate the effectiveness of the program for various levels of achievers. Plans for developing BDM are determined and methods for reducing alternative conceptions are identified.

Figure 14. BDM research design: Sequential Mixed Model (Tashakkori and Teddlie, 2003).
used to analyze the data. The case studies also had discussions about their Visual Field Worksheet which helped to reveal their changes in visual fields. Selected Biology AP Exam questions were also answered and discussed. The interviews were emergent and items were pursued as there was opportunity.

The details of the Sequential Mixed Model research design are included in Figure 14. For more details see Figure 1, The Vee Diagram, and Figure 2, The Flow Chart of Research.

**Sampling**

Since the goal of the research was to profile the knowledge representation and visual fields of different achieving levels of students in depth, the qualitative section involved a small number of participants which were selected stratified purposively. The selection criteria was based on equal verbal and math ability level, but different prior biology knowledge as indicated by completion of a Biology AP course. The quantitative item analysis of the Biology Advance Placement Examinations from 1990, 1994, 1999, and 2002, courtesy of Educational Testing Services, which involved the entire population of test takers for those years.

**Course Description and Selection Processes**

The students were enrolled in a traditional Biology majors’ introductory biology course. The course met three times per week for 50 minutes. The course used a popular majors’ introductory biology book and most of the content was delivered with lectures that used Microsoft® PowerPoint® 2003 slides. The course lecture Microsoft® PowerPoint® 2003 slides were made available to the students for study with the Internet. The course was selected because of the importance of introductory biology courses in a biology major’s success (Halyard, 1993).

**Research Site, Instructor Description, and Selection Process**

Energy University, EU, (a pseudonym for the research site) has a Carnegie classification of a Doctoral/Research University-Extensive – which is an institution that offers a wide range of
baccalaureate programs, and is committed to graduate education through the doctorate, and the university awards 50 or more doctoral degrees per year across at least 15 disciplines. More than 80 percent of Energy University students plan to go on eventually to graduate or professional school. Shortly after graduation, 10 percent enter medical school; 16 percent, law school; and 32 percent, other graduate study. Just over one third accept jobs. Energy University’s students are among the country's most likely to be selected for several prestigious fellowships that support postgraduate study. Energy University is a national independent university in the South with approximately 5,600 full-time undergraduates and 85% of the students are from out of state. There are students from the 50 states and foreign countries. U.S. News & World Report ranks it in the nation's top quartile. The site was selected because the university taught a traditional introductory majors’ biology course to students from across the United States and the Biology AP Examination data is from students across the nation. The instructor has received many teaching awards, is concerned with educational objectives, and recognizes the importance of the introductory level courses in the curriculum. Also, the researcher is familiar with the instructor and has had a good working relationship with the instructor.

Institutional Resource Board’s (IRB) exemption forms and other requirements were submitted to the researcher’s university and to the university of the participants (Appendices A-N). Table 6 summarizes the researcher’s university (Appendices A-E) and Table 7 summarizes the items submitted to the participants’ university (Appendices F-N).

Participant Recruitment Process

During the first week of the selected introductory majors’ biology class, the researcher gave a brief description of the project to the participating class. The students were given a written description of the biology education research project which is located in Appendix H and
Table 6

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<td>A</td>
<td>Application with Approval for Exemption from IRB Oversights</td>
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<td>B</td>
<td>Abstract of Study with Approval</td>
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<tr>
<td>C</td>
<td>Interview Protocols</td>
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<td>D</td>
<td>Questionnaire</td>
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<td>E</td>
<td>Louisiana State University-Baton Rouge: IRB for Human Research Consent Form</td>
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Table 7

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<th>Appendix</th>
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<td>F</td>
<td>Request For Expedited IRB Review and Approval Letter</td>
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<td>G</td>
<td>Consent Form</td>
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<td>H</td>
<td>Biology Education Research Project with Cell-101 Class (Professor Lucia Crickson’s Section)</td>
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<td>I</td>
<td>Application for Participation in Biology Education Research Project with Cell 101 Class</td>
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<td>J</td>
<td>Consent to Audio-or Video- Taping and Transcription</td>
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<td>Questionnaire</td>
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<td>Interview Protocols</td>
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<td>Visual Field Perception Map Heuristic™</td>
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<td>N</td>
<td>BioDatamation™ Strategies for IRB Forms</td>
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an Application for Participation in Biology Education Research Project (Appendix I) which has requirements to participate and a form for the student to complete requesting participation in the project. It was mandatory that the student be in the one section of major biology taught by the selected professor, at least 18 years of age from an urban or suburban educational and residential background and a U.S. resident. All students in the introductory college level biology course of the participating professor were invited to volunteer to participate in the research study. The residency requirement was necessary due to the AP Biology sampling demographics and the size of the participant pool while the urbanization requirement is in response to the recently
presented findings of Kao and Su (2004) regarding differences in the understanding of photosynthesis and cellular respiration between rural and urban students in elementary and secondary schools.

**Participant Selection Process**

Twenty-four students were selected. Interviews were conducted to select six students of high and nine of low academic ability instructed with the BDM learning strategy and interviews, and this group of fifteen were termed the Merged BDM Group. Also, a second group of nine students of similar academic profile was selected for evaluation with baseline, post lecture, post strategy, and delayed interviews, but they did not receive BDM instruction and were termed the Comparison Group. They received visual field instruction consisting of the relationship of past, present, and future visual fields at the clinical interviews and traditional instruction. The selection was purposive intensity sampling: applicants with prior Biology AP high school courses were characterized as “high biology knowledge” and those with no prior Biology AP course in high school were considered “low biology knowledge.” All students selected completed a Consent Form (Appendix E) for the researcher’s university, a Participant’s University Consent Form (Appendix G), and a Consent for Audio- or Video-Taping & Transcription (Appendix J).

Pseudonyms were assigned to each student. In the BDM Extended Analysis Subgroup (BDM EAS), names that began with “B” were assigned, while those in the Comparison Group had names that begin with “N.” Also, those participants in the Merged BDM Group with no extended analysis interviews were called BDM Overall Analysis Subgroup (BDM OAS) were given pseudonyms with the letter “S.” The assigned research pseudonyms were: Baxter, Bella, Bertha, Beth, Brandon, Bridgette, Brooke, Bunny, Sabrina, Sage, Shelly, Sherlock, Stephanie,
Susie Q, Sylvia, Nancy, Natalie, Natasha, Neka, Nick, Niomi, Nicole Sonia, Norma Jean, and Norman.

Data Collection

Clinical Interviews

Due to the fact that this study had no risks to the participants, this study requested an exemption from oversight by the researcher’s university Institutional Review Board (Appendix A), and an “Expeditied Exemption” (Appendix F) was requested from the participant’s university because their university students were involved. Assurances included anonymity for all participants and transcriptions of the recorded interviews by the researcher and a paid transcriptionist. Transcriptions and all subsequent analysis and public presentation used nonidentifying pseudonyms.

BDM instructional activities did not last more than two hours. All BDM EAS sessions had an interview. The interview did not exceed one hour in length and were administered to each student. Since two hours is the length of a typical college biology laboratory, the time of these sessions was reasonable. A previous study (Griffard, 1999) used a similar scheme and it was successful.

Scheduling

Clinical interviews were scheduled with 24 participants in a small area in the research lab of their professor. The researcher assessed their knowledge and alternative conceptions of photosynthesis and cellular respiration by interviewing them and administering questionnaires ( Appendices D and K ) to all of them at the beginning, middle and end of the research (designated as Phases 2, 3, 11, and 12). The nine that did not receive BDM instruction, the Comparison Group, received visual field instruction analysis and traditional instruction
(Appendix S). However, this instruction was not integrated with BDM learning strategies. Eight of the fifteen participants, the BDM EAS, received six one-hour BDM instruction sessions, developed by the researcher (Appendix S), Phases 4 - 9, and an interview after each session. The other seven participants, the BDM OAS, received three two-hour BDM instruction sessions with an interview after each session. All participants were interviewed at phases 2, 3, 11, and 12. After the instruction of each phase, the researcher conducted interviews and surveys to determine if there was a value added at each phase to the participants’ learning in the BDM EAS.

This BDM research was conducted outside of the scheduled times of the General Biology class and did not interfere with scheduling or course content. Participants signed consent forms (Appendices E and G) and the study required no more than 20 hours of each participant's time. Participants were referred to by pseudonym and their identity remained confidential at all times. They could have ended their participation at any time during the study if they so wished. They were reimbursed for their time with a stipend of seven dollars per hour, and this study did not interfere with the participants’ performance in the normally scheduled General Biology course.

**Recording Interviews**

All interviews were videotaped and audiotaped for the purpose of data collection. Term sorting was used for the concept mapping, which was created using Cmap Tools. Participants created slide presentations in Microsoft® PowerPoint® 2003 which were saved and duplicated.

**Questioning During Interviews**

Participants were asked planned questions throughout the structured, open-ended interviews. Some questions were asked *ad hoc* in response to the emerging data. The researcher’s deep knowledge of photosynthesis and cellular respiration was a resource. A wait-time of five seconds was used to allow the participants time to gather their thoughts. The
researcher was careful to remain neutral and avoid giving cues to responses so that the
participant was not directed by the researcher’s positive or negative response. The researcher
was aware of body language, facial expression, and comments with regard to this situation. The
ad hoc questions helped to expand on gaps and to better define the knowledge representation and
profile of the participants.

**BDM Group: Interview Protocols and Instructional Materials**

The following describes the interview protocols of each phase of the research:

**Phase 1 (Pre-Interview Preparation).** Quantitative analysis of Biology AP Exam
multiple-choice item analysis was performed to help determine alternative conceptions. The
analysis is in Appendix O.

**Phase 2 (Baseline- Prior Knowledge -Interview A).** The following data were gathered at
the beginning of the course before photosynthesis and cellular respiration were taught to the class
and administered to all 24 participants.

1. Introductions about the BDM study.
2. Provide agenda and information about the study.

Steps 3-6 pertain to the details of the clinical interviews. Baseline individual interviews
about photosynthesis and cellular respiration and their relationship and pre-visual field
measurement were determined by individual interviews (1 hour/student) as outlined below.

3. Think-aloud initial activity was used to determine literacy, and was a material sorting task.
The materials were: bread, piece of wood, head of cabbage, yogurt, pill bugs, cup of water, flash
light, cup of soil, plant in a jar with top closed tightly, animal in a jar with top closed tightly, jar
of Kimchee, Ziploc® bag label with oxygen, Ziploc® bag label with carbon dioxide, mushroom,
and red bean. Ten minutes were allowed for the activity.
The following directions were given to the participants before they began to sort the objects:

A. Sort the objects into living, at one time living, and nonliving and explain why.
B. Sort the objects into categories of photosynthesis and cellular respiration and explain why.

The purpose of this activity was to help give an overall level of photosynthesis and cellular respiration knowledge, and biological literacy.

4. Term sorting task and modified co-concept mapping was done using dragging and dropping of terms on a computer screen using graphic software, and required about 10 minutes. The participants had to sort the terms into the categories of photosynthesis, cellular respiration, both photosynthesis and cellular respiration, do not recognize, or recognize but can not define.

The terms to sort were:

Cellular Respiration - fermentation, Krebs cycle, heterotrophic mitochondria, NADH, oxidative phosphorylation, glycolysis.

Photosynthesis - autotrophy, Calvin cycle, carbon dioxide fixation, chlorophyll, chloroplast, light dependent reaction, NADPH, splitting of water, photophosphorylation, ATP, photons, photosystems, thylakoid.

Both Cellular Respiration and Photosynthesis - ATP, ATP synthase, carbon dioxide, chemiosmosis, cytochromes, electrons, glucose, electron transport, both endergonic and exergonic reactions, hydrogen ions, intermediate e- acceptor, oxygen, redox reaction, autotroph, water.

The following directions were given:

A. Choose the concepts that you recognize from the left side of the screen.
B. Give a simple oral definition of each term recognized.
C. Now we will create a map that shows how you think about the concepts and how they are related. We will begin with the most general idea and then take the others and group them under the most general idea to work our way to the most specific ideas.

D. Now type a linking work between each pair of words that tells the relationship between the terms.

E. Are there any changes that you would like to make in your map (arrangement, concepts or links)?

5. The concepts were interpreted with the chloroplast and mitochondria models. Students used the models to compare and contrast the parts of the chloroplast and the mitochondria for the photosynthesis and cellular respiration during this section of the interview. Students were requested to label parts and explain the structure and function of each part. Students were specifically requested to explain chemiosmosis using pinheads as hydrogen ions. The interview continued with specific questions about the processes of cellular respiration and photosynthesis.

6. Using the Visual Field Perception Map Heuristic™, visual perception was determined. The following are the directions:

Visualizing is a mental image of what you know or understand.

A. From your past what do you visualize about your experiences with photosynthesis and cellular respiration? The items that they sorted are in their view to help students to remember.

B. How do you visualize your present experience with photosynthesis and cellular respiration?

C. How do you visualize your or other people’s future experiences with photosynthesis and cellular respiration?

D. How do your visualizations of your past, present, and future help you understand photosynthesis and cellular respiration concepts?
7. Students discuss learning of photosynthesis, cellular respiration, metacognition and BDM strategies with researcher through *a priori* and emergent questions.

8. Pre-BDM Introduction Instruction was given in order to briefly explain concept mapping, visual fields, WebQuest-style activities, data collection, and Microsoft® PowerPoint® 2003, and samples are included in Appendix N.

   Phase 3 (Post Lecture Knowledge After Class Presentations- Interview B). The steps were repeated with all participants after the normal Energy University class material on photosynthesis and cellular respiration were presented.

   Phases 4 – 10 (BDM Phases of Instruction and Post Strategy Interviews C- K). In phases 4 -10 there was a BDM instruction and then interviews that followed the interview protocol of Phase 2, steps 3 - 6. There was also a dedicated interview after BDM instruction as to the interrelationship of cellular respiration and photosynthesis. Those fifteen students that received BDM instruction participated in phases 4-10. The following summarizes phases 4 – 10 of the BDM instructional content and student tasks. The BDM instructional content are located in Appendix S. Only the BDM EAS received interviews after each phase of instruction.

   Phase 4 (Cellular Respiration Past Visual Field).

A. A Pre BDM Cellular Respiration Baseline, Prior Knowledge Interview was conducted.

B. Next, Past Visual Field Cellular Respiration Instruction (brief WebQuest-style activities and videos which are 1 hour maximum/student) was given to the BDM EAS and BDM OAS Groups. These materials were created by the researcher, and are located in Appendix S.

   Videos from a Korean Restaurant about making Kimchee that were created by the researcher were presented. These videos have real-life situations related to anaerobic respirations and subtitles were used to help direct attention to important events, and the video was simple and lacking of much detail.
The lesson “Making Kimchee: Tracking Microbes with Sensors” created by the researcher (Appendix S) with the characters Adele and Pierre helped the students understand the value of anaerobic respiration. It was related to cooking at a Korean Restaurant to help the student build familiar knowledge about anaerobic respiration. The visualizing agent, V. Fields™, guided students through their discovery of their visual field contents. Data collection and analysis with the Kimchee was introduced.

C. Then, BDM Past Visual Field Cellular Respiration Interviews were conducted as outlined (1 hour/student) with the BDM EAS. These interviews were designed to build and reveal prior knowledge obtained at each phase.

Phase 5 (Cellular Respiration Present Visual Field).

A. The BDM Present Visual Field Cellular Respiration Instruction (data collection and brief animated Microsoft® PowerPoint® 2003 Presentations and videos) (1 hour maximum/student) were given to each student. Special annotated animated Microsoft® PowerPoint® 2003 presentations (see Appendix R) that were layered from simple to complex were used to present the concepts of cellular respiration. (See Past Visual Field for more details.) Data Collection with graphing calculators or computers was used to help relate the real world to the chemical equations. Data were collected with Kimchee, and soil samples during labs created by the researcher and qualitative laboratories were done with bread, ATP, and fireflies (see Appendix T). Students set up lab apparatus and viewed the change in oxygen or carbon dioxide levels graphically as the data points appeared on the screen of the computer. The lab was related to making Kimchee faster. Then they analyzed the data with the data collection software.

B. BDM Present Visual Field Cellular Respiration Individual Interviews as previously outlined (1 hour/student) were conducted with each BDM EAS student, but students began with their concept map from phase 4.
Phase 6 (Cellular Respiration Future Visual Field).

A. BDM Future Visual Field Cellular Respiration Instruction (animated and annotated student-created Microsoft® PowerPoint® 2003 presentations, viewing video clips, and data collection which was 1 hour maximum/student) were given to each student. A clip from the James Bond movie *Moonraker* (Gilbert, 1979) and an online broadcast from National Institute of Health on Alzheimer’s disease relating a real world problem to cellular respiration concepts were viewed. The session included the experiment called “Cellular Respiration and the Mystery of the Mexican Jumping Bean” created by the researcher (Appendix S). The students then created annotated animated presentations to address the case problem about how to make more Kimchee faster. The students were given a Microsoft® PowerPoint® 2003 toolbox of images and captions which is located in Appendix U. It was a modified lab report that contained layered information from the basic to the complex concepts (according to a rubric of information layering), and at least one annotated animation in each of the following sections: a brief introduction about the biology background of the problem, methods of how they did their investigation, results that include some sort of ‘living graph’ that shows the visual differences of the results of the Kimchee production and quantitative data, and recommendations about the problem’s solution. The students used software similar to TechSmith’s Camtasia™ or Microsoft’s Producer 2003® to add narrations.

B. BDM Future Visual Field Cellular Respiration Individual Interviews (1 hour/student) were conducted with each BDM EAS student, which began with their concept map from phase 5.

Phase 7 (Photosynthesis Past Visual Field).

A. The BDM Past Visual Field Photosynthesis Instruction (brief videos and WebQuest-style activities which is 1 hour maximum/student) were given to each student. An animated
PowerPoint® presentation (Appendix R) was included. This phase was similar to Phase 4, but the WebQuest-style activities and videos were centered on a problem that farmers are having growing their crops. A video clip on the dust bowl from *The Grapes of Wrath* and a story of the Victory Gardens in World War II created by the researcher were presented. A “Junior Mint® Chloroplast Home Study Kit” created by the researcher (Appendix S) was given to each participant. A lesson with twigs of *Elodea* with bromthymol blue demonstrated photosynthesis (Appendix T). Moss balls were also used to demonstrate photosynthesis in a lab called “Made in the Shade” created by the researcher (Appendix S). Another lesson was using tangerine sections to simulate guard cells that surround the stoma to regulate the exchange of gasses (Appendix T). The participants also did paper chromatography with cabbage leaves to see separation of the various pigments.

B. The Past Visual Field Photosynthesis Individual Interviews as outlined (1 hour/student) were conducted with each BDM EAS student.

Phase 8 (Photosynthesis Present Visual Field).

A. The BDM Present Visual Field Photosynthesis Instruction (data collection and brief videos, which was 1 hour maximum /student) were given to the student. This phase was similar to Phase 5, but the Microsoft® PowerPoint® presentation (Appendix R) was centered on photosynthesis concepts in detail. An activity using iron filing on a special diagram of a plant and a magnet created by the researcher (Appendix S) was conducted. The experiment “The Hunt for the Red Mulch” created by the researcher (Appendix S) was performed. This experiment demonstrated the increase in photosynthesis in red light reflected by red mulch. The spinach leaf experiment was included (Appendix T) to show the production of oxygen from the splitting of water.

B. The Present Visual Field Photosynthesis Individual Interviews as outlined (which was 1 hour/student) was conducted. Participants then created a new concept maps.
Phase 9 (Photosynthesis Future Visual Field).

A. The BDM Future Visual Field Photosynthesis Instruction (animated and annotated participant-created Microsoft® PowerPoint® 2003 presentations at one hour maximum/student) reviewed concepts by explaining C₃, C₄, and CAM plants. Current research from Massachusetts Institute of Technology was presented to explain using photosynthesis as an energy source (Halber, 2004). Participants created an animated PowerPoint® presentation that concerned red mulch. The participants viewed a demonstration of the DPIP blue dye (Appendix T) used as NADP⁺ in the light reaction of photosynthesis.

B. Future Visual Field Photosynthesis Individual Interviews as outlined (1 hour/student) were given, but students began with their map from phase 8.

Phase 10 (Post Photosynthesis and Cellular Respiration Relationship Knowledge and BDM Analysis). The relationship between photosynthesis and cellular respiration and postVisual Perception measurement were determined by individual interviews as outlined (1 hour/student) with the BDM participants. A large map of photosynthesis and cellular respiration terms were mapped to determine the cross links between the concepts.

Phase 11 (Delayed Interview). Cellular respiration, photosynthesis, relationship of cellular respiration and photosynthesis and visual perception field measurement, and overall comments about BDM learning strategy were considered in individual interviews with students (1 hour/student). This phase was administered to all groups, BDM EAS, BDM OAS, and the Comparison Group.

Phase 12 (Debriefing Interview). The researcher discussed the design of the research with the participants. The participants reviewed and analyzed research results with the researcher. This phase was administered to all groups.
Comparison Group: Interview Protocols and Instructional Materials

A. Instruction. The first hour of instruction began with a review of difficult questions from the Official Energy University Second Introductory Biology Class Exam on photosynthesis and cellular respiration. The format of the session was similar to a focus group, and the topic was how to get a better understanding of cellular respiration and photosynthesis. The researcher used the dry erase board to explain the answers with diagrams and notes. The next part of the session involved the researcher demonstrating the making of yogurt and tracking its progression qualitatively (Appendix S). The process was explained on the dry erase board along with the demonstration.

The second hour of the session was participants conducting the lab Basic Fermentation BioKit® by Carolina Biological Supply (Appendix T). The next part of the session used old fashion respirometers to track the aerobic cellular respiration of various organisms with Biology AP Laboratory 5: Cell Respiration (CEEB, 2001). An animation from The Biology Place (Pearson, 2005) for Biology AP Lab 5 was viewed and discussed.

The third hour and fourth hour session began with an analysis on the difficult photosynthesis questions from the participant’s official second course exam. The participants worked on a brief lab report on aerobic and anaerobic cellular respiration as they watched the respirometers (Appendix T). After the lab reports were complete, the session continued with a demonstration of bromthymol blue and Elodea (Appendix T). DPIP was also demonstrated to show the function of NADP⁺ reductase. On the dry erase board the reaction of DPIP⁺ (blue in color) forming DPIPH (clear in color) was explained. Chromatography was also done by all the participants and the Rf values were determined (Appendix T).
In the fifth and sixth hour sessions the participants performed a lab called “Photosynthesis: The Light Reaction of Photosynthesis” modified by the researcher (see Appendix T). The lab was explained on the dry erase board. The participants placed punched spinach disks in water and watched them rise with the production of oxygen. Then the participants did a chromatography experiment with various plants. The “Dissolved Oxygen and Aquatic Primary Productivity,” Biology AP Laboratory 12 was demonstrated and discussed. The researcher used these topics to relate the importance of photosynthesis to the participants. Table 8 illustrates the phases of interviews and the group of participants involved in each phase. The gray shaded areas identify the stages for the BDM Overall Analysis Subgroup, the Extended Analysis Subgroup and the Comparison Group. The unshaded areas are the phases only for the BDM Overall Analysis Subgroup and the Comparison Group. The black shaded areas are only for the BDM Extended Analysis Subgroup.

Table 8

<table>
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<tr>
<th>Phases of Interviews for BDM and Comparison Groups</th>
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<tr>
<td></td>
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<tr>
<td>BDM Extended Analysis Subgroup</td>
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<tr>
<td>nonAP</td>
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<tr>
<td>BDM Overall Analysis and Comparison Groups</td>
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<tr>
<td>nonAP</td>
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B. Interviews. The interview protocol for the Comparison Group was identical to the BDM Group. The previous section explains the protocol.
Use of Technology in the Study

This study made extensive use of technology in both the BDM strategy and in the study infrastructure. All research data collection was performed digitally as was most data manipulation and analysis. The only exception in manipulation and analysis of research data was the manual generation of some statistics before the SPSS program was available for use. After its availability, SPSS greatly decreased the time required for statistical calculations. Even the researcher’s note taking was performed on a tablet PC. This note taking was performed with Windows Journal with a Tablet PC.

In order to ensure data backup and portability approximately twelve removable memory sticks ranging in capacity from 256 megabytes to 4 gigabytes were used for file storage and file transfer between the seven laptop PC’s and the single desktop used in the course of the study. Further dedicated backup capacity was provided by a CMS brand automatic backup system utilizing the BounceBack® Professional software (CMS, 2003) to ensure complete restorability of data in the event of human error or act of God. Additional backup and storage capacity was available on a Buffalo LinkStation™ which also served as a file server.

The actual technology used in the course of the BDM strategies included four laptops for use by the participants at an average usage of two participants per laptop per session. The researcher used an additional two laptops to run presentations and demonstrations due to projector compatibility in the two conference rooms used. Because the conference rooms were not dedicated classrooms with a preinstalled or preconfigured technology infrastructure, there were initial compatibility problems in each venue but these technological concerns declined in importance rapidly as permanent fixes were found by the researcher. In a dedicated classroom
used for a full semester of teaching, such compatibility problems would likely be resolved as rapidly as other, more traditional venue difficulties.

The actual hardware used for display was a pair of digital projectors, one in each conference room. These projectors interfaced with minimal problems, which were resolved with a few settings changes on the laptops. The students encountered no significant problems in the interface between their laptops and the Vernier hardware used in the laboratory exercises.

The student laptops were interfaced with an equivalent number of Vernier sensors including turbidity sensors, carbon dioxide sensors, oxygen sensors, conductivity sensors, pH sensors, and microphones (used for recording the frequency of Mexican jumping bean movements). These sensors were accessed by the computer with the Vernier Lab Pro® interface and Logger Pro® software which ensured easy compatibility and calibration with same brand sensors.

Students also used Microsoft® PowerPoint® to implement BDM strategies designed to engage all three visual fields. These presentations were assembled from elements that had been prestaged onto the individual computer hard drives by the researcher. There were no technical problems encountered in these exercises and user error was minimal following a brief walkthrough of PowerPoint® features by the researcher with the participants.

During their individual interviews, the participants performed all exercises on a laptop computer. The software used for concept mapping was the Cmap Tools Knowledge Modeling Kit® distributed by the Institute for Human and Machine Cognition (Canas, 2004). Cmap is a very simple program and was used under the supervision of the researcher; there were neither human nor technological problems with its use.
The preparation of the actual manuscript was undertaken on a Microsoft® Windows desktop PC using the Word® component of the Office® XP Suite. Subcomponents of the manuscript were then prepared on laptops and added to the main document to allow simultaneous composing and editing. Academic citations were performed automatically by the EndNote7® software available from ISI Researchsoft. While there were initial teething problems, Endnote’s ability to automatically update references and the table of works cited saved considerable time and allowed a significantly smoother finished product.

**Data Analysis**

**Value-Added Assessment Analysis**

Value-added was a way of comparing assessments to determine whether a student, subject, or group was performing better or worse over a period of time. The use of value-added comparisons allowed for the comparison of the present achievement with past history of achievement (Stone, 1999). The research methods of BDM used value-added in relationship to assessment. The term value-added assessment analysis (VAAA) were used to pertain to knowledge representation and visual perception. According to a research report "value-added performance data can play an important role in aligning polices, resources, and instructional strategies" (Drury & Doran, 2003, p. 1). The VAAA allowed the determination of the students’ change of knowledge with respect to themselves or to the group. Because VAAA allowed for judgment on the grounds of success in producing actual achievement, it extended beyond a quantitative test score by including learning characteristics such as knowledge structure, visual perception, metacognition, and disposition towards technology. One can see how the value-added processes work in the information systems of Taylor (1986).
Qualitative Data Analysis

Qualitative Data Analysis, QDA, was used to analyze the various “thick” descriptions of the observations, interview transcripts, concept maps, perception map heuristics, and open-ended questions. The constant comparative method (Lincoln & Guba, 1985) was used to help utilize and categorize the information. Chi's (1997) verbal analysis method, which is similar to the constant comparative method of Lincoln and Guba (1985), helped to determine alternative conceptions and was also used in conjunction with the constant comparative method. The information about knowledge representation from the interviews was summarized into a knowledge representation map (which is similar to both taxonomy analysis and social network diagrams).

For further scrutiny of the data, Spradley's (1980) Developmental Research Sequence (DRS) methods of analysis were used. The major analysis steps of the DRS were: making a taxonomic analysis, making selected observations, and making componential analysis.

These qualitative data analysis methods were applied to the research questions: What is the students’ knowledge representation with BDM instruction compared to those with traditional instruction? How does the knowledge representation change as each instructional strategy of BDM is added to instruction?

Mixed methods analysis of quantitizing the data were used. The quantitative Biology Advanced Placement Exam test data were used to analyze the questions and the item analysis of the answers. The alternative conceptions were derived from the quantitative data and the verbal description (profile of alternative conceptions). The qualitized quantitative data from the 1990, 1994, 1999, and 2002 Biology Advanced Placement Examinations, and is the profile of alternative conceptions that were derived from this qualitized data is given in Appendix O.
These alternative conceptions were determined in the interviews (i.e. were triangulated with the alternative conceptions that were determined with the qualitized data). This is an example of mixed data analysis.

The qualitative answers of the survey were scored into rubrics to generate quantitative data for analysis, thereby quantitizing the data (Tashakkori & Teddlie, 2003). The constant comparative method determined the participant alternative conceptions about biology that emerged from data analysis.

Using both qualitative and quantitative data analysis methods allowed for a mutual transfer of information and facilitated the answering of the “sequential mixed model research question”: What is the value added to high and low achieving students’ knowledge representations and visual fields as each of the three instructional strategy components of BDM is included in instruction? What are the students knowledge representations and visual fields with BDM instruction compared to the same parameters for students without BDM instructional strategy?

**Concept Map Scoring**

A selected set of terms was used for scoring the participants’ literacy with concept maps. For each proposition, two points were assigned. Three points were assigned for any proposition beyond the given set of terms. One point was assigned for a proposition that was not properly linked with other terms in the set. One point was assigned for the first branch and three points were assigned for each successive branch. Five points were assigned for each level of hierarchy. Each cross link to another term was assigned ten points. Each example was assigned one point.

Terms that were assigned for cellular respiration were: ATP, ATP synthase, carbon dioxide, chemiosmosis, cytochromes, electrons, electron transport, both endergonic and
exergonic, fermentation, glucose, glycolysis, heterotrophic, hydrogen ions, intermediate e-acceptor, Krebs cycle, NADH, oxygen, oxidative phosphorylation, photons, redox reaction, and water.

Terms that were assigned for photosynthesis were: ATP, ATP synthase, autotrophy, Calvin cycle, carbon dioxide, carbon fixation, chemiosmosis, chlorophyll, chloroplast, cytochromes, electrons, electron transport, both endergonic and exergonic reactions, glucose, hydrogen ions, intermediate e-acceptor, light dependent reaction, NADPH, oxygen, photons, photosystems, photophosphorylation, redox reaction, splitting of water, thylakoid and water.

**Analysis of Clinical Interview Protocols**

A modified form of Chi's (1997) verbal analysis method was used to analyze the protocols from the clinical interviews. This analysis included the participants' gestures and utterances as they performed the task. The data were not sampled as recommended by Chi because it was anticipated that interviews would develop as they progressed (Griffard, 1999). A method based on unitizing and categorizing (Lincoln & Guba, 1985) was used to code the data. An emerging topology was determined using modified methods of Spradley's (1980) DRS. The pattern that emerged from the final typology is discussed and interpreted in the Conclusions.

**Other Data Analysis**

Novak and Gowin’s (1984) and Mintzes and associates (2000) methods were used for analyzing object and term sorting, model task, interviews, concept maps, field notes and other tasks. Value added was determined with a special science assessment rubric that was developed with methods developed from Mintzes, and associates (2000).

**List of Qualitative Data**

(a) Transcription and analysis of audiotapes of student interviews (Novak & Gowin, 1984)
(b) Analysis of videotapes of activities/interviews/think aloud sessions (Grabinger, 1996)
(c) Analysis of object and term sorting (Campbell & Reece, 2002)
(d) Analysis of concept maps (Novak & Gowin, 1984)
(e) Analysis of Visual Field Perception Map Heuristics™
(f) Analysis of field notes
(g) Analysis of specially annotated student-created animations
(h) Analysis of chloroplast and mitochondria study kit models

List of Quantitative Data

(i) Item analysis of selected multiple-choice AP Biology Examination questions
(j) Descriptive and statistical analysis of Photosynthesis/Cellular Respiration Survey

Limitations

This exploratory study had limited generalizability due to the small number of students in the study. Since there were at least four students in each academic stratum sample, there was not an equal percentage of gender. Previous studies of this sort have shown that gender was not a factor (Griffard, 1999).

Pilot Report

Student Debriefing About Using BDM Learning Strategy

August 2002

At the end to the BioDatamation™ pilot study, the students discussed the various learning components of BioDatamation™. The students were given a list of questions to discuss and the following is a summary of their comments.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>What are your thoughts about BioDatamation™?</th>
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</thead>
<tbody>
<tr>
<td>Michael</td>
<td>I think it is interesting discussing BioDatamation and learning in new ways.</td>
</tr>
<tr>
<td>Kristen</td>
<td>I liked learning about photosynthesis and cellular respiration.</td>
</tr>
</tbody>
</table>
In summary students do not have to be bored and uninterested in science. Photosynthesis and cellular respiration can be interesting topics using an interesting method like BioDatamation™.

**Researcher** How do you see BioDatamation™ related to your everyday life?

**Michael** I think it’s cool that cellular respiration is used in cooking and everyday life. Kimchee is a form of respiration I never knew about. I love learning about new things. Respiration is part of cooking. It was fun watching the bubbles which are a result of carbon dioxide.

**Steven** Application of photosynthesis and cellular respiration. It is interesting how it is related to everyday life.

**Kristen** Learning about how the air, sun and water producing food was interesting. Also how carbon dioxide can produce sugar. The videos and animations helped in the beginning of the units.

The overall analysis of transcript was that the students were quick to indicate their lack of knowledge prior to the BioDatamation™ activity. The videos and animations were helpful in relating the concepts to everyday life.

**Researcher** How did BioDatamation™ help you before you learned the detailed concepts of photosynthesis and cellular respiration?

**Michael** I thought learning about photosynthesis and respiration with videos before the actual lesson helped. It helped with learning basics before the really hard stuff.

**Steven** Videos helped before the complex concepts and details. The first section helped create a past visual field.

**Kristen** Photosynthesis and respiration videos and diagrams helped learning by creating a past visual field.

**Michael** The diagrams made a background of past experiences with the content.

**Kristen** It layered the information and helped me start learning the basic concepts to learn the complex ones. The images and animations helped me see what I was learning.

The overall analysis of transcript was that the students identified videos and diagrams as helpful learning tools. The simplicity and layers were identified as helpful. They were also able to identify this as a past visual field; therefore, they showed metacognition.

**Researcher** How did the labs with digital data collection and animated presentations of the detailed concepts help solve some alternative conceptions about photosynthesis and cellular respiration?
Michael The present visual field was created by seeing data points on the screen as it happens with the sensors. I could have immediate results.

Steven I liked the lyrics of “I Want to Soak Up the Sun.” I could hear them in my head while I studied. It was fun making the model of the chloroplast. It was interesting to see all the parts and their structure and function.

Michael Also, our instructor had an interesting way of testing us with animations and diagrams.

Kristen The Microsoft® PowerPoint® 2003 presentation helped layer the information and gave an easy way to present the information to a group.

The overall analysis of the transcript was that the sensors and instant results allowed students to use technology to receive a visual representation of the detailed concepts they were learning in class. Students had better retention of the material because they were seeing the graphs and reading about the concepts. They appreciated the nonlecture components and used them as a memory device. Also, the layering made the information easier to understand.

Researcher How did BioDatamation™ help the students retain the information for a longer period of time through the techniques in the past, present, and future visual fields?

Steven The future visual field was created by solving problems and making predictions useful to everyday life.

Michael It was helpful to science by relating photosynthesis and respiration together.

Steven The videos gave a good background for the past visual field which led into laboratory studies. The lab studies created the present visual field. The future visual field was created by learning and applying the information studied.

Kristen Daily life and learning helped me remember the information after the test.

Michael Our good instructor helped make learning fun through BioDatamation™.

The overall analysis of transcript was that all the visual fields were connected and enhanced learning. The videos, labs, and application of the information helped the students retain the information. The students acknowledged the necessity of all the visual fields integral to the learning experience.

Summary of Pilot

Protocols and instructional materials were adjusted during the pilot. The results of the pilot study indicated that BDM helped students construct meaning. Significantly improved
student knowledge resulted from the construction of a common past visual field, and indicated that the BDM utilization of the past visual field is meaningful. The future visual field was validated by better student knowledge integration and the assertion by students that they had experienced better encoding into long-term memory. Samples of the pilot study videos are included in Appendix N.
RESULTS AND DISCUSSION

The Theory of Interacting Visual Fields™ was used with all research groups and it provides the theoretical infrastructure for BioDatamation™. Two levels of data were presented in this section. Primary data were data documenting the participants’ solutions to tasks (e.g. concept maps and participant-created PowerPoint® Presentations) and data from Biology AP Exams derived from large groups. Secondary data were derived from interviews. Verbalizations and gestures were scored throughout the discussions. Cognitive processing involving the tasks and their thoughts about how the tasks related to their learning were scored to reveal the impact of BDM learning strategies. The clinical interviews consisted of complementary tasks and discussion questions to reveal the development of knowledge with the application of the various concepts and strategies.

Description of Primary Data

Biology AP Study

High school students’ understanding of photosynthesis and cellular respiration was analyzed from multiple-choice test responses to questions about photosynthesis and cellular respiration. The sample consists of 263,267 student exams from the four most recently released Advanced Placement Biology Examinations (CEEB, 2004; ETS, 1992; ETS, 1994; CEEB, 1999). The methods and results of this study are in Appendix O, and a summary follows.

Concept and data analysis maps were used to illustrate the hierarchical relationship of concepts. Reference numbers with sublevel letters were applied to score the level of conceptual difficulty and to identify possible paths for assessing or teaching these concepts. This novel use of concept maps focuses on instruction and assessment of science knowledge. The content of the test items was also characterized using Bloom's taxonomy for cognitive categories, conceptual
distance levels, physical science knowledge levels, and levels of difficulty related to the history of biology focus on the discovery of key concepts.

Analysis of the AP data indicated that the students missed the most questions on the topic of photosynthesis, scoring somewhat better on the interrelationship of photosynthesis and cellular respiration, and on the topic of cellular respiration alone. The most difficult concepts for the students tested were thylakoid structure, the role of light and chlorophyll, carbon fixation, hydrolysis of ATP, electron transport and chemiosmosis. These concepts were targeted in the research used in creating the BDM sessions and analyzed to determine value added from the BDM strategies.

More recently discovered scientific concepts (e.g. chemiosmosis and ATP synthase activity) were linked to questions yielding the lowest percentage of correct answers. In addition to identifying difficult concepts, these data provided the paths for teaching and assessing these concepts using BDM’s targeted Concept and Data Analysis Maps™ of Photosynthesis and Cellular Respiration. Gaining integrated knowledge of photosynthesis and cellular respiration merits greater attention during instruction. Results of the comparison of Biology AP multiple-choice question data analysis and BDM mapping scores are in Appendix Q. Correct concept mapping did not necessarily indicate a correct answer to multiple-choice questions. Students needed to interrelate concepts in a map to be able to answer the multiple-choice questions.

**Concept Maps and Term Recognition**

Students constructed concept maps at each phase; these were analyzed with the scoring methods of Novak and Gowin (1984) described in the methods section. Concept maps of the case study participants are located in Appendix P. The scores of all maps as well as term recognition and object sorting (determined with a key) are located in Appendix Q. Both the concept map score and term recognition were used to determine biological literacy.
**Biological Literacy**

Biological literacy was determined using the Biological Literacy Model developed by the BSCS (1993) specifically adapted for cellular respiration and photosynthesis. The Methods section describes this analysis tool’s background and applicability in detail. For statistical data manipulation and analysis, numerical values were assigned to literacy levels: nominal literacy-1, functional literacy-2, structural literacy-3, multidimensional literacy-4. The concept map score in conjunction with visual field results determined literacy. The raw scores determined the following literacy levels: a concept map score of 0-20 - nominal literacy, 21-50 – functional literacy, 51-80 – structural literacy, above 80 – multidimensional literacy if the visual field analysis showed application to everyday life or current research. Multidimensional literacy was achieved only if the participant had both the required map score and application of knowledge.

Table 9 shows the literacy level of each participant in the two groups throughout the study. There was a significant, sustained increase in biological literacy in both cellular respiration and photosynthesis for the Merged BDM Group, while the Comparison Group had little growth followed by decay. The results for cellular respiration are shown in Figure 15 and those for photosynthesis are shown in Figure 16. The Merged BDM Group, across all time periods, shows an increase in literacy and no decay.

Average literacy levels achieved by the Merged BDM Group and the Comparison Group at each phase for cellular respiration is shown on Figure 15. As seen in the graph both groups were at the same literacy level of 1 with nominal literacy for the Baseline Phase. At the Post Lecture Phase the Comparison Group was slightly higher at an average literacy level of 2.33 and the Merged BDM Group had an average of 2.27 with both groups at the functional literacy level. By the Post Strategy Phase, the Merged BDM Group rose to the structural literacy level of 3.2 but the Comparison Group had only a slight rise to 2.44 and was still at the functional literacy
<table>
<thead>
<tr>
<th>Name</th>
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<th>Post Lecture</th>
<th>Post Strategy</th>
<th>Delay</th>
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<tr>
<td></td>
<td>CR</td>
<td>P</td>
<td>CR</td>
<td>P</td>
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<td>3</td>
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<td>2</td>
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<td>Norma Jean</td>
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**Legend:**

1 = Nominal Literacy  
2 = Functional Literacy  
3 = Structural Literacy  
4 = Multidimensional Literacy  
CR = Cellular Respiration  
P = Photosynthesis
Figure 15. Literature development for cellular respiration.

Figure 16. Literature development for photosynthesis.
level. By the Delayed Phase the Comparison Group dropped to 1.89 and the decay had put the group down to the nominal literacy level and Merged BDM Group rose to an average 3.6 at the functional literacy level. The Merged BDM Group experienced a rise in literacy level at each phase with no decay.

The average literacy levels achieved by the Merged BDM Group and the Comparison Group at each phase for photosynthesis are shown in Figure 16. At the Baseline Phase both groups were at nominal literacy and the Comparison Group had an average literacy level of 1.44 and the Merged BDM Group had a average literacy level of 1.2. At the Post Lecture Phase there was a rise in literacy to the functional level with the Comparison Group average literacy at 2.44 and the Merged BDM Group average literacy at 2.07. By the Post Strategy Phase the Merged BDM Group rose to an average literacy of 3, which was at the structural literacy level, and the Comparison Group was at the functional level with an average of 2.67. By the Delayed Phase the Comparison Group dropped to an average of 2.22 at the functional literacy level and the Merged BDM Group rose to an average of 3.4 at the structural literacy level. As was seen in the cellular respiration graph in Figure 15, the Merged BDM Group experienced a rise in literacy level at each phase with no memory decay. These figures show that participants who start at equal literacy levels profit from BDM strategies. There was a significant value-added to knowledge and elimination of memory decay.

The percent changes of the value added from the BDM strategies between phases for the Merged BDM and Comparison Groups, as well as AP and nonAP students, are given in Table 10. Those participants who used BDM strategies had consistent increases in literacy with a lack of knowledge decay after instruction for both AP and nonAP. Overall the nonAP group had a slightly greater gain in literacy at each phase. The average group literacy levels at each phase are given in Table 11.
Table 10

Percent Change in Biological Literacy Between Phases

<table>
<thead>
<tr>
<th>Group</th>
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<th></th>
<th></th>
<th></th>
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<td>39%</td>
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<tr>
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<td>Merged BDM AP</td>
<td>150%</td>
<td>40%</td>
<td>9%</td>
<td>53%</td>
<td>117%</td>
<td>38%</td>
<td>17%</td>
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<tr>
<td>Merged BDM NonAP</td>
<td>110%</td>
<td>43%</td>
<td>15%</td>
<td>63%</td>
<td>54%</td>
<td>50%</td>
<td>11%</td>
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<tr>
<td>Comparison Group All</td>
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<td>-17%</td>
<td>69%</td>
<td>9%</td>
<td>-19%</td>
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<tr>
<td>Comparison Group AP</td>
<td>150%</td>
<td>10%</td>
<td>-18%</td>
<td>-10%</td>
<td>83%</td>
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<td>-27%</td>
<td>-27%</td>
<td>57%</td>
<td>18%</td>
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</table>

Table 11

Average Group Literacy Levels at Each Phase

<table>
<thead>
<tr>
<th>Group</th>
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<th>Post Lecture</th>
<th>Post Strategy</th>
<th>Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CR</td>
<td>P</td>
<td>CR</td>
<td>P</td>
</tr>
<tr>
<td>Merged BDM</td>
<td>1</td>
<td>1.2</td>
<td>2.3</td>
<td>2.02</td>
</tr>
<tr>
<td>Comparison</td>
<td>1</td>
<td>1.4</td>
<td>2.3</td>
<td>2.4</td>
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</table>

Legend:
1 = Nominal Literacy       CR = Cellular Respiration
2 = Functional Literacy    P = Photosynthesis
3 = Structural Literacy
The Comparison Group had very little increase and much decay in literacy. The comparison of the percentage changes in the Merged BDM Group and Comparison Group is shown in Figure 17.

Figure 17. Percent change in literacy levels between phases for Merged BDM and Comparison Groups.

The percent change between each phase of both AP and nonAP of the Merged BDM Group and Comparison Group is shown in Figure 18. Both groups had approximately the same change between Baseline and Post Lecture, while between Post Lecture and Post Strategy the BDM Merged Group had a 39% value added in cellular respiration literacy (Figure 17). The
Comparison Group had only 4% value added to literacy. Figure 18 shows the decay of the Comparison Group with the use of the negative quadrant to emphasize the memory decay. Figure 18 uses the same graphing technique to help analyze the data. It shows that there was a slightly greater change in literacy in the BDM nonAP group, and there was no memory decay with the BDM groups. This figure also shows there was the most decay with the nonAP Comparison Group than any other group.
Between Post Strategy Phase and Delayed Phase the Merged BDM Group had a value added of 13%, whereas the Comparison Group experienced a 23% decay in literacy. The same pattern was seen for photosynthesis. The overall trend was a greater gain between Baseline Phase and Post Lecture Phase by the AP participants for both BDM and Comparison groups. Overall, the nonAP Comparison Group had the greatest decay. In the Merged BDM Group, there was little difference in the rates of retention [probably due to awareness of multidimensional application to everyday life during the two-week delay].

The literacy level for BDM Extended Analysis Subgroup participants is contained in Table 12 and illustrated in Figure 19. This shows the value added at each phase of BDM instruction. Overall, the AP participants had a slightly greater value added to literacy than the nonAP participants. The nonAP participants had an increase in literacy between the Post Strategy and Delayed Cellular Respiration Phases. The AP participants had a slight decay from Post Strategy and Delayed photosynthesis. There was a value added to literacy with each phase of BDM instructional strategy.

**Description of Secondary Data**

Secondary data take the form of verbalizations to help characterize the profile of the BDM learners and the BDM strategies. The taxonomy of the strategies was revealed by discussions. Where quotes are offered to support the taxonomy, the symbol “…” is used to denote a pause of at least three seconds. Empty brackets “[]” indicate where a portion of the protocol was omitted, usually for clarity or continuity. When the brackets contain words (e.g. she [Dr. Smith]), they indicated antecedents or provide other such context missing from the excerpt but present in the intact transcript. Occasionally comments are included (e.g., [this is correct]) to guide the nonscientific reader. The symbol [sic] is used to emphasize that the transcript is accurate but awkward, and is used to reinforce the authenticity of the quote. A
<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
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<th>Present Respiration</th>
<th>Future Respiration</th>
<th>Past Photosynthesis</th>
<th>Present Photosynthesis</th>
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<th>Delay</th>
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<td>Photosynthesis</td>
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<tr>
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</table>

Legend:
1 – Nominal Literacy
2 – Functional Literacy
3 – Structural Literacy
4 – Multidimensional Literacy
The taxonomy of a BDM learner was derived from this secondary data, and is summarized in Figure 20. The main nodes of a BDM learner were metacognitive strategies, technology, and the three visual fields. These details in this figure are a profile of the characteristics of BDM AP and nonAP learners. The data did not show a difference between BDM AP and nonAP learners.

The aforementioned is a summary of the focus of the research. The following four case studies and group analyses explain the details of the results.

Figure 19. Change in literacy level for each phase of BDM for the BDM Extended Analysis Subgroup.
Figure 20. Taxonomy of a BDM learner.
Case Studies

Case Study 1-Baxter

Participant Description. Baxter is a Caucasian male and a first year biomedical engineering major. He was born in West Virginia and moved to Texas while he was in the 4th grade. His father is an engineer and his mother a homemaker. He attended a magnet middle school and a magnet high school. He took Biology AP in the 11th grade and scored a 3 on the Biology AP Exam. He plans on going to medical school. He had a composite ACT score of 32 and a composite SAT score of 1290. He had a 4.0 grade point average in high school and had taken several other AP and honors courses. These courses included Integrated Physics and Chemistry Honors, Biology Honors, Computer Science I AP, Computer Science II AP, Chemistry Honors, Physics Honors, and Physics AP. His favorite subject was “science” while English was his least favorite.

Baxter started using computers when he was 7 years old and continues to use them about three times per day. He preferred learning with computers and had experience using PowerPoint®. He took chemistry, physics, and calculus II this past semester in college. He has had limited previous experience with sensors, using them to measure air pollution.

Baxter was interested in understanding the best way to learn. He said he tried in the past to determine how he learned. He believed that teachers need to discover the way students think so they can teach material more effectively. In addition to understanding the learning process, he was interested in participating in this project to learn more about photosynthesis and cellular respiration. He also wanted to do the project because he had spoken with doctors at a hospital and was told that it is important to get opportunities to grasp the future and explore.

Baxter was very interested in working to his full ability. He liked to stimulate conversation by making comments that invoked reply. He preferred one on one discussions to a
group format. He respected the work of the researcher because he himself enjoys research and wished to improve his understanding of science.

**Baseline Phase, Prior Knowledge Phase.** Prior knowledge is important to the student’s learning and awareness of the prior knowledge is helpful for the instructor. According to Ausubel (1968) prior knowledge is essential for meaningful learning and impacts each visual field. Prior knowledge is a component of the past visual field. The participant’s prior knowledge was evaluated at each stage of the research.

Object sorting helped the researcher to establish Baxter’s initial baseline knowledge about real-life objects. First, the participants had to sort a given item into one of three categories: living, nonliving, and at one time living. Then they sorted the item by whether it performed photosynthesis, cellular respiration, or both processes. Another purpose of this exercise was to help the participants begin thinking about common objects and organisms.

Baxter appeared to find the object sorting activity interesting, but he had few comments about each object. He considered an object that was at one time living the same as a nonliving object. Among the items he classified incorrectly were the cup of soil and the red bean, both of which he identified as nonliving and performing neither cellular respiration nor photosynthesis. He considered the soil as nonliving because he did not consider the effect of the microbes releasing carbon dioxide into the soil. He identified the head of cabbage as living and performing only photosynthesis, but not cellular respiration. He did not recognize that “it” was doing both photosynthesis and cellular respiration. He then properly identified that the plant in a tightly closed jar was doing both photosynthesis and cellular respiration. Baxter identified the yogurt as “at one time living” so he thought it was not doing photosynthesis or respiration at this time. Because of his decision that both at one time living and nonliving things were now dead,
he incorrectly categorized many of the objects as not performing either photosynthesis or cellular respiration. Baxter scored 47% overall for this exercise.

In the term recognition activity, there were 35 terms related to only photosynthesis, only cellular respiration, or to both. He was given the option of sorting the words into five categories: photosynthesis only, cellular respiration only, both cellular respiration and photosynthesis, neither cellular respiration nor photosynthesis, or unrecognized. Baxter scored 92% correct in the category of photosynthesis only. In the group of cellular respiration words, he identified only 17% correctly. In the category of both photosynthesis and cellular respiration he sorted 24% of the words correctly. Baxter had a much stronger background in the concepts of photosynthesis than cellular respiration and had an overall score of 46% correct.

The concept map activity allowed the students to create concept maps from a pool of terms for both cellular respiration and photosynthesis. The rubric used to score the concept maps consisted of links and branches, and is described in the Methods section. In the cellular respiration map, Baxter had 2 links and scored 4 points. In the photosynthesis map he had 3 links and scored 6 points. His maps are in Appendix P and their scoring can be found in Appendix Q.

In Baxter’s baseline visual field he stated that he wanted to go to medical school and become a doctor. His prior knowledge of cellular respiration and photosynthesis was based on his AP Biology course in high school. He had a stronger past visual field at this phase compared to his future visual field. He knew the past and the present were interwoven. He had never thought of his future visual field in terms of application. He “thought the future would just come.”
Based on his concept maps, visual fields, object sorting, and term sorting activities Baxter’s overall baseline literacy was determined to be nominal for both cellular respiration and photosynthesis.

**Post Lecture Phase.** In the term sorting activity, Baxter scored 67% correct on the photosynthesis only words and 57% correct on the cellular respiration only words. In the words associated with both photosynthesis and cellular respiration he identified 71% of the words correctly. His overall score was 67% correct. He had the most difficulty with terms related to cellular respiration only. The terms he recognized for cellular respiration were “Krebs cycle,” “glycolysis,” “mitochondria,” and “phosphorylation.” Baxter’s cellular respiration concept map indicated 27 links, 5 branches, and 3 levels of hierarchy. He scored a total of 87 points on this map. His photosynthesis map had 14 links, 3 branches, and 2 levels of hierarchy. His score for the photosynthesis map was 49 points.

Baxter was disappointed in his prior knowledge of photosynthesis and respiration and had to study in his present. He stated that he wants to be a doctor and he does “not think that respiration will prove to be the basis of energy of cells in the body.” He thought research would identify a different process, and that this research was in its infancy. Based upon his term sorting, concept maps, and visual fields, Baxter’s overall literacy was determined to be structural in cellular respiration and functional in photosynthesis, which was an improvement from his baseline literacy level of nominal in both photosynthesis and cellular respiration.

**BDM Cellular Respiration Past Visual Field Phase.** After the mapping and sorting activities a discussion was held about the various learning strategies used in the BDM Past Visual Field session. BDM strategies were contrasted to traditional strategies to help reveal more about the BDM strategies. The questions were used to help reveal the components of the
strategies as understood by the participants and to help the participants learn the process of metacognition.

The first BDM strategy used was an exercise involving Kimchee, which is Korean sauerkraut (Man-Jo, Kyou-Tae, & O-Young, 1999). Kimchee was selected because the participants generally were not familiar with it. It was hoped that the unusual nature of the Korean specialty would arouse the participants’ attention for learning and later recollection (Langer, 1989; Tulving, 1985). This activity utilized BDM strategies similar to WebQuest-style activities (Dodge, 1997; Watson, 1999) that use stories, animations, and carefully designed, hands-on live biological experiences that introduce the constructs of cellular respiration. These exercises include data collection experiences using living systems and electronic sensors, coupled with real-time display and analysis with calculators/computers (Brasell, 1990).

A bottle of Kimchee was shown to the students. The accompanying PowerPoint® presentation explained the details of the fermentation and is found in Appendix R. A thirty second Kimchee commercial was shown along with a 1.5 minute video about the ingredients used to make Kimchee. The video was made by the researcher at a local Korean grocery. The videos told a story and were modeled on the format of WebQuest-style activities, which always establish an interesting story at the beginning of an activity. The custom video and Korean Kimchee commercial were enhanced alternatives to the Web pages prescribed by others (Dodge, 1997).

A scenario about a restaurant near the campus needed to speed up the process of making Kimchee was used to help capture the participants’ attention and extend the story (Tulving, 1985). Adele and Pierre, characters in the scenario helped to explain the situation. The researcher then discussed both the introduction to the Kimchee activity and the basics of cellular respiration with Baxter. He had been expecting more of a lecture format to the sessions, and so
he was caught off guard by the Kimchee scenario. He thought the video and data collection were
effective strategies.

Researcher What are your thoughts about the Kimchee scenario?
Baxter [It ]Basically tried to give a reference.
Researcher What is the purpose of the Kimchee scenario?
Baxter To see anaerobic respiration and to spur thoughts about it and it was interesting.
Researcher How did you like the use of characters in the scenario about the shortage of Kimchee at the restaurant near campus and video about making Kimchee?
Baxter Video is a visual reference and characters are seen. [Video allows for a] Visual learning system. [Video with a scenario] Pulls people in.
Researcher How does the Kimchee scenario involve cellular respiration?
Baxter Anaerobic form of cellular respiration. A little carbon dioxide and ethanol is produced.
Researcher Did you gain familiar knowledge about anaerobic cellular respiration?
Baxter [It shows how] fermentation works. If you know it is anaerobic.
Researcher How did the data collection impact your understanding?
Baxter Data collection [He cited his data collection at] - 1 week old - 200 - 2500 ppm. Linear line. Carbon dioxide enters.

The researcher also helped Baxter explore his past experience with cellular respiration.

His past experiences at school were his focus, and he believed that his prior knowledge was
important to his learning. He did not consider practical, real-life examples as part of his past.

Researcher Did you already know about Kimchee?
Baxter No.
Researcher How does something new and different help you to learn?
Baxter It gives you a new perspective. Video creates vision.
Researcher Have you had previous experience?
Baxter Not had any experience. Read biology book. No hands on experience. All textbook.
Researcher Have you previously had experience (hands on, reading, stories or movies) about aerobic and anaerobic cellular respiration?
Baxter Have had anaerobic experience but do not remember all text.
Researcher Have you studied anaerobic cellular respiration in school? If yes how?
Baxter If hands on just a textbook. Have written on PowerPoint® [slides]

The researcher attempted to guide Baxter to become aware of the impact of incorrect
knowledge on his current learning. Students encounter learning difficulties when they have
incorrect prior knowledge (Griffard, 1999); (Wandersee, 1983; 1994). This has been termed “alternative conceptions.”

Researcher: Is it possible that what you learned in the past not complete or correct?
Baxter: Possibly not complete but not incorrect. [I used] the Biology book. Details.

Researcher: If knowledge from the past is incorrect could it cause problems with your current learning? Yes or No and explain.
Baxter: If it is it will confuse biology.

Researcher: Why is it helpful to identify your past knowledge?
Baxter: Unless obtained from past to check what is value added.

Researcher: Why is it important to have past knowledge?
Baxter: It is the base of the pyramid. If created use it.

The researcher learned, from the analysis of Biology AP Exam questions and the baseline interviews, that the participants had very limited prior knowledge about cellular respiration. The researcher was interested in “planting” prior knowledge to the participants so that they could have some common prior knowledge. The researcher created a diamond shaped visual fields’ agent, V. Fields™, to lead the participants through each of the visual fields. The researcher was interested in Baxter’s perspective on the possibility of building a pool of common prior knowledge, the use of V. Fields™, and the importance of the establishment of correct prior knowledge.

Researcher: Is it possible to establish a common past visual field?
Baxter: Two weeks for long term memory (past). Short term is in between.

Researcher: How can correct previous knowledge help you to learn?
Baxter: It can refresh and rebuild.

Researcher: Was V. Fields™ helpful in the presentation?
Baxter: Yes.

Researcher: What was the purpose of V. Fields™?
Baxter: Imprint and bring you into the story.

Researcher: Were you surprised by V. Fields™?
Baxter: Not surprised. The figure was something to pull in not make the slide.

Researcher: Was V. Fields™ helpful to your establishing the past visual field?
Baxter: Something to relate to. Child’s video. Purpose was to bring you back to childhood. Kid’s brain.
Baxter was interested in the various brief videos used in the past visual field presentation. The researcher wanted to probe his perspective to get an understanding of his thoughts about the videos used in the presentation.

Researcher: How were the videos helpful for explaining Kimchee?
Baxter: Video of the grocery was like a commercial. Different and new perspective. Video creates vision.

Researcher: What is the impact of video on learning?
Baxter: Different learning style. Video draws mind a reference.

Researcher: Why do you think seeing video can help you to learn?
Baxter: Vivid. Live. Live it and you will never forget it.

Researcher: Is the length of the video important?
Baxter: Short and you don't get it all. Long video you lose focus.

Baxter was quick with his answers and highly opinionated. During the instruction session, he was very attentive and appeared to enjoy the videos.

The researcher also included special layered and animated PowerPoint® slides as the core of the presentation in which the videos and concepts were delivered to the participants (Appendix R). The PowerPoint® slides were built from the bottom starting with little information. The details were layered sequentially with animation. The final layer of the slide had reasonable detail and therefore conformed to Tufte’s Theory of Information Design (2001).

Researcher: Describe a traditional PowerPoint® slide.
Baxter: Bullets and text.

Researcher: Do you like traditional PowerPoint® Presentations?
Baxter: Not descriptive.

Researcher: What was different about the research project PowerPoint®? List.
Baxter: Different, colorful, visual. Easy to read. Text and visual fields.

Researcher: How does a layered approach help you to learn?
Baxter: Focus on what you need. Brings together concepts. Very effective. Focuses the individual. Layered - you do not have to sit and try. Layers help you learn and pulls you in.

Researcher: How are animated PowerPoints® different than the book presentations?
Baxter: Creates memory.

Researcher: Did what we did last night contribute to your long term memory?
Baxter: Long-term [memory]. Kimchee and carbon dioxide are long term.
He did not focus as much on the details of cellular respiration as which ones he thought were in his long-term memory. His attention was focused on the Kimchee example provided in the past visual field presentation.

BDM Cellular Respiration Present Visual Field Phase. The next instructional session focused on animated data collection and animated concept presentations for understanding. The major activities were data collection activities with sensors and Logger Pro® software (Holman & Masterson, 2000) and the viewing of animated and layered PowerPoint® presentations containing the details of the concepts. Data collection was done with Kimchee and soil samples (Appendix S). Qualitative laboratories were conducted with bread, ATP, and fireflies (Appendix T). The ability to track conceptual change in these laboratories was patterned on the recommendations of two educational studies (Boo & Watson, 2001; Posner et al., 1982).

Which activities and what content were most memorable to the participants? In order to answer this question the researcher asked the following questions.

Researcher

What are the first five things that come to your mind when I ask you, "What new things did you learn last night at the Present Visual Field Presentation?"

Baxter

Chemiosmosis, ATP and firefly tail [experiment], carbon dioxide sensors, bread, PowerPoint® slides, remember it [live yeast] overflows tube and dead yeast does not. Bread did not do anything [i.e. rise] due to the temperature of the room.

Researcher

What are your thoughts about the bread demonstration compared to the yeast in the tube?

Baxter

Yeast in tubes is more individual to bread [Pairs of participants had their own inverted tubes of yeast to view and the bread was demonstrated to them as a group.]

The researcher then probed more to learn about what Baxter thought about the bread and yeast demonstrations. The researcher was interested to see his reaction to these qualitative experiences compared to the qualitative data collection experiences.

Researcher

What is the purpose of the bread demonstration compared to the yeast in the tube?
Baxter   Bread you can relate to yeast. You can remember.
Researcher Were these experiences interesting?
Baxter   Yeast in tube interesting and extreme. Bread is not interesting.
Researcher How did looking at the chemical reactions on the board with the
demonstration material in your presence help you think and learn about
cellular respiration?
Baxter   Did not pay attention.
Researcher How do these demonstrations of yeast in the tube and bread dough involve
cellular respiration?
Baxter   Examples of fermentation.

Baxter was very observant of the activities done in each instructional session. The yeast
in the tubes appeared to be extreme to him because there was approximately two inches of yeast
solution displaced by the carbon dioxide gas over a twenty minute period when the tube was
placed in a warm water bath. During the instruction session the researcher noticed that he was
not attentive to the explanation given by the researcher on the board. Baxter explained that he
had attention deficient problems and that he was not always attentive for long periods of time.
He was one of the few students who missed something written on the board. Most students
enjoyed having concepts explained on the board. He was more attentive to the animated
PowerPoint® presentations and videos. According to Mayer (2003) it is important to offer
various methods of learning because each student has different learning preferences. The
researcher then probed to help Baxter determine his learning activity preferences.

Researcher How do the different types of presentations (lecture, demonstrations and
labs) impact your thinking?
Baxter   Labs - wake you up to get your attention. Demonstrations The same.
Lecture - If you are talking to me [there is impact], but I do not pay
attention much to long lectures and I do not like to attend long lectures.

The researcher sensed Baxter’s frustration with the large amounts of lecture materials that
he had to deal with during his first semester in college throughout his various classes. He was
realistic, however, that this was the most common method of presentation. Further, he could
read the book or the PowerPoint® presentations that were posted in Blackboard® and learn more
than what he would learn by attending the class lecture. He did not think he needed to attend classes to see 70-80 PowerPoint® slides presented to him within a 50 minute class period. He felt there was a lack of explanation in those classes. He much preferred hands-on activities.

The researcher then explored the impact of data collection on his understanding. In the instructional session the night before, the participants took the rate of cellular respiration of loose and compacted soil to study the rate of respiration of aerobic soil microbes. During the subsequent postinstructional session clinical interview, the researcher gave Baxter a bottle of disinfectant and asked him to predict the rate of cellular respiration if the soil was sprayed with the disinfectant. He then had to compare the impacts of disinfectant and compression. A scenario was presented about a sugar cane field that had trucks which compressed the soil during the previous harvest. The soil had been compacted and the current crop was not growing well.

Researcher Predict the rate of respiration of the soil sample in the container if it has been treated with a disinfectant. Draw your prediction on the screen using Logger Pro®, and explain your prediction.

Baxter [He draws a straight line on the screen, as he says the following.] It would be a straight line because the microbes would die.

Researcher Last night in the instructional session, what is the purpose of using the bottle to push on the soil?

Baxter Simulate trucks to compact the soil.

Researcher How did soil lab help you to understand about cellular respiration?

Baxter Soil lab showed how oxygen is required [by aerobic organisms].

Researcher How did the data collection with the sensors and Logger Pro® software impact your understanding?

Baxter Drew my attention and makes understanding.

Researcher Did viewing the data better help you to understand cellular respiration?

Baxter Graphs help. Anything you see helps.

Researcher What were you thinking as you saw each data point appear on the screen?

Baxter Wanted it to be over. I like to see the full picture. Can't interpret unless all are there. Wanted to see the whole thing. See slope. Want the slope. Want the vertices. Watch at the end.

Researcher How does viewing the graphing of the data point by point help you to understand?

Baxter Does not help at all.

Researcher What is the benefit of seeing the data collected on the screen in real time?

Baxter No benefit.
Have you had previous experience with data collection?

Baxter: Logger Pro® [with his pollution science project].

Baxter and another participant who had attention deficit disorder did not think watching the graph appear on the screen was beneficial. Baxter did think it was important that he view his own graph’s results in accord with Windschitl and Andre (1998). He thought it was much more meaningful to get the slope of his own graph and not just the slope of a demonstration. He was one of the students who had previous experience with digital data collection.

The researcher wanted to guide Baxter to an analysis of his past experiences relating to cellular respiration and his perception about his visual fields. The researcher requested him to draw his perception of the three visual fields.

Researcher: How did your past knowledge influence your understanding of the soil lab?
Baxter: [I] did not understand microbes.

Researcher: When does the past end and the present begin in your thoughts of photosynthesis and cellular respiration?
Baxter: Past is high school. Present is last 2 weeks.

Researcher: Draw the fields and indicate dominance of the field to you by the size of the field.
Baxter: The largest is the present visual field, the present is the next largest and the future is the smallest.

Researcher: How will the activities we did impact your learning?
Baxter: Activities are good. Kimchee and fermentation.

Researcher: How will the activities we did impact your long-term memory?
Baxter: Kimchee will last, because you knew about it.

Baxter was sure that Kimchee would remain in his long-term memory. Craik and Tulving (1975) and Langer’s (1989) research would support his prediction. Contextual items that have a deep trace layered have a great chance of recall (Tulving & Thomson, 1973).

Interestingly, at the baseline Baxter had mentioned that he wished he could remember something about cellular respiration that would help him to remember more.

**BDM Cellular Respiration Future Visual Field Phase.** The future visual field applied the elements of constructing animated knowledge to help solve a problem by
using knowledge learned in previous sessions. It was important to keep the interest of the participant by including a new example of cellular respiration that would allow review of the previous examples to determine the contrast. The session introduced the rate of respiration of Mexican jumping beans and mealworms under various environmental conditions (Appendix S).

Researcher: What are the first things that come to your mind when I ask you “What new things did you learn today in the research session?”
Baxter: Cytochromes, water, jumping beans.
Researcher: What are your thoughts about the jumping beans compared to the mealworms?
Baxter: Jumping beans have worms living in it.
Researcher: How did studying jumping beans help you to understand about cellular respiration?
Baxter: Could correlate jumping to carbon dioxide and ATP.

Baxter had not previously studied cytochromes. He had a physics test and other school work on his mind and he admitted to not paying full attention during the sessions. He did not remember anything about the cytochromes until after the BDM Future Visual Field of Cellular Respiration presentation. This video about the cytochromes in this session caught Baxter’s attention more than the animated PowerPoint® presentations of the previous sessions. The short James Bond videos caught his attention and helped him to remember. The use of James Bond movies that include rather unusual screens was based upon research that supports the use of episodical memory for better long-term memory (Tulving, 1985) and Langer’s (1989) suggestion that the unusual helps to capture attention and improves long-term memory.

Researcher: Have you previously studied cytochromes?
Baxter: No, didn't pay attention in class.
Researcher: Would you consider cytochromes to be part of your past, present or future visual fields as we learned about it today? Explain.
Baxter: Present [I] didn't pay attention [to the] previous class [Thursday].
Researcher: How did the study of poisons impact your understanding cytochromes?
Baxter: Shows which poisons affect individual cytochromes along electron transport, determines where it shut downs.
Researcher  How did looking at the use of cyanide in James Bond movies impact your understanding of cytochromes?

Baxter  [It was a] Visual reference point.

Researcher  How do you think the viewing of poison information and videos help your memory of cellular respiration?

Baxter  [It] makes it stand out.

Researcher  Did you like the poison information and do you have any examples to add?

Baxter  Did it work very well for me? Made it come to my mind more.

These examples of PowerPoint® presentations prepared for the construction of the student constructed animated PowerPoint® presentation, for the Korean restaurant owner that made a recommendation as to how to make Kimchee faster (see Appendix U). The students were given a toolbox of graphics and slide templates to make a brief PowerPoint® presentation that explained the theory of Kimchee, how to monitor the making of Kimchee, and the recommendations as to how to make it faster. This strategy reflected Boo and Watson’s (2001) finding’s involving audio-visual technology. Baxter preferred viewing the researcher’s presentations to making his own presentation for understanding concepts. He thought making his own would help him to pay attention.

Researcher  What is your previous experience with PowerPoint® authoring?

Baxter  5th grade thing, always use it.

Researcher  How do your PowerPoints® help to explain the concepts?

Baxter  Largely effected by the ones the researcher showed, [you need to] understand process to create [a PowerPoint® presentation].

Researcher  Does making animations help to understand the concept?

Baxter  Not help to understand them, but help to pay attention to them.

Researcher  How do you think making animations will help you to remember the concept?

Baxter  Associate work with process.

Researcher  How is making an animated PowerPoint® presentation different in thought process than making a traditional PowerPoint® slide?

Baxter  Have to think about actual process and where each part goes, instead of concept.

Researcher  Do you prefer making traditional PowerPoints® or layered and animated PowerPoints® and why?

Baxter  Professor makes traditional ones because they are easier.
Researcher: What is the impact of you making a recommendation to the restaurant owner make to your learning and thinking about cellular respiration?

Baxter: Makes you think about different variables affecting process.

According to Ellis’s (1996) realizing delayed intentions, the creation of the animated PowerPoint® presentation for the Korean restaurant owner was based on the future visual field that utilized prospective memory. Concept utilization to solve a problem for a better future fosters better understanding and memory. Baxter realized that he had to think about the entire process and the variables affecting the process. The researcher then asked him questions about his perception of present and future.

Researcher: When does the present end and the future begin in your thoughts of photosynthesis and cellular respiration?

Baxter: Future never begins, beyond this second [philosophical answer].

Researcher: What is your future visual field with cellular respiration? Give examples.

Baxter: Understanding processes, understanding poisons as a doctor, MCAT, classes.

Researcher: How will the activities we did impact your thoughts of the future?

Baxter: If I remember them they will help me as a biologist and a doctor.

Developing a better sense of what the future is and how using knowledge can impact the future are important components to concept formation. Having participants create animated PowerPoint® presentations to solve problems in this case by having the participants consider their own future visual field in comparison to the Korean restaurant, helps the participants not only to apply their knowledge but also place it in the timeline so that it will be easier to recall.

**BDM Photosynthesis Past Visual Field Phase.** This phase involved the basic concepts of photosynthesis. It included presentations of animated PowerPoint® slides on the basic concepts, videos, student interactive models, a few demonstrations, and data collection. The PowerPoint® presentation slides are included in Appendix R. The concepts were presented in a general fashion. A quick clip on the dust bowl from *The Grapes of Wrath* movie was used. The clip illustrated the impact of climate on food production and showed that the United States was not
exempt from these problems. In addition, the story of World War II Victory Gardens was presented in the PowerPoint® presentation. Finally, the research presented a video on what appeared to be a successful Victory Garden in which women increased their food and used fewer ration stamps.

A chloroplast home study kit called “Making a Chloroplast Model” was given to each participant; the directions for the kit are located in Appendix S. The model helped the student to understand the structure of the chloroplasts by allowing them to use a knife to cut through the model “thylakoid membranes” which were represented by the chocolate of the mint patty. They could better appreciate two dimensional electron micrographs of chloroplast structure.

The researcher demonstrated “Bromthymol Blue: Photosynthesis and Human Carbon Dioxide”, located in Appendix T, which consisted of blowing carbon dioxide into two tubes of bromthymol blue to slowly obtain a yellow color, inserting twigs of Elodea, and placing one in the light and the other in the dark helped to explore the Calvin cycle and light reaction of photosynthesis. The bromthymol blue had turned yellow because of the carbon dioxide entered it as a result of blowing into the tube. In two tubes, twigs of Elodea were placed with water and sodium bicarbonate. Next, the tubes were inverted and one was placed in the light and the other in the dark. The tubes were observed over the course of the session to detect changes. Over time the illuminated one returned to its original blue color because the light exposed Elodea used the carbon dioxide from the solution for photosynthesis (Appendix T). Further, the illuminated Elodea had a bubble at the top of the tube which was the accumulation of oxygen which is a byproduct of photosynthesis. The Elodea kept in the dark remained yellow.

In another demonstration tangerine sections were used to simulate guard cells that surround the stoma which regulate the exchanges of gasses (Appendix T). The participants were
given the tangerine sections as a model to observe swollen guard cells which simulates the situation when the stomata are open. With only a little pressure, the sections collapse which simulated closed stomata.

Other experiments included paper chromatography with extracts from cabbage leaves to see the separation of the various pigments, and digital measurement of the rate of photosynthesis of “moss balls.”

“Moss balls” are filamentous green algae that have taken a spherical shape due to a mutation. They have the appearance of large green cotton balls and are good specimens because they lack roots and their entire mass consists of photosynthetic cells that are good for photosynthesis data collection experiments. In “Heat Wave: The Effects of Temperature on Particular Algae and Photosynthesis” (Appendix S), a scenario about Cotille and Boudreaux was used to help relate the need for light in photosynthesis. The scenario involve Boudreaux parking his shrimp boat near Cotille’s garden. He extended the large shrimp nets over the garden which reduced the amount of light the plants below received. Cotille did experiments to show Boudreaux that shade of the nets was reducing the plants’ rate of photosynthesis and the lab centered on the scenario. Cabbage plants were also used for data collection. The data collection experiments with moss balls included scenarios to help students relate experiments to daily life.

Which activities did participants remember most? How did their retention relate to their past experience? Baxter realized that he had not previously thought about plant cellular respiration.

Researcher: What things come to your mind when I ask you what you remember about the research session tonight?
Baxter: Moss balls, cabbage leaves, blowing into bromthymol blue, dust bowl movie, chromatography.
Researcher: Were you taught about plants making oxygen as a child or do you remember other comments about plants from your childhood?
Baxter: Yes oxygen.

Researcher: Have you studied photosynthesis in school? If yes how?

Researcher: Have you learned something in the past that is not correct about photosynthesis?
Baxter: I don't think so, [I] may have gotten mixed up, [but I] didn't now about plant [cellular] respiration.

Researcher: Had you learned about guard cells and stomata before tonight? If so how?
Baxter: Yes, biology junior year.

Researcher: Was the tangerine model helpful to your understanding? If so how?
Baxter: Yes, how it closes and opens at different times.

Researcher: Had you done chromatography before? If yes how?
Baxter: No, but I did it Monday, got a 100 on quiz in lab, squeezed 2.5 hr lab into 1hr.

He thought the data collection helped him to see real time data and helped him to understand photosynthesis, which is in agreement with Krajcik and Laymen (1993). He was asked to predict the curve for moss balls in the dark, and he drew a line with a positive slope on the Logger Pro® interface on the computer screen. The researcher requested that Baxter relate the moss ball in the dark to the Elodea in the light. He was able to correlate that plants use carbon dioxide in the light but not the dark.

Researcher: How did moss ball prediction help you to understand about photosynthesis and cellular respiration?
Baxter: [It] Help[ed me] understand that cell respiration takes place actually in dark.

He also related the production of oxygen by Elodea in the light to the demonstration of the inverted tube of illuminated Elodea in the sodium bicarbonate solution. He found the combination of data collection and qualitative analysis of the demonstrations to be useful to understanding photosynthesis.

Researcher: Does the different presentation, impact your thinking? How?
Baxter: [It] had different ways to show the processes.

Baxter thought the agent V. Fields™ was helpful explaining the World War II stories and that the videos were helpful for remembering photosynthesis, on the other hand, uninterested in
the Victory Garden information and was not familiar with *The Grapes of Wrath*. Neither was he able to think of better video scenarios.

There was much discrepancy between how the various participants perceived the past, present, and future. The researcher discussed the use of the visual field worksheet (i.e. how the class from the night before was placed into the past visual field and the class to follow was placed in the future visual field). Baxter said that he could understand the researcher’s perception and actions, and appreciated being aware of the researcher’s perception. The researcher also discussed the value of metacognition with Baxter and he revealed his intense interest in metacognition. His comments revealed that BDM strategies have had a big impact on him.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>“Metacognition refers to the knowledge, awareness and control of one’s own learning.” Are you interested in this?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baxter</td>
<td>Yes, that is why I signed up.</td>
</tr>
<tr>
<td>Researcher</td>
<td>Does this research study involve metacognition? Explain.</td>
</tr>
<tr>
<td>Baxter</td>
<td>Definitely, you're trying to learn how we learn.</td>
</tr>
<tr>
<td>Researcher</td>
<td>How are you becoming more metacognitive? Compare yourself now to before the study began?</td>
</tr>
<tr>
<td>Baxter</td>
<td>Yes, being forced to look at how I am learning, I can transfer [this] to another subject.</td>
</tr>
<tr>
<td>Researcher</td>
<td>List the metacognitive strategies that you have learned during this research thus far.</td>
</tr>
<tr>
<td>Baxter</td>
<td>Visual, hands-on [activities] and presentations; visuals add color and animations.</td>
</tr>
</tbody>
</table>

**BDM Photosynthesis Present Visual Field Phase.** During the Present Visual Field of Photosynthesis Instructional Session, the Past Visual Field of Photosynthesis Instructional Session was reviewed. The previous used demonstrations were integrated with the new activities. Starch production in spinach leaves exposed to the light and lack of starch production while in the dark were demonstrated with iodine fumes. An animated and layered PowerPoint® presentation (Appendix R) supplemented the concepts in detail. Finally, they did an activity
called “Radionuclides and Autoradiographs: Applications for Understanding Photosynthesis and Cellular Respiration” (Appendix S) utilized iron filings and a magnet on a special diagram of a plant to simulate the radiographs used by Calvin in his research of the Calvin cycle. This activity was designed using the principles of the toy that used iron filings and a magnet to move the filings to make a beard and mustache on the face of a man.

The major data collection experiment utilized black and red mulch and was called “The Hunt for the Red Mulch” (see Appendix S). The rate of photosynthesis in plants grown in red mulch was compared. Red light is reflected from the red mulch while absorbed by the black mulch. The rate of photosynthesis is digitally determined with the carbon dioxide sensor and Logger Pro®. The mulch experiment had similarities to the Engelmann Experiment (Lehninger, 1970). The experiment with the spinach leaves called “Photosynthesis: The Light Reaction Using Spinach Disks” is described in Appendix T. Disks of spinach are punched from leaves, the air is removed from them with the suction of a syringe and they are placed into a solution of sodium bicarbonate. The disks sink in the solution due to the lack of oxygen. Then some disks were placed in the dark and some in the light. When the disks are placed in the light, oxygen produced in the light reaction of photosynthesis causes the leaf disks to float. The number of floating disks is an indication of photosynthesis. Baxter understood that the experiment was related to the light absorption of photosystems I and II of the light reaction of photosynthesis.

Baxter indicated that he watched to see if his data reflected the prediction he made at the start of the experiment. In addition to the qualitative experiments he found the moss ball experiment very stimulating. He did not find the Junior Mint® chloroplast model necessary since he already understood the structure of the chloroplast. He did not consider the need to have such a model for long-term memory. His opinion was contrary to most other students.
The researcher began with the standard question about what he remembered the most from the previous session. He had become more sensitive to learning strategies. In a previous session he did not think that the use of the board for explanation was effective, but now he said having formulas on the board was a most memorable experience. He also valued the PowerPoint® presentations more. Perhaps Baxter’s deficiencies in photosynthesis concepts compared to cellular respiration concepts contributed to his increased interest in metacognition.

Researcher: What things come to your mind when I ask you what you remember about the research session tonight?

Baxter: Mulch experiment, PowerPoint®, formulas on board.

Researcher: “Metacognition refers to the knowledge, awareness and control of one’s own learning.” Have you discovered more strategies or understand more about strategies you have previously described? Explain.

Baxter: Yes, [I] definitely observed that putting this thing [strategies] in on whims and guesses is messing me up.

Researcher: Why is it important and useful for you to be aware of strategies that are effective for you?

Baxter: So you can study the most effective way not waste time; conversely- you analyze what you're doing and try to figure out a way to make it better, you already know the way you learn, you know where you need to go.

He was very interested in the paper chromatography experiment and was very attentive to the analysis of the data that was collected in the previous session. The researcher probed his increased knowledge of photosynthesis and how he appreciated the building of knowledge from session to session.

Researcher: What did you learn new about chromatography last night? How did you use your previous knowledge as we reviewed it?

Baxter: [I] used a ruler, find R_f values by measuring distance that chlorophyll travels in solute, solubility and attraction of the chlorophyll,

Researcher: Do you like building on a topic?

Baxter: [I] like the building; sometime it’s better to presented all at once, sometime in parts, it depends.

He was able to quickly and correctly answer questions about the spinach disk experiment, and he understood that it was tracking the accumulation of oxygen. He knew that the oxygen
was from the splitting of water. He also liked the use of bromthymol blue to track carbon dioxide consumption because he gets tired of looking at computers even though he is into computers. He understood that the bromthymol blue experiment tracked carbon dioxide consumption whereas the spinach disk experiment tracked the production of oxygen. He also understood that the iodine experiment allowed the tracking of the production of starch as a product of the Calvin cycle of photosynthesis.

The researcher was interested in Baxter’s thoughts about the animated PowerPoint® presentation and how he was using them to help him understand photosynthesis by focusing on those things that he did not understand.

Researcher: What was the impact of the PowerPoint® slides to your learning last night?
Baxter: [I used] individual things from PowerPoint®. I looked for ones [I] didn't know in the PowerPoint®, got details [I] didn't know in the PowerPoint®, [there were] definitely more details in PowerPoint®.

The researcher was curious as to how he could identify those things that he did not understand. The researcher noticed that the participants had become very interested in the items that they were not able to map during the clinical interview, so the researcher asked Baxter questions about how concept mapping might impact his learning.

Researcher: Do you see the present building on the past in the sessions?
Baxter: [I] See present building on past sessions.
Researcher: How does the mapping impact your thoughts and behavior?
Baxter: Very effectively, it helps organize thoughts, since photosynthesis and cellular respiration are mainly processes it gives a run down, when I see this I see a cycle, of the processes going on, helps to keep thoughts.
Researcher: How has mapping impacted your thought about visual fields and each field?
Baxter: I don't think visual fields are impacted by mapping, in a way it does affect it, but the visual fields help me to separate what I already know and what [I am] going to learn next semester, (cleaning out the present-helps researcher and me understand what I need to learn later).
Researcher: Has mapping helped you to make connections to the visual fields?
Baxter: Mainly between future and (present and past), now we have a present/past.
Researcher: How does the mapping impact your learning?
Baxter  It separates the past and the present and what I want to learn in the future. The items that I am not able to map, I keep them on the right side of the map and this helps me to see what I need to learn in the next session and I pay attention to these items in the session.

Researcher  Do you like mapping?
Baxter  I like the mapping a lot, it gives me a way to organize my thoughts, [it] gives the researcher a look at how I think. When you don't know what's going on, it's [the maps are] very spaced out and disconnected.

The researcher and Baxter discussed the value of the visual fields related to his learning and the instructor’s approach to teaching. An awareness of visual fields was revealed and it helped to track the development of his metacognitive processes.

Researcher  Can you put the last class into your past? Explain.
Baxter  [I] Don't put it in my past. It's too recent.
Researcher  Can the next session be a part of the future? Explain.
Baxter  Yeah, definitely.
Researcher  Can you accept or understand that I place the last class as becoming part of your past visual field—honestly?
Baxter  Yeah, I can accept it, that last class is part of our past and next class is future.

BDM Photosynthesis Future Visual Field Phase. This visual field included: videos, predicting data, viewing demonstration of the DPIP blue dye, analyzing current research on application of photosynthesis concepts to make our lives easier, a PowerPoint® presentation of more concepts and student constructed animated PowerPoint® presentations. A NASA video of soybeans growing in space (NASA, 2002), herbicide killing a plant, and an infrared time-lapse animation of the difference in photosynthetic productivity in the hemispheres during the various seasons was included. A demonstration with DPIP blue dye (AP Lab 4 Photosynthesis, Part B) was also included in Appendix T. The DPIP blue dye simulates NADP⁺ in the light reaction of photosynthesis. When it is reduced and becomes DPIPH, it turns clear. This experiment helped participants to closely follow the reduction of NADP⁺ in the light reaction of photosynthesis. It helped students focus on the complex path of NADP⁺ from the point it was first produced in the light reaction
to where it is used in the Calvin Cycle. It was difficult for most students to related the production of NADP$^+$ in the light reaction and its use in the Calvin Cycle.

The researcher’s animated PowerPoint® presentation helped to review concepts by explaining $C_3$, $C_4$ and CAM plants. Current research on photosystem I from the Massachusetts Institute of Technology was considered (Halber, 2004). It explained how photosystem I was isolated and was being tested to power laptop computers. Also the use of photosystem II for powering cars was described using a current research article (Ferreira, 2004). Using a tool box of images and slide templates, the participants constructed a PowerPoint® presentation that concerned the use of red mulch by farmers to help increase the productivity of their crops.

During the interview Baxter identified the $C_3$, $C_4$, and CAM PowerPoint® slides as the things he remembered the most from the presentation. He had identified difficulty with these concepts in the concept mapping as indicated in the last interview. He appreciated the Vernier photosynthesis video that is included with Logger Pro® software. The video of the plant and its condition is interfaced with data collection of simultaneous fluctuations in light, carbon dioxide and oxygen. He thought the video helped him to understand the relationship of carbon dioxide and oxygen concentrations in relationship to the presence and absence of light. This video was important in helping Baxter to change an earlier alternative conception about how a plant in a closed jar would die because it would run out of carbon dioxide.

**Researcher** Describe a plant closed in a jar and its metabolic condition? Predict its fate.

**Baxter** Different. Carbon dioxide runs it.

**Researcher** Are your thoughts on the plant in the jar new or the same as you have thought in the past? Explain.

**Baxter** Not comfortable - really from shock.

**Researcher** Are you comfortable with your present thoughts?

**Baxter** No. [I feel that I have] Failed.

**Researcher** Predict the carbon dioxide vs. time graph of plants living in a sensosphere with light. Explain.

**Baxter** [It is] Level [a flat line with 0 slope].
His analysis of his predicted data helped him to realize that the plant would live and that the carbon dioxide would not run out if the plant was in a sealed jar. Mealworms were added to the plant into a closed jar. He quickly understood that the overall carbon dioxide level would increase as the number of mealworms were increased. He associated this situation with deforestation and global warming. Moreover, he identified the Calvin cycle as the phase of photosynthesis that could be affected by the increase in carbon dioxide because he knew the Calvin cycle requires carbon dioxide. He preferred the spinach experiment and the bromthymol blue demonstration to the DPIP demonstration. He was also able to relate the advantage of C3 and CAM plants in stressed situations.

He was one of the few students in the study group who was not fully excited about making animated PowerPoint® presentations to show the solution to a problem with supporting scientific theory. He thought making the animated PowerPoint® presentation was too time consuming and that concept maps offered much more to his learning. Nevertheless he recognized the impact of making a recommendation to the farmers about the mulch in the PowerPoint® presentation.

Researcher What is the impact of you making recommendations to the farmers to your learning and thinking about photosynthesis?

Baxter [We] self test when we explain it. Efficient combining experiments to real life.

The researcher probed to see why he preferred the concept mapping to make animated PowerPoint® presentations. He was so much in favor of concept mapping that he did not even see a value of including student constructed PowerPoint® presentations as part of the activity. He was the only participant that was fully in favor of concept mapping and the elimination of student constructed PowerPoint® presentations.

Researcher Compare and contrast the thought process of making an animated PowerPoint® to making a concept map?
Baxter thought PowerPoint® not just conceptual thinking process. [PowerPoint®] Takes away from the picture by making comprehensive. Concept map is so easy and [and there is a] focus on concepts.

Researcher: What benefit could come from using both techniques in your study of photosynthesis?
Baxter: No benefit.

Baxter appreciated the inclusion of information about the MIT research about the laptop battery, photosystem II (Halber, 2004), the story about generating hydrogen for power with photosystem I, and the demonstration about how red mulch allowed greater crop productivity. He was also interested in the theory behind the research. He understood the similarities between herbicide toxicity and the poison discussed in reference to cellular respiration. He explained how the herbicides caused problems at different stages of electron transport of photosynthesis. The herbicides helped him to learn more about the different points in the process. He thought his study of herbicides would help him to better remember photosynthesis, and that the video showing the plant dying with the herbicide helped him to better visualize and remember how the plant died.

During the biology education research project, he was invited to participate in an engineering project that was designing new methods for detecting sunken ships. He related the biology research to his engineering project. Early in the BDM project, he firmly believed that the activities of the BDM Future Visual Field of Photosynthesis Phase would help him to remember even those things that he identifies as most difficult.

Researcher: What is your future visual field with photosynthesis? Give examples.
Baxter: Right now with photosynthesis [I am working with a] professor [who is using a] light detector to map the bottom [of a local lake] of [with] the [sic] sonar, use of submarines at different depths [sic], and predict what plants would grow and predict algae ships grow on [sic]. Chain reaction - organisms that live on ships. For [the purpose of] measure[ing] environmental light at different degrees [of depth] and relate to it.

Researcher: How will the activities we did impact your thoughts of the future and learning and remember photosynthesis?
Baxter  [It has an] impact on you; it’s a lot harder to forget and [it] comes back easy.
Researcher  What are your deficiencies in photosynthesis, what do you think you know best, and what do you think you know least?
Baxter  Least from hydrogen ion to Calvin cycle that sent Calvin different from cellular respiration. Good electron transport and splitting of water.

Delayed BDM Instructional Strategy Sessions Clinical Interview. Two weeks after the end of the BDM Instructional Strategy Sessions Baxter felt like he realized how the sessions helped him retain knowledge better, instead of “putting it away after the test.” Below he describes how he has retained general knowledge from the sessions and what strategies helped him do so.

Researcher  List the things that you remember most about the sessions or interviews.
Baxter  Kimchee commercial, Kimchee labs, plant in jar, chlorophyll thing, yeast.
Researcher  List the things that helped you to learn photosynthesis and cellular respiration most in the project.
Baxter  Kimchee, pigment, [red] mulch thing.
Researcher  List the strongest things that you remember least about photosynthesis and cellular respiration.
Baxter  General process of photosynthesis.
Researcher  List the weakest things that you remember least about photosynthesis and cellular respiration.
Baxter  Specifics of photosynthesis.
Researcher  What is impact of metacognition in success?
Baxter  Proven how he studies. [I] put it away after test. [I usually do not think about it after the test.]

Concept Map Analysis. The concept map score and visual field analysis determined literacy level. Baxter’s baseline content knowledge of cellular respiration was very low; he scored 10 and his literacy was nominal. The traditional lecture class helped him to advance to a score of 87, but he had no application in his visual fields and had a structural literacy level. He still had problems understanding fermentation and the use of oxygen. He advanced to a score of 120 and a multidimensional literacy level after the BDM Cellular Respiration Past Visual Field Instructional Strategy Session. He added details about creating a gradient of hydrogen ions but
he still had a problem with oxygen. Since he used oxygen at the top of his map to distinguish the difference between anaerobic and aerobic respiration, he had difficulty using it again to keep track of where it is used. He added application to his visual fields.

Researcher: What is your mapping strategy and are you having difficulty with any concept?
Baxter: I map one layer at a time. I put oxygen in at the top end and I need to move it to the end, but I am not sure where to use it.

He had difficulty with the location of creating water in the process of cellular respiration. He left it on the side and did not map it. The cognitive distance of explaining the difference between aerobic and anaerobic conditions seemed to confuse Baxter and many of the other students. He successfully added fermentation and the formation of a hydrogen gradient but did not include the term chemiosmosis. Baxter scored a 141 at the completion of the BDM Cellular Respiration Present Visual Field Instructional Strategy Sessions, and had a multidimensional literacy level. He was still unsure about the use of oxygen and did not show the production of water, however he added the terms chemiosmosis and FADH₂.

After the BDM Cellular Respiration Future Visual Field Phase, Baxter constructed more knowledge. He scored 176 and had a multidimensional literacy level. Baxter’s future visual field identified further applications of cellular respiration. Finally, Baxter included cytochromes as part of electron transport and oxygen as the final hydrogen ion acceptor to produce water. Carbon dioxide was included as a product of the Krebs cycle. He identified the mitochondrial matrix as the location of the Krebs cycle. Baxter was confused about oxidation-reduction reactions and the function of the various parts of the mitochondrion. During the Delayed Phase he lost knowledge of the production of carbon dioxide with the Krebs cycle and production of water from hydrogen ions and oxygen. In other words, the concepts last added are the concepts
that decayed fastest. His concept map score for Delayed Phase was 117 and his literacy level
was multidimensional.

At the beginning of the study, Baxter’s baseline knowledge photosynthesis map score
was 6 and his literacy was nominal. He knew very little. He knew that light is used by
chlorophyll to create glucose. During the past visual field, he mistook the use of water and
oxygen in the Calvin cycle. His map score was 57 and he had a structural literacy level. During
the BDM Photosynthesis Past Visual Field Phase, he mistakenly kept the splitting of water in the
Calvin cycle and used NADPH as a hydrogen ion donor to the electron transport chain. During
the BDM Photosynthesis Present Visual Field Phase, Baxter correctly included the splitting of
water as part of the light reaction to produce oxygen and hydrogen ions. He still mistakenly
identified NADPH as the hydrogen ion donor to electron transport and was unable to identify
rubisco. Baxter correctly added the proton gradient and placed carbon fixation within the Calvin
cycle. His map score was 136 and his literacy level was multidimensional. He added application
to his future visual field.

During the mapping Baxter talked about the importance of not mapping those items he
was not sure of so that he would not remember them incorrectly, demonstrating a metacognitive
understanding of the importance of avoiding alternative conceptions (Griffard, 1999). During
the BDM Photosynthesis Future Visual Field, his knowledge greatly increased with a map score
of 177 and had multidimensional literacy level. He added NADP⁺ reductase, C₃ and C₄ plants,
and redox. In the Delayed Phase he still had NADPH enter the electron transport chain instead
of hydrogen from water. Baxter’s map score was 80 and he had a structural literacy level.

He related all the major components of his Post Strategy Interrelationship of
Photosynthesis and Cellular Respiration map except water and he did not have carbon dioxide as
a product of the Krebs cycle. He was slow making this map and had a score of 159. In the delayed Interrelation Photosynthesis and Cellular Respiration Map his knowledge decayed, with a map score of 171.

Concept map links that corresponded to the selected Biology AP questions were correlated. Baxter’s average concept map score was 100% and his average Biology AP question score was 75% (the details are in Appendix Q). Baxter could visualize more on a map.

The researcher was interested in Baxter’s overall thoughts about BDM learning strategies and visual fields. The following provided a quick look at his thoughts.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Baxter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Look at multiple-choice test questions and problems. Comments.</td>
<td>Did terrible on multi choice. Preferred mapping. It gave more info on what I studied.</td>
</tr>
<tr>
<td>What is impact of metacognition in success?</td>
<td>[It has] proven how I study. I put it away after test.</td>
</tr>
<tr>
<td>If the project continues, would you consider being in it?</td>
<td>Yes, for free.</td>
</tr>
<tr>
<td>What do you think the next step could be?</td>
<td>Integrate into a larger field.</td>
</tr>
<tr>
<td>What do you think about the analysis process that I am using with your maps and clinical interview information?</td>
<td>It tells how to improve ourselves.</td>
</tr>
<tr>
<td>What characteristic of BDM hands on experiences makes it memorable?</td>
<td>Visuals, movies, and PowerPoint®, are very memorable.</td>
</tr>
</tbody>
</table>

**Case Study 2-Bunny**

**Participant Description.** Bunny is a female Indian American and a first year biology major. She plans on going to dental or medical school. Her father is a cardiologist and her mother manages his practice. Bunny went to a magnet high school in Louisiana. Her background in biology is from her experience with science fairs. She took Botany in 10th grade.

Bunny had a 4.0 grade point average in high school. Her composite score was 31 on the ACT and 1450 on the SAT. She scored 620 on the Chemistry SAT II. Bunny has also taken the
Writing SAT II, Math IC SAT II, and the U.S. History AP Exam. In her opinion, her strongest subjects are advanced level math and science and her weakest subject is history.

Bunny uses the computer at least once a day. She prefers to learn without a computer and likes reading from a book. She likes to be taught one on one or with a book by herself. She does not like sitting in front of a computer. She has not used sensors in class but has experience with a hand held calculator.

Bunny had never thought about how she learns science, but thinks research in this area would be helpful. She remembered about photosynthesis from high school but had no recollection of cellular respiration. She believes she had a very strong general science background in high school although she considers her biology background horrible. She grew plants in high school under colored lamps to determine phototropism and tested for the presence of starch to confirm the process. She contends she had some lab experience in high school. Bunny is a very dedicated student, but one who was not interested in learning how to learn before the research.

**Baseline Phase, Prior Knowledge Phase.** Bunny correctly identified that the head of cabbage, plant in a tightly closed jar, and red bean were doing both cellular respiration and photosynthesis. However, for most of the other objects she did not know if they did cellular respiration or photosynthesis. The failure to identify these objects could be due to her conception at the time of whether they were living or dead, as many were labeled as either at one time living or not living.

In the term sorting activity, Bunny correctly identified 50% of the words associated with photosynthesis only. For words associated only with cellular respiration she had identified 33% correctly, and only 18% correctly for words dealing with both photosynthesis and cellular
respiration. Her overall score was 31%. She seemed to have the most difficulty with words that are related to both but was able to properly identify words such as water, oxygen, and carbon dioxide.

Bunny scored a total of 2 points on her cellular respiration concept map in which she indicated one link with the words cellular respiration and sugars. Her photosynthesis map, however, had 13 links, 6 branches, and 2 levels of hierarchy. Her score for the photosynthesis map was 43 points, the highest Baseline concept map score of all of the participants. In the photosynthesis map she used the terms “plants,” “photons,” “sun’s energy,” “water,” “carbon dioxide,” “light dependent reaction,” “chlorophyll,” “splitting of water,” “hydrogen ions,” “chloroplasts,” “energy,” and “starch.”

In Bunny’s baseline visual field, she remembered her biology teacher and science fairs. She remembered the pepper plant she used in a science fair project. She thought she had relatively the same level of knowledge of photosynthesis and cellular respiration. Based on her concept maps, visual fields, object sorting, and term sorting activities, Bunny’s overall literacy was determined to be nominal in cellular respiration and functional in photosynthesis. Bunny’s concept maps can be found in Appendix P, and Appendix Q contains their analysis.

Post Lecture Phase. Bunny scored 100% correct on the photosynthesis-only words. She scored 57% on cellular respiration only words and scored 79% correct for both photosynthesis and cellular respiration words. Her overall score was 82% correct. As was seen in the baseline data, she did not do as well with cellular respiration and both cellular respiration and photosynthesis words.

Bunny’s cellular respiration map contained 27 links, 6 branches, and 5 levels of hierarchy for a total of 103 points. Her photosynthesis map had 19 links, 4 branches, and 3 levels of hierarchy for a total of 70 points.
In Bunny’s past visual field she said she thought of pictures from slide shows and from old books. She saw pictures of PowerPoint® slides for her present visual field. In the future visual field she saw flow charts for the exam. Her insight was seeing how it all connects. Based upon her term sorting, concept maps, and visual fields, Bunny’s overall literacy was determined to be structural in both cellular respiration and photosynthesis which was an improvement over her baseline literacy of nominal in cellular respiration and functional in photosynthesis.

**BDM Cellular Respiration Past Visual Field Phase.** The Kimchee activity described in Baxter’s case study was the focus activity of this session (Appendix S). She had previous knowledge of Kimchee due to her cultural background, but she was not familiar with seeing it outside of ‘ethnic’ cuisine. She thought the characters in the scenario “spelled it out easier than the book.” Tulving’s (1985) research on episodic learning/memory would support her comments. She appreciated and enjoyed the Kimchee video at the Korean grocery and the Kimchee commercial because it gave her visuals and allowed her to hear it. She thought the video needed to be just the right length to keep it interesting, but still informing. She said “[If the] length is too long it buries you. If too short it can't connect.” She fully understood the relationship of Kimchee to lactic acid fermentation, and she thought that the BDM style of presentation that included the various strategies would help her to understand. She said, “It helps me remember it more clearly.” The BDM activities were her first experience with hands-on cellular respiration activities.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>How does something new and different help you to learn?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunny</td>
<td>New and different approach if it connects to you. If [it is] familiar that could help some if it sticks out in your mind.</td>
</tr>
<tr>
<td>Researcher</td>
<td>What is the impact of video on learning?</td>
</tr>
<tr>
<td>Bunny</td>
<td>It is a visual aid.</td>
</tr>
<tr>
<td>Researcher</td>
<td>Why do you think seeing video can help you to learn?</td>
</tr>
<tr>
<td>Bunny</td>
<td>Seeing audio and video different. Some people hear and [some] see.</td>
</tr>
</tbody>
</table>
She gave her perception of a traditional PowerPoint® presentation vs. an animated and layered BDM PowerPoint® presentation, and she concluded that the BDM style PowerPoint® presentations could help her learn to read a diagram. According to Tufte (1990) the use of multiples with variation allows the successful representation of multivariate visuals on paper. The animated PowerPoint® presentations allowed for multiples with variation. Mayer’s (1999) research indicated that an animation using both visual and verbal channels helped to accomplish dual coding that reduces cognitive overload.

Researcher      Describe a traditional PowerPoint® slide?
Bunny          Main points, outline, concepts.
Researcher      Do you like traditional PowerPoint® presentations?
Bunny          Prefer PowerPoints® that actually have less teasing and [is] easier to follow.
Researcher      What was different about the research project PowerPoint® presentations to traditional and commonly used PowerPoint® presentations?
Researcher      How does a layered approach help you to learn?
Bunny          Time frame, 2D all at concepts, layers, help you to learn how to read a diagram.
Researcher      How are animated PowerPoint® presentations different than the book presentations?
Bunny          [It] help[s] you to learn how to read a diagram.

She thought prior knowledge was important because “you build on it.” It was possible to establish a common past visual field and that Kimchee was an example of doing this. She vividly described why she thought her experience with Kimchee will help her remember fermentation in the long-term memory.

Researcher      Did what we did last night in the instruction session contribute to your long term memory?
Bunny          Long term - Kimchee and bubbles clearly showing carbon dioxide lactic acid fermentation. [It] make[s] you think of fermentation.

BDM Cellular Respiration Present Visual Field Phase. According to Langer (1989) unusual elements of a presentation would be most memorable. Bunny appeared to remember items that had uncommon presentations.
Researcher: What are the first five things that come to your mind when I ask you, “What new things did you learn last night?”

Bunny: Cytochromes, fermentation to produce NAD⁺, more soil microbes, carbon dioxide gathering data.

Her answer is a combination of detailed conceptual understanding and examples. Her overall answer includes an interesting distribution of BDM strategies that includes concepts derived from the animated PowerPoint® presentations to the scenarios of the labs with the data collection. This phase used stories, animations, and carefully designed, hands-on live biological experiences that together served to introduce and exemplify the constructs of cellular respiration.

The participants were offered a range of experiences with the goal of finding one that was interesting to them, and the opportunity for the researcher to compare the various activities. The production of carbon dioxide in a yeast solution in a tube and in bread dough was used to illustrate fermentation. Bunny preferred the bread rising to the yeast solution in an inverted tube.

Researcher: What are your thoughts about the bread demonstration compared to the yeast in the tube?

Bunny: [I] liked the bread demonstration better. You were familiar with it.

Researcher: What is the purpose of the bread demonstration compared to the yeast in the tube?

Bunny: Bread was bigger and showing yeast in the tube show what’s going on, and it was more interesting than the tube of yeast.

Researcher: How did looking at the chemical reactions on the board with the demonstration material in your presence help you think and learn about cellular respiration?

Bunny: Chemical reactions to employ formulas do not give the entire picture. I liked seeing the chemical reaction written on the board as we did the yeast in the tube experiment and the bread rising. It helped me to see the reactions under the things I was observing.

Researcher: How do these demonstrations of yeast in the tube and bread dough involve cellular respiration?

Bunny: Dough rises because yeast employs cell respiration.

Even though Bunny preferred the bread rising demonstration, the yeast solution in the inverted tube along with the explanation on the board helped her to understand the underlying
process of fermentation that produced carbon dioxide. A combination of visual explanations appeared to keep her interest and helped her to review the concepts.

Real-time inquiry data collection experiences were another critical BDM strategy. This session emphasized a soil lab called “Picturing Microbes: A Pressing Issue” (Appendix S). Before the lab is introduced, V. Fields™ explains the importance of oxygen to the soil microbes with a few examples about the importance of tilling the soil. He remembered watching his grandfather plowing and hoeing the soil before he planted the crop. The lab included a scenario about a sugar cane farm that had crop difficulty, which was possibly due to compressed soil.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>How did your past knowledge influence your understanding of the soil lab?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunny</td>
<td>From past knowledge of the soil lab I knew that you had to aerate the soil.</td>
</tr>
<tr>
<td>Researcher</td>
<td>Did your study of Kimchee influence your understanding of the soil lab?</td>
</tr>
<tr>
<td>Bunny</td>
<td>No, [I am] not thinking of fermentation.</td>
</tr>
<tr>
<td>Researcher</td>
<td>Predict the rate of respiration of the soil sample in the container if it has been treated with a disinfectant. Explain your prediction.</td>
</tr>
<tr>
<td>Bunny</td>
<td>[It would] go down because microbes die.</td>
</tr>
<tr>
<td>Researcher</td>
<td>What is the purpose of using the bottle to push on the soil?</td>
</tr>
<tr>
<td>Bunny</td>
<td>The bottle lets out oxygen and proves to slow down respiration.</td>
</tr>
<tr>
<td>Researcher</td>
<td>How did soil lab help you to understand about cellular respiration?</td>
</tr>
<tr>
<td>Bunny</td>
<td>Soil lab helped me understand cellular respiration by seeing it.</td>
</tr>
</tbody>
</table>

The researcher was interested in understanding the input of data collection on her learning. She explained how she anticipated the data points and how it “validates” her learning.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>How did the data collection impact your understanding?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunny</td>
<td>Validating it. Hard facts. Seeing it go. Quick is good.</td>
</tr>
<tr>
<td>Researcher</td>
<td>Did viewing the data better help you to understand cellular respiration?</td>
</tr>
<tr>
<td>Bunny</td>
<td>Not necessarily help you understand more.</td>
</tr>
<tr>
<td>Researcher</td>
<td>What were you thinking as you saw each data point appear on the screen?</td>
</tr>
<tr>
<td>Bunny</td>
<td>Watched to see if it was proving what you learned.</td>
</tr>
<tr>
<td>Researcher</td>
<td>How does viewing the graphing of the data point by point help you to understand?</td>
</tr>
</tbody>
</table>
Bunny: Not necessarily understand cellular respiration. It validates it.

Researcher: What is the benefit of seeing the data collected on the screen in real time?

Bunny: Seeing it go right now is the present. Direct effect.

Researcher: Have you had previous experience with data collection?

Bunny: No, but used graphing calculators in chem [chemistry] lab in 11th grade and physics lab in 12th to analyze data. I did not use sensors.

Researcher: How do predictions effect your learning?

Bunny: Predictions test your short term knowledge. [It makes you] more interested in data. [It is] fun. [It will] impact later learning.

Bunny had a good first experience with the BDM data collection and analysis labs. Her comment about seeing the data in real-time allowing her to see the “direct effect” was important because most traditional labs do not show the direct effect.

Bunny was directed to compare the strategies used in the presentation. She has had much experience being a student and she has her opinions.

Researcher: How was its overall presentation of the soil lab different than the bread and yogurt?

Bunny: [In the] soil lab [I] did it [with the] yogurt and bread, [I] watched.

Researcher: How do the different types of presentations (lecture, demonstrations and labs) impact your thinking?

Bunny: [They were] combined to help me understand. Lecture and PowerPoint [are] most important because things are broken down. Then there are demos [demonstrations] and labs that reinforce [what is learned in lectures and PowerPoint presentations].

The researcher wanted to get her perception on animation in detail. She indicated the importance of breaking down the concepts and reducing the “junk” to be her major criteria used to judge the methods. She thought the BDM animated PowerPoint presentations were similar to a “movie you watch and never forget what’s going on.”

Researcher: Do the animations help to explain the concept?

Researcher: How did the PowerPoint presentations help to explain the concepts?
Bunny: [It] definitely helps. [I] learn best with animation and prior knowledge.

Researcher: How are the animated PowerPoint presentations different than the book presentations?
Bunny: Broke down some of the concepts. The book is all at once.
Researcher: Do you prefer the book, traditional PowerPoint® presentations or layer PowerPoint® presentations and why?

Bunny: Proper layering creates more details. Easier to follow. Recap you can review later on. Like a movie you watch and you never forget what's going on. You can study for half that time and be [more] productive.

Most students did not remember studying cytochromes, the proteins in the electron transport chain, in high school and the textbook used in the course did not include much information about them. As a result, most students were curious about them. The researcher attempted to discover how the students constructed new knowledge.

Researcher: Have you previously studied cytochromes?

Bunny: [I have] not previously studied cytochromes.

Researcher: Would you consider cytochromes to be part of your present visual field as we learned about it last night?

Bunny: Cytochromes are [in the] present visual field. One thing I did not know. [I] replayed it in my mind and did not know.

Researcher: Did your prior knowledge help your understanding of cytochromes? How?

Bunny: No prior knowledge of cytochromes. Repeated prodding.

The researcher was interested in her reception to the information about the cytochromes. Since the cytochromes compose the electron transport chain, it is a detail about electron transport. The researcher wanted her to consider the consequences of building knowledge from general to specific with this example.

Researcher: If you had learned about cytochromes in lecture with all the other concepts, do you think you would have noticed them as much and so how was learning about them afterward helpful or not?

Bunny: If it was made a point.

Researcher: Is going from the general concept and zooming in on a specific process helpful? How?

Bunny: Helpful. You can back out to see the general picture. Give you more to deal with.

The researcher probed to see how she related the visual fields and if she had ideas about how the strategies might impact her long-term memory. The present visual field dominated her perception.
Researcher When does the past end and the present begin in your thoughts of photosynthesis and cellular respiration?

Bunny Past ends at the beginning of the semester. Present is biology class at Energy University.

Researcher Draw the fields and indicate dominance of the field to you by the size of the field and describe it.

Bunny [While she draws the visual field lobes, she says the following.] [the] present [is] larger. [The] past and future [are] the same size.

Researcher How will the activities we did impact your learning?

Bunny [I am] interested in cellular respiration now. [I have] seen more.

Researcher How will the activities we did impact your long-term memory?

Bunny My long-term memory will have visual things that generate ATP synthase, water and hydrogen ion seen [as a visualization she indicated], Long term remembers a few of the things of Kimchee with fermentation, Krebs cycle – [I will] remember it better [than I would have without the [BDM] strategy sessions. [I will be able to better] extract the specifics.

**BDM Cellular Respiration Future Visual Field Phase.** The construction of animated PowerPoint® presentations is a strategy used during the future visual field sessions. (Beth and Bunny’s PowerPoint® presentation “What’s Happening With the Data While Making Kimchee” is included in Appendix U). The researcher asked Bunny what first came to her mind from the session.

Researcher What are the first things that come to your mind when I ask you “What new things did you learn today in the research session?”

Bunny I learned what a jumping bean is. [I] learned about cytochromes already. [I had] thought jumping beans were a joke.

At the beginning of the session the researcher presented the students with a story about the 2004 Mexican jumping bean crop that affected their doing the lab called “Cell Respiration: Solving the Mystery of the Mexican Jumping Bean” (Appendix S). There was a drought in Mexico in the area where jumping beans are produced. For the first time in three years the researcher was unable to purchase fresh jumping beans for the lab called “Cellular Respiration: Solving the Mystery of the Mexican Jumping Bean” (Appendix S). The jumping bean seller reluctantly sold the researcher leftover jumping beans from the 2003 crop and he was not sure
that they were very active. Never the less he sold the 2003 crop of beans with a request. Would the participants determine the vitality of the beans? Should he sell the rest of the leftover jumping beans from the 2003 crop? The researcher told the students about the merchant’s dilemma at the beginning of the session. Then the participants tested the jumping beans. First, they observed the beans’ response to light and heat by measuring the rate of cellular respiration using the carbon dioxide sensors. The researcher was interested in Bunny’s comments about jumping beans being a joke. More questions were asked, but the beans were placed in metal tins to amplify the sound of movement by the jumping beans.

**Researcher** What are your thoughts about the jumping beans compared to the mealworms?

**Bunny** Mealworms are gross. [In] 2nd grade we had a pet mealworm.

**Researcher** How did changing the temperature help you to understand the importance of constant temperature?

**Bunny** Organisms are going to respond to change in temperature, it’s going to effect them more because they are ectothermic [organisms].

**Researcher** Did making a prediction about the jumping beans and their movement help you understand something about cellular respiration?

**Bunny** [I’m not] not sure if it help[ed] me understand more about cellular respiration.

**Researcher** Were the jumping beans interesting?

**Bunny** Yes, fascinating.

**Researcher** What is the purpose of using the metal tin with the jumping beans instead of the mealworms?

**Bunny** To hear them better.

Bunny appeared to enjoy making the recommendations to the jumping bean seller.

She recognized that this activity could help her remember cellular respiration despite her present understanding of it.

**Researcher** What was your recommendation as to whether the jumping bean seller should sell the 2003 leftover jumping beans?

**Bunny** The beans were able to jump and respond to light if they were warm, but they did not jump as high as I expected. I think he should sell them at a reduced price and he should be sure to recommend that the buyers keep the beans cool until they want to play with them. He should warn them that they may not last as long as fresh jumping beans.
Researcher  How did studying jumping beans help you to understand about cellular respiration?
Bunny   [I] don't think it helped much because I already understood most aspects of cellular respiration, but I liked them. I think they will help me to remember how organisms that are alive have a rate of cellular respiration and when they move there is a higher rate of respiration.

Researcher  Were you interested in the new problem the jumping bean seller had with whether he should sell the leftover 2003 jumping beans?
Bunny   I was more interested in jumping beans.

The concept of cytochromes was reconsidered. In the previous session, cytochromes were explained with animated PowerPoint®. In addition, a short clip from the James Bond movie *Moonraker* was included. It showed how James Bond wore a watch loaded with darts laced with cyanide. In the movie clip Q, a British secret agent in charge of gadgetry, explained to Bond how to use the dart watch and a person who was hit with the dart would instantly die from the cyanide. After the video, animated PowerPoint® slides explained how cyanide and other poisons block electron transport and how ATP synthase worked (Baskin & Brewer, 1997).

Bunny’s was asked about the usefulness of the *Moonraker* clip and the animated PowerPoint® slides in explaining how the poisons work.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Have you previously studied cytochromes?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunny</td>
<td>No, Thursday night is considered [the] present.</td>
</tr>
<tr>
<td>Researcher</td>
<td>Would you consider cytochromes to be part of your past, present or future visual fields as we learned about it today? Explain.</td>
</tr>
<tr>
<td>Bunny</td>
<td>Present.</td>
</tr>
<tr>
<td>Researcher</td>
<td>How did the study of poisons impact your understanding cytochromes?</td>
</tr>
<tr>
<td>Bunny</td>
<td>[It] helped [me] understand how poisons work.</td>
</tr>
<tr>
<td>Researcher</td>
<td>How did looking at the use of cyanide in James Bond movies impact your understanding of cytochromes?</td>
</tr>
<tr>
<td>Bunny</td>
<td>Cute way of making me remember it, same as poisons, not monotonous or repetitive.</td>
</tr>
<tr>
<td>Researcher</td>
<td>How do you think the viewing of poison information and videos help your memory of cellular respiration?</td>
</tr>
<tr>
<td>Bunny</td>
<td>[It] gave interesting information, and redirected attention back to subject.</td>
</tr>
<tr>
<td>Researcher</td>
<td>Did you like the poison information and do you have any examples to add?</td>
</tr>
<tr>
<td>Bunny</td>
<td>Yes. It was so interesting and it drew in my attention and will help me to remember.</td>
</tr>
</tbody>
</table>
The metacognitive aspects of the session was the student constructed animated PowerPoint® presentation. Bunny enjoyed making the PowerPoint® presentation using the toolbox provided by the researcher. She thought making the layered and animated PowerPoint® presentation had great and positive impact on her learning. This activity kept her attention and kept her anticipating the next step of the process.

Researcher: What is the impact of you making a recommendation to the restaurant owner make to your learning and thinking about cellular respiration?

Bunny: Like making own PowerPoint®, you have to understand it and it makes you work through it. I really liked making the animated PowerPoint® and I thought it was fun and interesting to make a recommendation to the restaurant owner. It felt like a real situation and that science could help provide a solution to a problem. All of this kept my attention.

Researcher: How do you think constructing animated PowerPoint® presentations impacts your learning?

Bunny: There were more visuals and I can be specific with the order and you have to anticipate the next step as you are constructing the animated PowerPoint®.

What about Bunny’s previous use and exposure to PowerPoint®? Although she had some previous experience, the BDM animated PowerPoint® presentations were different from the ones she had been exposed to previously.

Researcher: What is your previous experience with PowerPoint® authoring?

Bunny: Learned last year in computer science, and a few times before that.

Researcher: How do your PowerPoints® help to explain the concepts?

Bunny: Laid out better than book because it is animated and helps me understand process.

Researcher: Does making animations help you to understand the concept?

Bunny: Yes, breaks down concepts.

Researcher: How do you think making animations will help you to remember the concept?

Bunny: [It was the] same effect as watching animated, except more hands on, and you have to know the process.

Researcher: How is making an animated PowerPoint® different in thought process than making a traditional PowerPoint® slide?

Bunny: You make a traditional PowerPoint® before the animated one and then you have to think about how it happens to animate it. The animation process requires you to break the process into steps and then have the big picture at the end.
Researcher  Do you prefer making traditional PowerPoints® or layered and animated
PowerPoints® and why?
Bunny  Prefer animated PowerPoints®, even though they are tedious.

There was a large variation in the participant’s perception or definition of the past,
present and future visual fields, so additional questions were asked about her visual field
perception. Bunny was encouraged by her need to do well on the MCAT and DAT to
remember the constructs of cellular respiration and photosynthesis.

Researcher  When does the present end and the future begin in your thoughts of
photosynthesis and cellular respiration?
Bunny  [The] present ends at [the] end of biology class; [the] future in gardening
etc, and pre-med if I go into pre-med.
Researcher  What is your future visual field with cellular respiration? Give 5
examples.
Bunny  MCAT, DAT, and another biology class.
Researcher  How will the activities we did impact your thoughts of the future?
Bunny  Not so much future, helping in present.
Researcher  What are your deficiencies in cellular respiration, what do you think you
know best, and what do you think you know least?
Researcher  What are the easiest and hardest things to remember in the future?
Bunny  Easiest: specific things; hardest: overall process and equations.

BDM Photosynthesis Past Visual Field Phase. As usual, the researcher inquired as to
what first came to Bunny’s mind about the session. The next part of the discussion considers
Bunny’s thoughts about her metacognition.

Researcher  What 5 things come to your mind when I ask you what you remember
about the research session tonight?
Bunny  Moss balls, chromatography, Junior Mints®, The Grapes of Wrath, (loved
the book).
Researcher  Were you taught about plants making oxygen as a child or do you
remember other comments about plants from your childhood?
Bunny  Yes, we breathe oxygen and exhale carbon dioxide and plants [do the]
opposite. That is why we need trees.
Researcher  Metacognition refers to the knowledge, awareness, and control of one’s
own learning. Are you interested in this?
Bunny  Not really, [I] never had to be, just hard work.
Researcher  Does this research study involve metacognition? Explain.
Bunny  Yes, everything asked is different methods.
Researcher: How are you becoming more metacognitive? Compare yourself now to before the study began?

Bunny: A little change, [I am] trying to integrate it.

Researcher: List 5 metacognitive strategies that you have learned during this research thus far.

Bunny: Concept map, mixed media, hands on experiments.

Bunny indicated that it is not easy to make changes, but she was aware of effective strategies to use. The session was the first time she had learned about guard cells and the tangerine model was useful. She had previously done paper chromatography in her high school chemistry class and she thought the experience was effective because she saw there were more colors of pigments than just green. She thought the moss balls were very interesting and helped her to gain familiar knowledge. The lab with the moss ball was called “Made in the Shade” (Appendix S). It centered around shrimping boat nets that block the sun and cause problems with photosynthesis. The lab was intended to show that plants need light to do photosynthesis and that plants always do cellular respiration. The researcher asked Bunny about the lab.

Researcher: Was it interesting? Yes or no and why.

Bunny: Yes, I really like moss balls.

Researcher: How does the moss ball scenario or shrimp boat scenario involve cellular respiration and photosynthesis?

Bunny: Shrimp boats block light – Photosynthesis gets hit [does not work].

Researcher: Did you gain familiar knowledge about photosynthesis with the moss balls and or cabbage?

Bunny: Cabbage, familiar knowledge.

Researcher: How did the moss ball experiment help you to understand about photosynthesis and cellular respiration?

Bunny: Understood about respiration.

Researcher: How did the data collection impact your understanding?

Bunny: It showed cellular respiration and photosynthesis.

Researcher: What is the benefit of seeing the data collected on the screen in real times?

Bunny: Makes it seem more real, more immediate.

Researcher: Did viewing the data better help you to understand photosynthesis?

Bunny: Helped me better understand relationship between cellular respiration and photosynthesis.

Researcher: Predict the graphs for slope of the line (concentration of carbon dioxide vs. time) for moss balls at night.

Bunny: No photosynthesis, all cellular respiration confused about CO2 and O2, Now I get it – there is an increasing graph [of carbon dioxide].
Bunny had a realization of how autotrophs do cellular respiration and she could best relate this to the slope of the line in Logger Pro®. She understood that bromthymol blue could also be used to track the carbon dioxide. Using different methods of tracking carbon dioxide concentration “reinforces without being boring.” Langer (1989) indicates the importance of variation in activity to prevent fixation and lack of observation due to repetition.

How did the animated PowerPoint® presentations impact Bunny’s learning? She indicated that the animated PowerPoint® presentations helped her to understand concepts by keeping her attention, helping her to learn visually with color and movement. The PowerPoint® presentations are similar to the board because you see it develop.

Researcher: How did the PowerPoints® impact your learning? Explain and give 3 examples.
Bunny: PowerPoint® helped me understand, it’s like the board; [it] keeps attention, [you] learn visually, color and movement helps.

She liked the videos on the Victory Garden and The Grapes of Wrath. She likes history and The Grapes of Wrath is one of her favorite books.

Researcher: How were the garden videos helpful for explaining photosynthesis?
Bunny: I do not know.
Researcher: Could the video be useful in helping you to learn and remember photosynthesis?
Bunny: Maybe if it explained about what’s going on – theory.
Researcher: What is the impact of the Victory Garden information on your learning and memory?
Bunny: Cute story, [I had] heard about [it] before.
Researcher: Was the Victory Garden information interesting to you?
Bunny: [I] find it interesting, like history.
Researcher: Was The Grapes of Wrath interesting and appropriate for this session?
Bunny: Yes one of my favorite books, [I] suppose [it was] appropriate.
Researcher: Other videos or stories that you know?
Bunny: Banana Plantation, [which is a video that she saw in India, and she is not sure if it is available in the United States.]
She had previous experience with photosynthesis with a science fair project, but otherwise she had little background. In response to a question about possibly learning something incorrectly in the past, she emphasizes her incomplete knowledge.

Researcher: Have you learned something in the past that is not correct about photosynthesis?

Bunny: Not very complete.

According to, Griffard and Wandersee (2001) and Wandersee, Mintzes, and Novak (1994), when students have missing knowledge, gaps, they tend to fill the gaps with incorrect knowledge. In interviews the researcher noticed that Bunny and many other participants force answers when they were not sure. The researcher repeatedly discouraged the students from guessing. They most often guess incorrectly. Then that incorrect answer is remembered as being correct and causes alternative conceptions.

The researcher had assumed that the last class would enter the past visual field, but by the last set of interviews it was apparent that there was a large variation in the participant’s perception for the various visual fields. The researcher needed to clarify her perception of the visual fields with the participants.

Researcher: Can you put the last class into your past? Explain.

Bunny: In a sense but [I] consider [it] present, [I] still see it in present because I am still studying.

Researcher: Is it possible to establish a common past visual field?

Bunny: Maybe, [but there is] different perception.

Researcher: Was V. Fields™ helpful to your establishing the past visual field?

Bunny: Don't know, may have been thinking about past before V. Fields™.

Researcher: Do you personally have an interest in photosynthesis?

Bunny: I have interest in byproducts [interested in oxygen and she laughs].

Researcher: Explain about your past visual field with respect to photosynthesis.

Bunny: Science Fair.

Researcher: I as the researcher am placing the last class into the past visual field and I need you to know my perception of the past visual field. Can you accept the last class as becoming part of your past visual field—honestly?

Bunny: Yes, I can now see the last class as part of past, [and] after this class there is more, future -very soon knowledge will change.
BDM Photosynthesis Present Visual Field Cellular Phase. Bunny remembered the Calvin cycle, splitting water, RuBP, and rubisco from the session. Her major concerns from this session was the details of the concepts of photosynthesis. The researcher also asked her about how her metacogniton was developing.

Bunny: Hard work, biology is just memorizing things, [I] try to memorize in class and practicing in class, and identifying problems.

Researcher: Why is it important and useful for you to be aware of strategies that are effective for you?

Bunny: I would be learning it effectively instead of being frustrated.

The basic hands-on activities and the data collection were considered in conjunction with each other. The major activities were: a demonstration with bromthymol blue and Elodea to track carbon dioxide changes; the inverted tube with sodium bicarbonate with Elodea to track oxygen production; the “Junior Mint® Chloroplast Model Study Kit;” the data collection of carbon dioxide with the red mulch lab (Appendix S) and the spinach disk floatation lab (Appendix T). She quickly saw the relationship between the consumption of carbon dioxide and production of an oxygen bubble with Elodea as indicated by the bromthymol’s return to blue color and the presence of the oxygen bubble at the top of the inverted tube of sodium bicarbonate. Further she understood the flotation of spinach discs in the light with the negative slope for the carbon dioxide consumption with the cabbage plants near the red mulch. Bunny understood that oxygen produced in photosynthesis originated from splitting of water, that the hydrogen ion was needed for ATP synthesis, and that oxygen was “given off.” She understood that iodine tracked starch production during photosynthesis, and that starch is formed at the end of photosynthesis. The product of starch is indicative that photosynthesis was complete; oxygen production only indicated the function of photosystem II. Bunny thought the “Junior Mint® Chloroplast Model Home Study Kit” was helpful to examine the structure of the chloroplast even
though she already understood this concept. She thought using iron filings to simulate the tracking of radioactive carbon dioxide was helpful to her. She liked the red mulch lab. The red mulch experiment tested frequencies of light that activate the electrons in the photosystems. She related Engelmann’s prism experiment (Lehninger, 1970) to the mulch because both experiments had the various wavelength of light as variables. The researcher asked her to predict how the black mulch and red mulch would impact the slopes of curves for carbon dioxide changes.

Researcher: How did the prediction of the curves impact your learning?
Bunny: Predicting curves makes use of our knowledge.
Researcher: Please predict the graph for green mulch, darkness, black and red mulch and explain.
Bunny: Green mulch, not photosynthesis more carbon dioxide, not as negative of a curve. Dark- carbon dioxide increasing, black slows down, red speeds up.

Bunny’s thoughts about the animated BDM PowerPoint® presentations and concept maps were explained in terms of layering new information on top of old. She had much to say about the impact of concept mapping on her learning.

Researcher: How does the mapping impact your thoughts and behavior?
Bunny: If I learn it is nice, at first it is tough. I would prefer [a] half-made map. It makes me think about how things fall logically, makes me think about location in time and order of process instead of memorizing. It make me pay attention in class, especially on stuff I missed.

Researcher: How has mapping impacted your thought about visual fields and each field?
Bunny: After finishing the map it is a good way to study. Missed stuff [things she could not map] makes me interested in next class.

Researcher: Has mapping helped you to make connections to the visual fields?
Bunny: [It] doesn't help me want to because [I am] not interested but [I] want to make good grades, so [it] helps there.

Researcher: How does the mapping impact your learning?
Bunny: After I finish I can understand it and study better.

Researcher: Do you like mapping?
Bunny: No, I just don't like seeing terms and relating things together. I like to use it for studying but not making it.
The researcher checked to see if she understood the researcher’s perspective on visual fields, and she understood that the researcher placed the next class in the future visual field. She said that she too could place the next class into the future visual field.

**BDM Photosynthesis Future Visual Field Phase.** The things that came to Bunny’s mind first from the last session were guard cells, C₃, and C₄ plants. The plant video viewed simultaneously with the graph of light, oxygen, and carbon dioxide fluctuations helped her to see what goes “in and out.” She explained that when there was light the carbon dioxide went down because of photosynthesis and when it was dark the carbon dioxide went up due to cellular respiration. She said her predictions were the same as the results, and that “making predictions forces you to use what you know. It is a test of what you know.”

The researcher discussed the plant in the jar. She had problems understanding that the plant in the jar was self-sufficient.

**Researcher** Describe a plant closed in a jar and its metabolic condition. Predict its fate.

**Bunny** Poor if carbon dioxide and water run out.

**Researcher** Are your thoughts on the plant in the jar new or the same as you have thought in the past?

**Bunny** Little more involved. I know water stays in photosynthesis and cellular respiration.

**Researcher** Are you comfortable with your present thoughts? Explain.

**Bunny** Yes.

The researcher then asked her to predict a few graphs to see if she understood. The first graph that she predicted may not be correct.

**Researcher** Predict the carbon dioxide vs. time graph of plants living in a sensosphere with light. Explain.

**Bunny** Carbon dioxide down. [She needed to include the conditions.]

Bunny should have indicated that the carbon dioxide would go down if the plant was in the light. She incorrectly predicted that the carbon dioxide would decrease if twenty mealworms
were included and if half the plants were cut down. The extra mealworms would have increased
the slope and not decreased it. However, she correctly related an increase in carbon dioxide to
the current situation on Earth with the increase in population, deforestation, and potential global
warming.

She accurately related the change in bromthymol blue from yellow to blue, and the
floatation of spinach disks and the changing of DPIP from blue to clear if there was
photosynthesis. She understood that DPIP accepted hydrogen ions in place of NADP\(^+\) to show
that NADP\(^+\) reductase was functioning. She understood that C\(_4\) plants had open stomata all day
and CAM plants had open stomata at night. However, she was not sure when the C\(_4\) pathway
had an advantage over the C\(_3\) pathway. She thought C\(_3\) and C\(_4\) plants were similar because they
both had stoma, but did not relate to the fact that they both had the Calvin cycle. She did not
think learning about the C\(_3\) and C\(_4\) plants was beneficial to learning photosynthesis, and she did
not think extra detail was beneficial.

She thought the explanation of V. Fields\(^\text{TM}\), about how he covered his aquarium with
black plastic sheeting to block the light to kill the algae in his aquarium was beneficial to
understanding how to apply the principle of photosynthesis to daily life. She remembered the
current MIT research on photosystem I and the model network based on the plant. She thought
learning about the research helped her understand and remember about reaction centers. She was
not surprised that there was so much interest in plants. She is interested in “cutting edge current
research,” but not in “looking under a microscope.”

The study of herbicides that block electron transport helped her to better understand
electron transport and she found the video of the herbicide was effective. The video helped her
to “believe” the information.
Researcher: How did looking at the video of the plant treated with herbicide impact your understanding of photosynthesis?

Bunny: [I] saw it. It works. You can believe.

Bunny understood the red mulch experiment and she saw great value in it for understanding photosynthesis. This session expanded on the theory of red mulch with the information about phytochromes increasing the blooming of the tomato and strawberry plants. I asked her to predict the carbon dioxide vs. time graph for a tomato plant that is near red mulch, and she quickly said the carbon dioxide level goes down.

After the extended theory of the red mulch was considered in the session, the participants were given a toolbox of slides and images to use to make an animated PowerPoint® presentation that made a recommendation to the farmers about using red mulch to increase the productivity of their crops. During the clinical interview following the instructional session, Bunny was asked to modify her PowerPoint® presentation (Appendix U) from the previous session to include more detailed directions to the farmers about the use of red mulch. Bunny was certain that sun, mulch, and soil with the plants was enough details for the farmers. The researcher probed her thoughts more deeply. The researcher asked her to explain exactly how the increase in red light could impact the photosynthetic output of a plant. After a few indirect comments, she finally explained that the red light was important for photosystem II. The researcher asked her to explain what is needed for photosystem II other than light, and she quickly responded that water was needed and it was split at photosystem II.

Researcher: Now that we have discussed the details of the red mulch related to photosystem II, add an important item or concept to your PowerPoint®.

Bunny: Water for the splitting of water.

The researcher then discussed the value of constructing the animated PowerPoint® to help the farmers solve a problem of crop production. Her learning the order of the process and her long-term memory were impacted by this strategy.
Researcher: How do your PowerPoints® help to explain the concepts?
Bunny: Yes. [It] helps a little even though teachers make you think about how it is ordered.

Researcher: Does making animations help to understand the concept?
Bunny: Yes, [the] order and what goes on.

Researcher: Do you think making animations will help you to remember the concept?
Bunny: [It will] help [me] remember [the] order.

Researcher: Compare and contrast the thought process of making an animated PowerPoints® to making a concept map?
Bunny: Thought the process. Simple relation process and plan it only in concept map and PowerPoints® not just using words and you can animate hydrogen ion through ATP synthase. Visualize the process. Some develop on PowerPoints® in steps in order for you to see how. General vs. specific. PowerPoints® [is] more specific or PowerPoints® [in] general.

Researcher: What benefit could come from using both techniques in your study of photosynthesis?
Bunny: PowerPoints® are better and more visual and can be in a specific order and not just for animated concept maps. You can anticipate the next answer.

Researcher: What is the impact of you making a recommendation to the farmers make to your learning and thinking about photosynthesis?
Bunny: [It helped me] digest knowledge from photosynthesis and red mulch. Transfer the learning of science thought to the real world beyond face values. Then you think of the impact of light going into C3, C4 and I put thought into it.

Bunny appreciated and enjoyed the opportunity to learn how to utilize and construct animated PowerPoints® presentations as a learning strategy. Her PowerPoints® presentation is in Appendix U.

The researcher also discussed her future visual field. She saw the value of comparing her current Visual Field Perception Map™ with her previous ones.

Researcher: What is your future visual field of photosynthesis? Give 5 examples.

Researcher: Of what use is the visual field worksheet to you?
Bunny: If planning a list [of] things to do, know what did and did not work to test.

Researcher: How will the activities we did impact your thoughts of the future and learning and remember photosynthesis?
Bunny: Remember concept good to know just to say you know.

What photosynthesis concepts did she think she will know best and least in the future?

The least specific things were predicted to be the easiest to remember.
Researcher: What are your deficiencies in photosynthesis, what do you think you know best, and what do you think you know least?

Bunny: Best – General [concepts]. Least - specifics of products and reactants. Make a list. [She thought making a list of what she did not understand was a strategy. She learned during the sessions and wanted to use this strategy].

Delayed BDM Instructional Strategy Sessions Clinical Interview. Bunny, like most of the participants, felt that she would be able to remember the general concepts and would likely lose the more complex concepts such as the names of the various compounds. She felt that participating in the program had allowed her to apply metacognitive strategies to her learning, which will save her time and help her in the future.

Researcher: List the 5 things that you remember most about the sessions or interviews?
Bunny: C maps, classes, PowerPoints®, interviews.

Researcher: List 5 things that helped you to learn photosynthesis and cellular respiration most in the project.
Bunny: Try to use what was learned in classes.

Researcher: List the strongest things that you remember most about photosynthesis and cellular respiration.
Bunny: General idea.

Researcher: List the weakest things that you remember most about photosynthesis and cellular respiration.
Bunny: Certain compounds.

Researcher: What is impact of metacognition in success?
Bunny: If I know how I learn, I can save a lot of time.

Researcher: If the project continues, would you consider being in it?
Bunny: Yes. Reason for participation: wanted to study better and learn biology.

Concept Map Analysis. Bunny’s Concept Maps are available in Appendix P and her scores are in Appendix Q. Bunny’s Baseline Cellular Respiration map score was 2 and her initial literacy level was nominal. She had little prior knowledge. Her Post Lecture map score increased dramatically to 103. Bunny was not able to map cytochromes. Her Past Visual Field of Cellular Respiration map score was 129 and her literacy was structural. She did not have application in her future visual field. Bunny increased her knowledge since Post Lecture, and continued to improve through the BDM strategy.
During the time between making the Post Lecture map to making the map for Past Visual Field of Cellular Respiration there was 6 days. During this time she forgot some concepts and learned others. Bunny forgot how water was produced, but she learned that ATP was produced in the Krebs cycle. During the Present Visual Field of Cellular Respiration Phase she had a map score of 174 and a structural literacy level. She still had not included application into her future visual field. She added substrate level phosphorylation, cytochromes, and proton gradients. During this mapping the researcher and Bunny discussed how high levels of salt in Kimchee establish anaerobic conditions. She scored a 174 Future Visual Field of Cellular Respiration Phase and had structural literacy. Bunny related the structure of the mitochondrion to the various processes, the regeneration of NAD$^+$ in fermentation, and the details of the Krebs cycle. Her major changes were with electron transport and chemiosmosis.

For the Delayed Cellular Respiration Phase map Bunny scored a 126 and had multidimensional literacy, which is comparable to the Post Lecture map, not the Future Visual Field of Cellular Respiration. She mistakenly used carbon dioxide as the source of oxygen. Her future visual field now included application.

Bunny’s Baseline Photosynthesis map scored a 43 and her literacy was functional. She had had prior knowledge as a result of performing a science fair project with plants. Her Post Lecture map score was 70 and a structural literacy level. She mistakenly had the Calvin cycle making ATP, and had carbon dioxide as an unrelated byproduct. Bunny’s Past Visual Field of Photosynthesis map score was a 72 and a structural literacy level. She mistakenly had the Calvin cycle producing oxygen, NADP$^+$ reductase, ATP, and the carbon fixation producing rubisco. Her map score on Present Visual Field of Photosynthesis was 110 and a structural literacy level. Her visual fields did not include application. Bunny added splitting of water by chlorophyll to
make oxygen and cytochromes in the electron transport chain. She had the same mistakes as in the Past Visual Field, and also had the Calvin cycle occurring in the lumen. Her map score for Future Visual Field of Photosynthesis was 116 with a structural literacy level. Bunny linked the light reaction to the Calvin cycle and had the electron transport to powering the cycle. She made no changes to her previous map. It was difficult for Bunny to correct her alternative conceptions (Wandersee, 1986).

Her Delayed Visual Field of Photosynthesis map score was 101 with a multidimensional literacy level, which can be compared with the Post Lecture map scores. She had included application in her future visual field. She lost the connection of light reaction to the Calvin cycle. Her Post Strategy Interrelationship of Photosynthesis and Cellular Respiration map was 185 and her Delayed Interrelationship of Photosynthesis and Cellular Respiration map was 201. In both maps Bunny did not have the NADPH from the light reaction going to the Calvin cycle. She did not produce carbon dioxide in the Krebs cycle to be used in the Calvin cycle, and she did not relate water from cellular respiration to photosynthesis. She did link the glucose from photosynthesis to glycolysis.

Selected AP questions were correlated to corresponding concept map links. Bunny’s average concept map score was 50% and her average AP question score was 17% and the details are in Appendix Q. Concept map scores were higher due to student’s ability to visualize more on a map.

Case Study 3-Bertha

Participant Description. Bertha is a Caucasian female student from New York City. Her father is in real estate and her mother is a homemaker. She is a first year biology major and plans on going to medical school. She attended a public high school in New York and took the
Biology AP Exam in 11th grade and scored a 4 without having done any AP Biology labs. She had a composite ACT score of 33, a composite SAT score of 1430, and a score of 760 on the Molecular Biology SAT II. Bertha had a 4.0 grade point average in high school and has taken other AP and honors courses, including Biology Honors, Biology AP, Calculus AP, Spanish AP, Chemistry Honors, and Physics Honors. Her favorite subject is biology while her least favorite is English.

Bertha is comfortable with computers and uses the computer many times a day. However, she prefers to write rather than use the computer for learning but finds computers good for visualizations. She has no previous experience with sensors in science classes.

Bertha is interested in understanding how to learn and feels that certain students individually respond well to certain teaching styles. She said that she has a photographic memory and learns by repetitive writing. Bertha likes to see words on pages. She does not procrastinate and does not like to wait. She is very organized and characterizes herself as compulsive. Bertha is punctual and completes her assignments on time and is bothered by those who do not.

Bertha was very satisfied with her adapted style of learning. Surprisingly, before the BDM instructional strategy sessions began, she experienced decay in her knowledge of photosynthesis and cellular respiration over a short period of time after the Energy University lectures and exam on photosynthesis and cellular respiration. She noticed her decay during the Post Lecture mapping section of the clinical interviews. This shocked her and because of her fear of losing a large percentage of what she had learned, she developed a special interest in BioDatamation™.
Baseline Phase, Prior Knowledge Phase. Bertha appeared to find the object sorting activity interesting but she had little to say about the objects. She categorized the head of cabbage, jar of Kimchee, and red bean as at one time living but she identified them as doing neither cellular respiration nor photosynthesis. She was not familiar with Kimchee, so the researcher described it as sauerkraut. Her lack of familiarity could have caused her to not realize that it was still living and was doing cellular respiration. The red bean was living and doing cellular respiration - knowledge that is usually part of a Biology AP course. She lacked understanding of the nature of seeds.

Bertha identified the plant in the jar as living and doing only photosynthesis and did not recognize that it was doing both photosynthesis and cellular respiration. She failed to recognize that plants performed cellular respiration. She correctly identified most of the objects that were doing cellular respiration and those objects that were doing neither cellular respiration nor photosynthesis.

There were 35 terms related only to photosynthesis, only to cellular respiration, or to both. She scored 40% correct overall. She correctly scored 50% that were related only to photosynthesis, 50% only to cellular respiration and 29% to both. She had the most difficulty determining which terms were related to both processes. Of the terms related to both, she recognized only the terms in the molecular equation for photosynthesis and cellular respiration: “glucose,” “oxygen,” “carbon dioxide,” “water,” and “ATP.” For photosynthesis she had problems with both the Calvin cycle and the splitting of water in the light reaction which are each the beginning of many processes.

After she sorted the terms associated with photosynthesis and cellular respiration, she mapped the terms she recognized. Her Baseline map of photosynthesis showed her limited
knowledge. Bertha associated plants, carbon dioxide, and chlorophyll with each other. She was shocked by the amount she forgot. She remembered the chemical equation for cellular respiration and she related the items of the equation. At first she said that cellular respiration involved glucose and water. Then she corrected herself and said it consumed glucose and oxygen while it produced water, carbon dioxide, and ATP. She also indicated that the Krebs cycle was involved. She said that the plants relied on animals and that animals relied on plants. She said, “I can see the words on the pages, but not too clearly.”

The Baseline interview with Bertha helped the researcher and the participant get to know each other, and for Bertha to learn about mapping. During the interview they both realized how little knowledge was available for immediate application. It was expected that a student with an AP background would have had more recall. Even though Bertha had previously learned photosynthesis and cellular respiration in reasonable detail, there was much relearning to be done. Bertha recognized that it might be helpful to find a way to learn the concepts so they were not as easily forgotten.

Bertha’s cellular respiration concept map indicated five links with words like “glucose,” “oxygen,” “ATP energy,” “carbon dioxide,” and “water.” She scored a total of 10 points on this map. Her photosynthesis map had three links and scored 6 points. In the photosynthesis map she used the terms “plants,” “sun,” and “carbon dioxide.”

In Bertha’s Baseline Visual Field, she indicated that she wants to go to medical school. Her prior knowledge of cellular respiration and photosynthesis was based on her AP Biology course in high school, which was over two years ago. She felt the terms she was sorting had “brought back some memories,” and realized that she needed to work to bring back her past knowledge. She had never before realized that the past and present were interrelated. She said,
“This is the first time thinking about this.” Based on her concept maps, visual fields, object sorting, and term sorting activities, Bertha’s overall literacy was determined to be nominal level for cellular respiration and photosynthesis.

**Post Lecture Phase.** In the term sorting activity, Bertha scored 100% for the photosynthesis only words, 100% for the cellular respiration only words, 100% for words that were both cellular respiration and photosynthesis, and 100% for all words.

Bertha’s cellular respiration concept map indicated 26 links, 5 branches, and 3 levels of hierarchy for a total of 83 points. Her photosynthesis map had 16 links, 3 branches, and 2 levels of hierarchy for a total of 46 points.

In Bertha’s past visual field she said she talked to plants as a child and knew she gave off carbon dioxide, which helped the plants. She saw trees being cut down in her present visual field. She plans to go to medical school and knows she will have to know the topics of photosynthesis and cellular respiration in the future visual field. She did not know the future but “she will learn from the present and apply to future endeavors.” Based upon her term sorting, concept maps, and visual fields, Bertha’s overall literacy was determined to be structural for cellular respiration and functional for photosynthesis which was an improvement over her baseline literacy of nominal in both cellular respiration and photosynthesis. Based on her concept maps, visual fields, object sorting, and term sorting activities, Bertha’s overall literacy was scored as nominal for cellular respiration and photosynthesis. Her concept maps are in Appendix P, and the scoring of the maps is in Appendix Q.

**BDM Cellular Respiration Past Visual Field Phase.** Most students thought Kimchee was the most interesting activity, and more activities were done with it in other sessions. Bertha became more interested as she learned more about Kimchee.
Researcher: What are your thoughts about the Kimchee scenario?
Bertha: Never heard of Kimchee.
Researcher: What is the purpose of the Kimchee scenario?
Bertha: Purpose was to apply cellular respiration and fermentation to real life.
Researcher: Was it interesting?
Bertha: Semi – interesting.

She was surprised by the presence of a scenario. The scenario was about a restaurant near campus that needed to speed up the process of making Kimchee. She had been expecting more of a lecture format, so she was caught off guard by the Kimchee scenario. According to Langer (1989) and Tulving (1985), it is helpful to catch the attention of people with stories.

Researcher: How did you like the use of characters in the scenario?
Bertha: Not necessarily. They were OK.
Researcher: How does the Kimchee scenario involve cellular respiration?
Bertha: Involves cellular respiration to try to induce fermentation in the cabbage with NaCl.
Researcher: Did you gain familiar knowledge about anaerobic cellular respiration?
Bertha: Yes, from Kimchee.

Bertha was more interested in tilling the soil than Kimchee, but during this portion of the interview, it was not obvious why. Later, during her visual field analysis, she revealed that her mother had shoes with spikes and walked around the yard to put holes in the ground through the grass to help air get to the soil. During her study of cellular respiration with BDM strategies, she began to understand some of her childhood experiences. Her childhood experience helped her to relate to learning the concepts.

Researcher: How did soil scenario help you to understand about cellular respiration?
Bertha: Tilling the field.
Researcher: How did the soil scenario help you to understand cellular respiration?
Bertha: Oxygen in the soil and cellular respiration.
Researcher: How did the data collection impact your understanding?
Bertha: Data collection helped my understanding by allowing ways to see quantities.
Researcher: Have you previously had experience (hands on, reading, stories or movies) about aerobic and anaerobic cellular respiration?
Bertha: Never had hands on experience.
Researcher: Have you studied anaerobic cellular respiration in school?
Bertha: No, never in school.
After basic cellular respiration concepts were established, the researcher helped her to think about her past knowledge. She was quick to make relationships and she was comfortable with this line of questioning. She appeared to enjoy discussing her imagery of her past experiences, and she also appeared to have an appreciation for it with respect to her present.

**Researcher**  Is it possible that what you learned in the past was not complete or correct?

**Bertha**  Yes, I did not learn complete information in the past.

**Researcher**  If knowledge from the past is incorrect could it cause problems with your current learning?

**Bertha**  Yes, its like batting the wrong way. [She then went on to give an example of how if something is incorrect, then the incorrect thing takes the place of the correct thing. She used ATP and plants as an extreme example of this situation that is obviously wrong.] If ATP is plants it symbolically takes the place of plants.

**Researcher**  Why is it helpful to identify your past knowledge?

**Bertha**  See what you learned incorrectly if you correct it. Time to accept the fact and then keep learning it incorrectly. Recall to use it.

**Researcher**  Why is it important to have past knowledge?

**Bertha**  Past knowledge - because you can but if incorrectly you can be confused. Recall to use it.

**Researcher**  How can correct previous knowledge help you to learn?

**Bertha**  Learn in the past that you can repeat.

The questions helped her to realize that she had incomplete knowledge, and the problems that she could have if she had learned something incorrectly. She was interested in gaining awareness of these thoughts about metacognition. The guiding questions helped her realize the importance of prior knowledge and how it all seemed to be a matter of common sense. She had never thought of the importance of these things before.

The possibility of establishing a common past visual field for students was discussed. At first she did not think it was possible. Then she thought about the Kimchee as an example because she realized that she and most other students had never seen it before, but a scenario in the PowerPoint® presentation made reference to how someone had watched the making of Kimchee as a child. V. Fields™ was created by the researcher to help guide students through the
realization of their visual field. Mayer, Dow, and Mayer (2003) had studied the effectiveness of
agents to help guide students in screen presentations. The Baseline interviews showed that most
students did not have much experience thinking about their past, present, and future visual fields.

V. Fields™ was adapted to help introduce examples of the past and future visual fields. V.
Fields™ is simple graphic and is shown in the PowerPoint® slides in Appendix R. Bertha began
to make the connection between how an unfamiliar situation can help her remember.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Is it possible to establish a common past visual field?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bertha</td>
<td>Probably not so you learn differently…[but maybe] Kimchee [could be an example].</td>
</tr>
<tr>
<td>Researcher</td>
<td>Was V. Fields™ helpful in the presentation?</td>
</tr>
<tr>
<td>Bertha</td>
<td>OK, repetitive.</td>
</tr>
<tr>
<td>Researcher</td>
<td>What was the purpose of V. Fields™?</td>
</tr>
<tr>
<td>Bertha</td>
<td>To emphasize certain things.</td>
</tr>
<tr>
<td>Researcher</td>
<td>Were you surprised by V. Fields™? [Were you surprised to see the use of a simple agent, character, like V. Fields™?]</td>
</tr>
<tr>
<td>Bertha</td>
<td>Yes.</td>
</tr>
<tr>
<td>Researcher</td>
<td>Was V. Fields™ helpful to your establishing the past visual field?</td>
</tr>
<tr>
<td>Bertha</td>
<td>No. Not helpful.</td>
</tr>
</tbody>
</table>

One of the reasons for developing and using V. Fields™ was that most students did not have much experience with cellular respiration (i.e. they did not have an extensive past visual field with cellular respiration). V. Fields™ not only helped the students recognize the visual fields, but it also helped direct their attention to the Kimchee example. In the PowerPoint®
presentation V. Fields™ tells a story from his childhood about his Korean friend’s mother making Kimchee. Further, V. Fields™ explains how his friend had a favorite Kimchee commercial. Then the group views the commercial within the PowerPoint® presentation.

Langer (1989) explained the importance of capturing people’s attention with unusual ideas. They helped people to remember. In this study, the students were asked about perception of Kimchee, a fermentation product. Bertha quickly explained the importance of new and different ideas in relationship to her learning.
Researcher: Did you already know about Kimchee?
Bertha: Did not know.
Researcher: How does something new and different help you to learn?
Bertha: New and different - new and different perspective. If you are interested, it helps get your attention.

Graphics also helped participants to learn according to Tufte (1990), Mayer and Gallini (1990), and Mayer and Sims (1994). Videos are examples of animated graphics and the researcher attempted to make them interesting while using them to provide a rich contextual presentation of information which centered around a situation. Tulving (1985) indicated the effectiveness of well designed video. The researcher created a video that was simple and brief. It’s goal was to help the students better understand Kimchee and also to develop their past visual field concerning cellular respiration. Bertha was queried regarding her perspective on the effectiveness of video and her idea of the ideal video format for an instructional situation.

Researcher: How were the videos helpful for explaining Kimchee?
Bertha: Videos were helpful.
Researcher: What is the impact of video on learning?
Bertha: Helps. Another media environment. Helps to learn because of another approach.
Researcher: Why do you think seeing video can help you to learn?
Bertha: Too boring, too short - not enough.
Researcher: Is the length of the video important?
Bertha: Too long - get disinterested.

PowerPoint® is a common presentation tool used in many instructional situations. Bertha was asked about the most common applications of PowerPoint® software to get her perception of a traditional, common PowerPoint® presentation. Bertha also was asked to record her impressions of the effectiveness of BDM PowerPoint® presentations (which are in Appendix R).

Researcher: Describe a traditional PowerPoint® slide.
Bertha: Traditional PowerPoint®: Bullet - Bullet - Bullet. Slide in and slide out.
Researcher: What was different about the research project PowerPoint® presentations?
Bertha: [I] liked the videos and showed information. [It] let you move closer.
Researcher: How does a layered approach help you to learn?
Bertha [A] layered approach move[s]. [You] see instead of imagine [what the words mean].

What was Bertha’s opinion on how animated PowerPoint® presentations compared to book presentations and writing on the chalk board? Contrasting items were offered for discussion so that she would not be led to what the researcher was looking for. Bertha, like all the students, was asked to be open-minded and honest.

Researcher How are animated PowerPoint® presentations different than the book presentations?
Bertha The book presents everything at one time and it lacks animation.

Researcher How does writing on the board with chalk compare to animated PowerPoint® Presentations?
Bertha Chalkboard writing - Writing as you speak. PowerPoint® can expand on this.

Researcher Is drawing different than a layered PowerPoint®?
Bertha Drawing is no different. [You] draw in layers.

BDM Cellular Respiration Present Visual Field Phase. Many discussions were opened with conversations about the five things that came to their mind as they thought about the previous instruction session. Bertha quickly correlated the presentation of the various examples of cellular respiration. She participated in both the Kimchee lab and the soil lab and was able to see the difference between anaerobic and aerobic respiration as a result of her experiences in the BDM instruction session.

Researcher What are the first 5 things that come to your mind when I ask you, "What new things did you learn last night?"
Bertha I learned that yeast produces carbon dioxide in anaerobic respiration, lactic acid and yogurt, new technology helps study respiration, learn about fermentation, salt and Kimchee in anaerobic respiration.

Researcher Did your study of Kimchee influence your understanding of the soil lab?
Bertha Kimchee is anaerobic and the soil lab is aerobic.

Researcher Give an example of this process from the presentation.
Bertha Kimchee project.

A demonstration of bread dough rising was done in parallel with a quick experiment with yeast in an inverted tube. Bertha quickly made the correlation between the carbon dioxide gas
being produced in the tube and the ability of the carbon dioxide to make bread rise. She realized glycolysis came first and then fermentation. She also recognized the bread as an animation. She enjoyed analyzing the activity.

Researcher  How did looking at the chemical reactions on the board with the demonstration material in your presence help you think and learn about cellular respiration?
Bertha   [It] helped to see how carbon dioxide is produced. [I could] Look at bread with animation [sic].

Researcher  How do these demonstrations of yeast in the tube and bread dough involve cellular respiration?
Bertha   Yeast fermented and gave off carbon dioxide. [It] goes through glycolysis and fermentation.

The soil lab, “Picturing Soil Microbes,” was another way to approach cellular respiration (Appendix S). Bertha made the association between her mother aerating the soil (past visual field) with the tilling of the soil during the soil lab demonstration (present visual field). She predicted the slope of the line of carbon dioxide production versus time when soil was sprayed with disinfectant. This exercise helped her use the future visual field and to open the discussion of why the soil samples have a rate of respiration. She quickly made the connection between the soil microbes and the rate of cellular respiration, and used Logger Pro™ to show her prediction (i.e. using the Analyze menu of Logger Pro™, she selected Predict, and drew a line on the graph on the computer screen). Logger Pro™ was easy to use, and she was interested in making the prediction.

Researcher  Predict the rate of respiration of the soil sample in the container if it has been treated with a disinfectant by drawing your prediction on the graph on the computer screen. Explain your prediction.
Bertha   Less respiration. Flat low line.
Researcher  Please explain your prediction.
Bertha   Disinfectant would kill microbes.

The participants also performed an experiment in which they determined the rate of respiration in uncompressed and compressed soil. They pushed the air from the soil by
compressing it with a bottle. The accompanying handout included a scenario about Adelle and Pierre and their quest to solve a problem with a sugar cane crop that might have been caused by the heavy cane trucks compressing the soil. The bottles were used to simulate trucks compressing the soil.

Researcher: What is the purpose of using the bottle to push on the soil?
Bertha: To simulate trucks rolling on the soil.

Researcher: How did soil lab help you to understand about cellular respiration?
Bertha: Showed the difference between aerobic and anaerobic respiration.

Researcher: How was the overall presentation of the soil lab different than the bread and yogurt?
Bertha: Soil lab was quantitative rather than qualitative.

Researcher: How did your past knowledge influence your understanding of the soil lab?
Bertha: My mother used to aerate the soil [by walking on grass with shoes with spikes].

Bertha realized that she understands the concepts better when she sees the data collected in real time. By seeing the data being plotted she can predict the outcome. Bowen, Roth and McGinn (1999) have shown that more context is retained if the data collection and analysis are simultaneous. Studies in prospective psychology also indicate the usefulness of considering the future (Ellis, 1996).

Researcher: How did the data collection impact your understanding?
Bertha: Data collection gave a quantitative view.

Researcher: Did viewing the data better help you to understand cellular respiration?
Bertha: Yes.

Researcher: What were you thinking as you saw each data point appear on the screen?
Bertha: I knew what was going to happen. Let me predict point by point.

Researcher: How does viewing graphing data point by point help you to understand?
Bertha: Let me see the steps.

Researcher: What is the benefit of seeing the data collected on the screen in real time?
Bertha: Relate to the process. Helps see the overall picture.

Researcher: How do the different types of presentations (lecture, demonstrations and labs) impact your thinking?
Bertha: Lectures, demonstrations and labs are hands on and help you to understand.

Researcher: Have you had previous experience with data collection?
Bertha: No.
Bertha used her prior knowledge in the understanding of cytochromes. She described the process as allowing her to see the picture more completely. She was one of the few students who had previously learned about cytochromes.

**Researcher**: Have you previously studied cytochromes?
**Bertha**: Yes.

**Researcher**: Would you consider cytochromes to be part of your present visual field as we learned about it last night?
**Bertha**: Yes, because I learned more about it.

**Researcher**: Did your prior knowledge help your understanding of cytochromes?
**Bertha**: Yes absolutely.

**Researcher**: If you had learned about cytochromes in lecture with all the other concepts, do you think you would have noticed them as much and so how was learning about them afterward helpful or not?
**Bertha**: Helpful. The picture is more complete.

PowerPoint® presentations helped Bertha to understand concepts by presenting them in an organized way. The organization of data is what Tufte (2001) meant by saying that data should be revealed in layers.

**Researcher**: Is going from the general concept and zooming in on a specific process helpful? How?
**Bertha**: General idea then details.

**Researcher**: Do the animations help to explain the concept?
**Bertha**: Animations help you see the flow sequentially.

**Researcher**: How did the PowerPoints® help to explain the concepts?
**Bertha**: They are organized.

**Researcher**: How are the animated PowerPoints® different than the book presentations?
**Bertha**: Animated using multimedia.

**Researcher**: Do you prefer the book, traditional PowerPoints®, or layer PowerPoints® and why?
**Bertha**: Not [book or] traditional PowerPoints [but I like] piece by piece [layered animations].

Bertha did not realize where her past visual field ends and the present visual field begins as evidenced in the responses that follow. Concepts she has learned in the research sessions have added to her long-term memory.
Researcher  When does the past end and the present begin in your thoughts of photosynthesis and cellular respiration?
Bertha  Past was AP Biology in high school. Present is Energy University.
Researcher  Draw the fields and indicate dominance of the field to you by the size of the field.
Bertha  Present and future are big.
Researcher  How will the activities we did impact your learning?
Bertha  Aerobic and anaerobic carbon dioxide help with seeing the bubbles.
Researcher  How will the activities we did impact your long-term memory?
Bertha  Help my long-term memory.

BDM Cellular Respiration Future Visual Field Phase. In the future visual field, Bertha applied what she has learned to further understanding cellular respiration. She compared jumping beans and mealworms and their data.

Researcher  What are the first things that come to your mind when I ask you “What new things did you learn today in the research session?”
Bertha  Jumping bean-larvae, produce oxygen in aerobic respiration, poisons effect cytochromes, PowerPoint®, types of lab equipment.
Researcher  What are your thoughts about the jumping beans compared to the mealworms?
Bertha  Mealworms make better graphs, jumping beans are cooled.
Researcher  How did changing the temperature help you to understand the importance of constant temperature?
Bertha  Higher temperature makes them respire faster, keeps same to test light. [Change in] Temperatures would not affect endotherms.
Researcher  Did making a prediction about the jumping beans and their movement help you understand something about cellular respiration?
Bertha  More they move more respiration- required more ATP.
Researcher  Were the jumping beans interesting? Yes or No and why.
Bertha  Yes, I've only seen them twice.
Researcher  What is the purpose of using the metal tin with the jumping beans instead of the mealworms?
Bertha  To hear the jumping beans.
Researcher  How did studying jumping beans help you to understand about cellular respiration?
Bertha  Carbon dioxide sensors [help to show the carbon dioxide production].

Bertha was again asked about cytochromes, which she had studied in AP Biology, and she remembered cytochromes were in previous interviews. She realized that learning is a
building process that was influenced by her past, present, and future visual fields. The researcher had her relate cytochromes to the mechanism of some poisons.

Researcher Have you previously studied cytochromes?
Bertha Yes, AP Bio, and last week.
Researcher Would you consider cytochromes to be part of your past, present or future visual fields as we learned about it today? Explain.
Bertha Past and present, and probably future.
Researcher How did the study of poisons impact your understanding cytochromes?
Bertha Applying it and making it more tangible.
Researcher How did looking at the use of cyanide in James Bond movies impact your understanding of cytochromes?
Bertha Shows how we don't understand things we see everyday.
Researcher How do you think the viewing of poison information and videos help your memory of cellular respiration?
Bertha May trigger my memory about cytochromes in the future.
Researcher Did you like the poison information and do you have any examples to add?
Bertha Cool aide.

Bertha appreciated animated and layered PowerPoint® presentations and she knew that seeing all the information at once can lead to cognitive overload. Edelson (2001) indicates that multimedia plays an important role in knowledge application.

Researcher What is your previous experience with PowerPoint® authoring?
Bertha 9th grade multimedia class.
Researcher How does your PowerPoint® presentation help to explain the concepts?
Bertha Layers concepts.
Researcher Does making animations help to understand the concept?
Bertha Yes, not seeing it all at once.
Researcher How do you think making animations will help you to remember the concept?
Bertha Can envision the order and what's going on.
Researcher How is making an animated PowerPoints® different in thought process than making a traditional PowerPoint slide?
Bertha Have to consider the order, and what to hide.
Researcher Do you prefer making traditional PowerPoints® or layered and animated PowerPoints® and why?
Bertha I prefer layered.layered/animated, more creative.

Bertha has begun to see that the future visual field is her application of her knowledge to a situation. She began to see how the various visual fields were related to each other.
Researcher What is the impact of you making a recommendation to the restaurant owner make to your learning and thinking about cellular respiration?
Bertha Had to apply everything I had learned the past few weeks about Kimchee.
Researcher Were you interested in the new problem of Oz, the jumping bean agent, selling last year’s jumping beans?
Bertha Another way to apply knowledge.
Researcher When does the present end and the future begin in your thoughts of photosynthesis and cellular respiration?
Bertha The past is everything I have learned till now, while the future everything from now.
Researcher What is your future visual field with cellular respiration? Give 5 examples.
Bertha Planting a garden, kids buying jumping beans, raisins.
Researcher How will the activities we did impact your thoughts of the future?
Bertha I know how to make Kimchee better.
Researcher What are your deficiencies in cellular respiration, what do you think you know best and what do you think you know least?
Bertha Strongest: glycolysis; weakest: Krebs and electron transport complex. Hardest to forget: overall equation; easiest to forget: cytochromes, whole picture, complex compounds.

BDM Photosynthesis Past Visual Field Phase. The chloroplast model, cabbage, moss balls, oxygen from water, and cyanobacteria were the things Bertha remembered most from the previous session. The concept of metacognition was raised with her. Bertha realized that there are other more effective ways to learn than by just memorization.

Researcher “Metacognition refers to the knowledge, awareness and control of one’s own learning.” Are you interested in this?
Bertha Yes, help me study for test, and long-term, learned it was useful when mapping could recall stuff.
Researcher Does this research study involve metacognition? Explain.
Bertha Yes, uses different teaching approaches to help us remember.
Researcher How are you becoming more metacognitive? Compare yourself now to before the study began?
Bertha Before relied on memorization, rely on other ways of learning now.
Researcher List the metacognitive strategies that you have learned during this research thus far.
Bertha Experiments, layered PowerPoints®, and constructing models and concept maps.
The researcher discussed if she had been previously taught about plants. Bertha recalled how she used to talk to plants, because she knew that talking to plants would raise the carbon dioxide level in their immediate vicinity.

Researcher: Were you taught about plants making oxygen as a child or do you remember other comments about plants from your childhood?
Bertha: Plants make oxygen, talk to plants. I talked to the plants to give them carbon dioxide and they gave me oxygen.

What about the various hands-on activities and demonstrations concerning photosynthesis? Did these visual activities impact her learning?

Researcher: Had you learned about guard cells and stomata before tonight? If so how?
Bertha: Yes. AP Biology.

Researcher: Was the tangerine model helpful to your understanding? If so how?
Bertha: Not really -- no appeal.

Researcher: Had you done chromatography before? If yes how?
Bertha: Yes. AP Biology.

Researcher: Was the chromatography helpful for learning about chlorophyll? Explain.
Bertha: Yes, helped to explain better.

Bertha was learning more about photosynthesis having had several lessons involving different aspects of photosynthesis. Labs that measured carbon dioxide as a product of photosynthesis had an associated scenario to help the participants learn about a situation.

Researcher: What are your thoughts about the moss ball scenario or the shrimping boat?
Bertha: Yes, used wire and saw photosynthesis decline.

Researcher: Was it interesting? Yes or no and why.
Bertha: Yes.

Researcher: How does the moss ball scenario or shrimping boat scenario involve cellular respiration and photosynthesis?
Bertha: When the container was wrapped in aluminum foil, this helped cell respiration to increase.

Researcher: Did you gain familiar knowledge about photosynthesis with the moss balls and or cabbage?
Bertha: Yes, saw fluctuations in carbon dioxide.

Researcher: How did the data collection impact your understanding?
Bertha: Good, could actually see fluctuations.

Researcher: What is the benefit of seeing the data collected and graphed on the screen in real time?
Bertha Helps to see it.
Researcher Did viewing the data better help you to understand photosynthesis?
Bertha Yes.

Bertha was asked to predict a curve for moss balls at night. She then compared the moss ball- carbon dioxide data to the *Elodea*- bromthymol blue experiment.

Researcher Predict the graphs for moss balls at night. Explain.
Bertha Some carbon fixation, moss ball at night, positive slope of carbon dioxide graph.

Researcher How was the moss ball presentation different than the *Elodea* with bromthymol blue?
Bertha See color in *Elodea*, color visual, seeing graph with moss.

Researcher Does the different presentation impact your thinking? How?
Bertha Not really, like *Elodea*, like combination.

Researcher What was the purpose of the *Elodea* demonstration? Explain.
Bertha Another example.

Researcher Have you had previous experience with these organisms and experiments?
Bertha Think I worked with *Elodea* before in my high school lab.

The researcher discussed Bertha’s past visual field. She quickly admitted that she did not remember anything. She assumed that she lacked alternative conceptions, but as noted with Bunny, the lack of knowledge can be the source of alternative conceptions. The diversity of perception for establishing a common past visual field was discussed.

Researcher Have you previously had experience (hands on, reading, stories or movies) about photosynthesis and plants? Please explain.
Bertha Reading bio textbook, gardens, chromatography lab.

Researcher Have you studied photosynthesis in school? If yes how?
Bertha Yes, high school biology.

Researcher Have you learned something in the past that is not correct about photosynthesis?
Bertha I don't remember anything.

Researcher Can you put the last class into your past?
Bertha Yes.

Researcher Is it possible to establish a common past visual field?
Bertha We all sat in same lecture that you presented - but different experiences- different views.

V. Fields™ was used throughout the study to relate background information. Bertha did not appear to like the videos in the photosynthesis lesson. She admitted that she prefers the study...
of cellular respiration to photosynthesis. Bertha thought she had a rather complete understanding of cellular respiration and she was surprised how much knowledge she lost during the 12-13 days after the course exam and the first BDM session/ interview on photosynthesis. Bertha obviously was disturbed as to how much she had forgotten over a few days and she seemed moody about her memory decay. Bertha was anxious to get to the more complex details of photosynthesis that she had forgotten. She was impatient with the Victory Garden and *The Grapes of Wrath* videos.

Researcher: Was V. Fields™ helpful to your establishing the past visual field?
Bertha: I guess, little stories and biology.

Researcher: How were the garden videos helpful for explaining photosynthesis?
Bertha: It was okay, watering.

Researcher: Could the video be useful in helping you to learn and remember photosynthesis?
Bertha: Sure. It might be helpful.

Researcher: What is the impact of the Victory Garden information on your learning and memory?
Bertha: It was a stretch.

Researcher: Was the Victory Garden information interesting to you?
Bertha: Not really.

Researcher: Was *The Grapes of Wrath* interesting and appropriate for this session?
Bertha: Somewhat, another stretch.

Researcher: Other videos or stories that you know?
Bertha: Not really.

Researcher: Do you personally have an interest in photosynthesis?
Bertha: Not really. I like respiration better.

Bertha had enjoyed the BDM animated and layered PowerPoint® presentations, and displayed attentiveness to the slides. She frequently mentioned of the effectiveness of the animated PowerPoint® presentations. Her favorable reaction to the PowerPoint® slides supports the study of Mayer and Chandler (2001) that showed that presentation in parts results in better transfer. Also, her attraction to simple graphics was the same effect that Tufte (2001) would predict.

Researcher: How did the PowerPoints® impact your learning? Explain and give 3 examples.
Bertha: Layers, multimedia is cool, neat and easy to see.
Researcher: Explain about your past visual field with respect to photosynthesis.
Bertha: Seed germination, talking to plants, AP Biology, and people can have common present visual field.
Researcher: Can you accept the last class as becoming part of your past visual field—honestly?
Bertha: Yes.

Bertha also identified that students can have a common present visual field and current classmates can become part of her past. The researcher needed to track and understand her visual field perception.

**BDM Photosynthesis Present Visual Field Phase.** Hands-on learning helped Bertha to learn the concepts better and distinguished which strategies were more useful than others.

Bertha became increasingly more appreciative of hands-on activities. It had been her practice to recopy her notes to learn. Now she had other ideas about how she learns.

Researcher: What 5 things come to your mind when I ask you what you remember about the research session tonight?
Bertha: Filings [tracking carbon dioxide], oxygen comes from water, glucose from carbon dioxide.
Researcher: “Metacognition refers to the knowledge, awareness and control of one’s own learning.” Have you discovered more strategies or do you understand more about strategies you have previously described? Explain.
Bertha: Hands on stuff.
Researcher: Why is it important and useful for you to be aware of strategies that are effective for you?
Bertha: Use them to learn better, you know what strategies are useful.
Researcher: What did you learn new about chromatography last night? How did you use your previous knowledge as we reviewed it? Do you like building on a topic?
Bertha: Shows you the different pigments.

Bertha analyzed the various lessons from the night before to understand the different components of photosynthesis. She saw that oxygen was produced by the spinach and developed a mental picture that oxygen came from the splitting of water, and that carbon dioxide and hydrogen are used to make glucose and starch.
Researcher: Did reviewing the bromthymol blue demonstration and the oxygen bubble experiment on the board help you better understand the demonstrations? Explain. Did it help prepare you for the details that followed in the PowerPoint® slides?

Bertha: Yes, helped you to understand.

Researcher: Describe the methods, purpose and results of the spinach disk experiment.

Bertha: Push the oxygen out; keep it in the dark, purpose to show that oxygen is in the leaf when photosynthesis is occurring if it's in the light.

Researcher: How was the spinach experiment similar and different than the bromthymol blue experiment and the bubble experiment?

Bertha: Similar that it's another qualitative way of seeing it; different- carbon dioxide with the bromthymol blue, and oxygen tracked by the spinach.

Researcher: Did you like the comparison of bromthymol blue to the computer graph to learn photosynthesis?

Bertha: Yes, it shows the negative slope in photosynthesis. Pairing qualitative and quantitative is useful.

Researcher: How is oxygen produced in photosynthesis?

Bertha: Photolysis of water.

Iodine was used to track starch production. Bertha understood the products of photosynthesis and how to track each one, and was enthusiastic as she explained the tracking methods.

Researcher: How does iodine help to study photosynthesis?

Bertha: It is used as a tracer, to see when starch is produced, starch is the end product.

Researcher: What are three ways to track the progress of photosynthesis? Explain.

Bertha: Look for end product which is starch, use C\textsuperscript{14}, or carbon dioxide or oxygen.

Researcher: Which is the most indicative the entire process occurred? Explain.

Bertha: Glucose because it's at the end.

The chloroplast model was used to explain the structure and function of the specific components of photosynthesis. She thought the visual aspect of it was important and we mentioned the model many times in passing during discussions. We even talked about developing an alternative models with green mint containers.

Researcher: How did the Junior Mint\textsuperscript{®} Chloroplast model from Monday night [session before last] help prepare you for last night’s class?

Bertha: You can see where everything is, visualize chemiosmosis and the stroma. Lumen was [white] candy, thylakoid was chocolate shell.
Researcher  Did you like the Junior Mint® Model? Why?
Bertha   Yes, it tasted good.
Researcher  Describe the iron filings experiment and compare it to Calvin’s studies.
Bertha   Calvin cycle similar to radio isotope, could see it.
Researcher  Did you like the filing activity? Explain.
Bertha   Yes. Similar to Calvin's experiment.

The red mulch experiment tested the effects of different colors of the spectrum to the level of photosynthesis. Bertha saw that the red mulch increased photosynthesis.

Researcher  Describe the red mulch experiment?
Bertha   Plants grow faster when there's red mulch.
Researcher  How is it like the Engelmann Experiment?
Bertha   He saw that oxygen loving bacteria congregated at the red and purple light.
Researcher  Relate the red mulch experiment to photosystems.
Bertha   Red has more absorption, has photon management in daytime, light hits and red light is reflected [by the mulch], red light goes in [is absorbed by] the photosystems, black mulch absorbs it all, and plants don't get and light.
Researcher  How did the prediction of the curves impact your learning?
Bertha   Predicting shows the expected, that you have an understanding.

Thus, Bertha understood that the present built on the past visual field. Further, she understood that the past, present and future can be used to solve problems. Bertha liked concept mapping and understood that mapping can organize the past, present, and future visual fields for application.

Researcher  What was the impact of the PowerPoint® slides to your learning last night?
Bertha   They were good; help me better understand the Calvin cycle.
Researcher  Do you see the present building on the past in the sessions? Explain.
Bertha   Yeah, each time you grow your present going to the past.
Researcher  How does the mapping impact your thoughts and behavior?
Bertha   Each time I learn something more I can add to the mapping, expand on it. Behavior, not sure.
Researcher  How has mapping impacted your thought about visual fields and each field?
Bertha   Show transformation from present to past, future- can use mapping in the future, can be used to solve problems.
Researcher  Has mapping helped you to make connections to the visual fields?
Bertha   Transformation of present to past, you can see the progression.
Researcher  How does the mapping impact your learning?
Bertha   It helps me see my learning.
Researcher: Do you like mapping?
Bertha: I like it, gotten more used to how to do it, sometimes difficult and frustrating, but once you put it together the right way, it's good.

Researcher: Do you like the C-map program?
Bertha: Yes, it's good and convenient.

Bertha understood the future visual field and accepted that the next session would become part of the past visual field. According to Jones (1995) the overlap of visual fields helped to achieve understanding.

Researcher: Predict the carbon dioxide graphs for green mulch. Explain.
Bertha: Green mulch- not as negative as red, black would be straight.

Researcher: Can you put the last class into your past? Explain.
Bertha: Yes- past that.

Researcher: Can the next session be a part of the future? Explain.
Bertha: Yes- it hasn't happened.

Researcher: Can you accept or understand that I place the next class as becoming part of your past visual field—honestly?
Bertha: Yes.

BDM Photosynthesis Future Visual Field Phase. Bertha was relaxed at this interview because she had learned most of what she had not understood, or forgotten, about photosynthesis. She had made a complete concept map of photosynthesis prior to our discussion and she appeared to be satisfied with herself due to her progress and accomplishment.

Researcher: What are the first 5 things that come to your mind when I ask you “What new things did you learn today in the research session?”
Bertha: When spinach makes bubbles it proves use photosystem II to generate energy with hydrogen ions and oxygen as a byproduct; DPIP blue without hydrogen ion and clear with hydrogen ion [in the form of DPIPH].

During this session the participants did the lab called “Ecosystem Model for Ratio of Photosynthesis and Respiration” (Appendix S). A combination of the video with the interfaced graphs, and the hands-on experiment with the plants and worms, helped Bertha to understand the physiology of the plant in the sealed jar. She was asked about a variety of situations to see if she understood the relationship of photosynthesis and cellular respiration.
Researcher: Describe what you remember about the plant video with the associated graphs and how we approached the conditions of the plant and the data.

Bertha: Video taping with plants and carbon dioxide and light.

Researcher: What were your predictions?

Bertha: Without light oxygen is down and carbon dioxide is up and there is plant respiration.

Researcher: What was the impact of making predictions about the situations in the video of the plant help you understand the concepts?

Bertha: Showed that you had to think about it with light reaction.

Most students were fascinated with the plant in the sealed jar. They were not sure about its fate. At her Baseline interview, Bertha said that it would only do photosynthesis. Had she learned that the plant did both photosynthesis and cellular respiration? The first set of questions were general.

Researcher: What concepts did we consider about the plant in the lab [Ecosystem Model for Ratio of Photosynthesis and Respiration]?

Bertha: Deforestation [deforestation]

Researcher: Describe a plant closed in a jar and its metabolic condition. Predict its fate.

Bertha: It is like a Terrarium. The plant will live and its cycles carbon dioxide and oxygen when there is light.

Researcher: Are your thoughts on the plant in the jar new or the same as you have thought in the past? Explain.

Bertha: Never thought about it.

Researcher: Are you comfortable with your present thoughts? Explain.

Bertha: Sure. It makes sense now that I think about it.

Next, the various predicted graphs for particular situations were discussed. The graphs helped her relate to the processes.

Researcher: Predict the carbon dioxide vs. time graph of plants living in a sensosphere with light.

Bertha: Carbon dioxide down. Mostly photosynthesis.

Researcher: Predict the carbon dioxide vs. time graph of plants living in a sensosphere with light and 20 mealworms. Explain.

Bertha: Carbon dioxide level. [is a flat line with 0 slope]. The mealworms will be producing carbon dioxide and the plant will use some of it.

Researcher: Now cut down ½ the plants. Predict the carbon dioxide vs. time graph of ½ the plants living in a sensosphere with light and 20 super mealworms. Explain.

Bertha: Carbon dioxide up, positive, [there is an] accumulation.
How did the lab and the predictions create a model for a real-life situation? Making the link to a real-life practical situation was critical for advancing biological literacy (Bybee, 1993) and to lay a deeper encoding trace for better long-term memory (Tulving & Thomson, 1973).

Researcher: Is this a model for a current situation? Explain.
Bertha: Yes, deforestation with a build up of carbon dioxide.
Researcher: What is the consequence of more animals and less plants?
Bertha: More carbon dioxide - global warming.
Researcher: How could this situation impact plants?
Bertha: Lots of carbon dioxide and less oxygen for them.

The DPIP indicator is blue when it is DPIP\(^+\) and it is colorless when it is DPIPH. The enzyme NADP\(^+\) reductase reduces DPIP\(^+\), so DPIP can be used to determine the function of NADP\(^+\) reductase.

Researcher: What are your thoughts about the DPIP compared to the spinach disks and the bromthymol blue?
Bertha: Visual thing differ with tricks with NADP\(^+\) reductase with DPIP. Only did DPIP test the function of NADP\(^+\) reductase in the labs or demonstrations we did.

C\(_3\), C\(_4\), and CAM plants were considered, and provided an opportunity to review the carbon fixation and the Calvin cycle in general. However, the instruction on this was limited due to the lack of time. Exposure to the variations in carbon fixation appeared to interest and benefit Bertha. She had wanted to know more about the various plants in her high school Biology AP class and in the current lecture course it was omitted. She appreciated finally getting to learn about them. Since Bertha had a strong understanding of photosynthesis, she benefited from this section. Students who did not have a firm understanding did not appear to benefit from this extended knowledge, which is why many introductory courses do not consider C\(_4\) and CAM plants.

Researcher: Compare and contrast C\(_3\) and C\(_4\) plants.
Bertha: C\(_3\) plant moderate [conditions], C\(_4\) extreme [conditions] and carbon is fixed in budle sheath.
When is the C₄ pathway critical to the plant and an advantage over the C₃ pathway?

C₄ stressful.

Compare and contrast C₄ and CAM plants.

C₄ and CAM is time [of carbon fixation].

How are C₃, C₄ and CAM plants similar? Explain.

All do the Calvin cycle and do photosynthesis.

How did studying C₃ and C₄ plants help you learn and remember about photosynthesis?

Remember steps of Calvin cycle and why those steps happen.

Is the extra detail beneficial to your learning and remembering?

Think so. Yes. Basic concept to get. [I] Liked C₃ and C₄ [plant information].

High technology and low technology applications of the theory of photosynthesis in daily life and research were discussed. These included wrapping aquariums with black plastic sheeting to block light and kill algae, using herbicides to kill weeds, using photosystem I to power laptops and using photosystem II to power cars with hydrogen. Bertha appeared to appreciate the various applications.

What are your thoughts on the contrast of V. Fields™ using plastic compared to the big science of current research?

Cool and simple.

Explain two recent advances in photosynthesis research?

Spinach to make bubbly cloud.

How does considering recent research impact your learning and remembering of photosynthesis?

Future visual field in mind [as she thinks about the research applications].

Were you surprised that there is so much current interest in photosynthesis?

No.

Are you interested in the research?

Yes.

How are herbicides useful in the study of photosynthesis?

Blocks certain cytochromes can follow the path.
Researcher  How did studying herbicides help you learn and remember photosynthesis?
Bertha   Talk of electron transport cytochrome agenda.
Researcher  How did looking at the video of the plant treated with herbicide impact your understanding of photosynthesis?
Bertha   Apply - just another way to help memorize. Video is something to look at.

During the instructional session on future visual field of photosynthesis, the explanation of the red mulch was extended with information about phytochromes for increased blooming. The integration of extended concepts and data prediction provided a different format to discuss the detail of photosynthesis. Langer (1989) indicated the importance of including a variety of stimuli to get the attention of the audience while Mayer and Massa (2003) indicated the necessity of varying presentation styles to allow for learning preferences.

Researcher  How did building on the red mulch information with the phytochromes stimulating growth of the plant above the ground impact your learning about red mulch and photosynthesis?
Bertha   Another way for red light. More light.
Researcher  Predict the carbon dioxide vs. time graph for a tomato plant that is near red mulch.
Bertha   Carbon dioxide goes down over time.
Researcher  Relate your predicted graph to the various reactions of photosynthesis.
Bertha   Red uses more carbon dioxide. Light reaction makes more ATP and NADP+. So goes in Calvin cycle.

The participant constructed a PowerPoint® presentation for the Future Visual Field of Photosynthesis that involved making a recommendation to farmers who wanted to increase their crop yield. Student authored presentations allow the instructor to diagram alternative conceptions Glynn and Muth (1994). Bertha made her presentation at the instruction session and was asked to add an important missing item. Through prodding, Bertha was encouraged to think about the need for adequate water and for the proper functioning of photosystem II. Fellows (1994) indicated that authoring forces students to interact with their prior knowledge.

Researcher  Add an important item or concept to your PowerPoint®.
Bertha   I added Water. I can not assume there will be adequate water and water is critical for the splitting of water with photosystem II.
Researcher  How do your PowerPoints® help to explain the concepts?
Bertha    Recommend to farmers for ideal conditions. Helps so you can do Calvin cycle.
Researcher  Does making animations help you to understand the concept?
Bertha    Yes - have to know old.
Researcher  How do you think making animations will help you to remember the concept?
Bertha    Put in required layers and order. More thought than previous ways. More thought to why things happen.

The researcher was interested in her perspective on the student construction of concept maps versus student constructed animated PowerPoint® presentations. She appreciated both strategies.

Researcher  Compare and contrast the thought process of making an animated PowerPoint® presentation to making a concept map?
Bertha    Put in required layers and order. More thought than previous. More why it happened. Grouping and flowing to more specific [ideas]- do not know if [making PowerPoint® and concept maps is] different. Mapping easier to use. Would go with…not sure which one I like better.
Researcher  What benefit could come from using both techniques in your study of photosynthesis?
Bertha    Different ways of learning to keep me interested.
Researcher  What is the impact of you making a recommendation to the farmers make to your learning and thinking about photosynthesis?
Bertha    It makes it interesting and makes me think again for a reason to help the farmers and this may help me to have good long-term memory.

The researcher wanted to specifically discuss her Future Visual Field of Photosynthesis related to research. The researcher wanted to explore the impact of the Visual Field Perception Map Heuristic™.

Researcher  What is your future visual field with photosynthesis? Give 5 examples.
Bertha    All technology and research, spinach, global warming, reforestation, and solutions [to the problem].
Researcher  Of what use is the visual field worksheet to you?
Bertha    Helpful in future to know what to study and which ways of learning more effective.
Researcher  How will the activities we did impact your thoughts of the future and learning and remember photosynthesis?
Bertha    Have attempted to find answers to my problems. [I] Think and look, work [with photosynthesis concepts during the sessions], and maybe I will not forget.
Researcher: What are your deficiencies in photosynthesis, what do you think you know best, and what do you think you know least?

Bertha: Know best photosystems. Least electron transport.

The researcher had her reflect on all the strategies used at the sessions. She remembered the hands on activities the most.

Researcher: List the first 5 things that come to your mind about the strategies from all the sessions.

Bertha: Kimchee, chloroplasts and mitochondria model, oxygen from solution of water, glycolysis, data collection.

Researcher: What would you add to the project?

Bertha: Experiments, models.

Researcher: What would you remove from the project?

Bertha: V. Fields™, Victory Garden, some stories.

Researcher: Comments about multiple-choice questions.

Bertha: Most easy. I did not see the choice. Wording is OK.

Delayed BDM Instructional Strategy Sessions Clinical Interview. Bertha felt that the PowerPoint® presentations and concept maps were the most important strategies in aiding her learning, and she felt it was because they went from general to specific and were organized.

Bertha has a past visual field with the Calvin and Krebs cycles and states that she knows them better due to the program.

Researcher: List the 5 things that you remember most about the sessions or interviews?

Bertha: Kimchee, graphing, Junior Mints® [chloroplast model], cytochromes and poisons, cyanide.

Researcher: List 5 things that helped you to learn photosynthesis and cellular respiration most in the project.

Bertha: PowerPoint® slide shows, mapping reinforcement.

Researcher: List the strongest things that you remember most about photosynthesis and cellular respiration.

Bertha: Glycolysis, electron transport chain.

Researcher: List the weakest things that you remember most about photosynthesis and cellular respiration.

Bertha: Calvin cycle.

The researcher was interested in recapping her interest in metacognition. She had appeared to appreciate the advancement she made through the sessions.
Researcher: What is the impact of metacognition on success?
Bertha: It helps you learn the most effective way for the individual.
Researcher: What impact does having more background or information have on memory decay?
Bertha: I remember Calvin and Krebs cycles from AP. It's easier to remember now.
Researcher: List five learning strategies that you use to learn concepts.
Bertha: General then understand details is better than learning details first.
Researcher: How do PowerPoint® presentations impact your learning?
Bertha: You can see things in order. Organization is key.
Researcher: Compare animated PowerPoint® presentations to concept maps.
Bertha: Concept maps you put things on the side, like PowerPoint®.

Concept Map Analysis. Bertha’s Baseline map score for cellular respiration was 11 and her literacy level was nominal based upon the basics of the molecular reaction. Her Post Lecture map score was an 83 and she had structural literacy. Bertha lacked cytochromes on her map. She did not have application in her visual fields. Her Past Visual Field of Cellular Respiration map score was 113 with multidimensional literacy level, in which she added fermentation. She had included application in her future visual field. It was six days since the post-lecture map and Bertha experienced some decay. Her electron transport chain became unlinked from cytochromes. Her map score on the Present Visual Field of Cellular Respiration was 134 and she had multidimensional literacy level. Her formation became more complex and her electron transport was reconnected with the main map; Bertha added cytochromes, the production of water with oxygen through the cytochromes, and carbon dioxide as a product of the Krebs cycle. Her map score for Future Visual Field of Cellular Respiration was 152 and had multidimensional literacy. She mistakenly linked the mitochondria to all of cellular respiration. Bertha added the reduction of NAD⁺ to NADH in the production of Acetyl CoA, the amount of ATP in glycolysis, and added that Krebs cycle produces NADH which is an intermediate electron acceptor. Her map score for the Delayed Visual Field of Cellular Respiration was 105 with multidimensional literacy level, which can be compared to the Post Lecture map scores. Fermentation was still
unconnected in this map. Bertha’s strategy was to try to remember and map the basic concepts sequentially, “and then it all began to come back,” said Bertha.

Bertha’s Baseline Photosynthesis map score was 6 and her literacy level was nominal. Bertha knew very little and her Baseline map even lacked the sun. Her Post Lecture map score was a 46 and she had functional literacy level. She mistakenly connected NADPH to the electron transport and carbon fixation occurring in the thylakoid. Her Past Visual Field of Photosynthesis map score 143 and she had multidimensional literacy. Bertha did not link glucose in the Calvin cycle, and she mistakenly did not include out the production of H⁺ ions and oxygen from photosystem II. She had included application in her future visual field. For the Present Visual Field of Photosynthesis Bertha scored 178 and had multidimensional literacy. The main addition in her map was the creation of oxygen from photosystem II which is linked to electron transport. Bertha showed a marked improvement from her last map. Her score for the Future Visual Field of Photosynthesis was 200 and had multidimensional literacy. She added C₃ and C₄ pathways requiring the active transport of hydrogen ions.

On the Delayed Visual Field of Photosynthesis map her score was 91 and she had multidimensional literacy. She showed good memorization and kept the complex relationships with cross links. Bertha’s Post Strategy Interrelationship of Photosynthesis and Cellular Respiration map was 190, and her Delayed Interrelationship of Photosynthesis and Cellular Respiration Map was 207. She did not link water from cellular respiration to the light reaction, but retained everything else in Post Strategy Interrelationship of Photosynthesis and Cellular Respiration. In the Delayed Interrelationship of Photosynthesis and Cellular Respiration map she lacked the carbon dioxide being produced in the Krebs cycle and being used in Calvin cycle, and relating the glucose from the Calvin cycle to glycolysis. Selected AP questions were
correlated to concept map links that corresponded to the questions. Bertha’s average concept map score was 92% and her average AP question score was 83%. Concept map scores were higher due to student’s ability to visualize more on a map.

At a debriefing interview the researcher attempted to get Bertha to make some conclusions. She indicated her desire to continue with the study.

| Researcher | What is impact of metacognition on success? |
| Bertha     | It helps you learn the most effective way for the individual. |
| Researcher | If the project continues, would you consider being in it? |
| Bertha     | Yes. |
| Researcher | What do you think the next step could be? |
| Bertha     | Use genetics, younger students, gender. Maybe testing short-term memory. |
| Researcher | How could the project be modified for more student success? |
| Bertha     | Liked examples and models. |
| Researcher | What impact does having more background or information have on memory decay? |
| Bertha     | Remembers Calvin and Krebs cycle from AP. It's easier to remember now. |

**Case Study 4-Brandon**

**Participant Description.** Brandon is an Asian American from Hawaii. He is a biology major and plans on going to medical school. He attended a private, college preparatory high school and had a 3.6 grade point average. He was a National Merit Finalist with a 31 on the ACT and a 1510 on the SAT. Brandon took several AP classes in high school including Physics AP, European History, Calculus BC, and English. His strongest subjects are history and English while his weakest are biology and chemistry. Brandon is an expert in and user of pidgin English, as can be seen in transcripts of his conversation.

In his freshman year in high school Brandon changed schools in the middle of the school year. As a result he studied genetics at both schools but was not taught photosynthesis and cellular respiration. He feels prepared for college and knows the scientific method.
Brandon took both biology and chemistry this past semester. He uses the computer 2 to 3 times a day and is used to learning with computers. He said it would be difficult for him to learn without computers. He has used sensors in physics class only. He used photoelectric gates with Logger Pro® and Graphical Analysis®. He has not used sensors in chemistry or biology.

Brandon is interested in video games. He likes the challenge they offer in the virtual arena. He likes to play games with friends in which they propose a situation and pretend what they would do to solve the problem. He was interested in learning how to learn science. Brandon wanted to understand the learning process both for college and when he is a doctor in 8 or 9 years. His concern for the future is in the application of his knowledge.

Brandon is interested in doing well in his classes by thinking first and then responding. He is interested in solving problems and realizes that learning more will give him more ability to do so. He enjoys doing research and understands the benefit of increased learning.

**Baseline Phase, Prior Knowledge.** Brandon was interested in the object sorting activity and made many comments about the objects. Overall, he did not understand whether the selected objects were doing cellular respiration or photosynthesis and responded most often that he did not know. Of the three that he identified, he correctly responded that pill bugs do respiration and incorrectly identified the head of cabbage and the plant in a tightly closed jar as doing photosynthesis only. He failed to recognize that plants do cellular respiration.

In the term sorting activity, Brandon scored 50% correct on the photosynthesis only words and 33% correct on the cellular respiration only words. In the words associated with both photosynthesis and cellular respiration he identified 24% correctly. His overall score was 34% correct. He seemed to have the most difficulty with terms related to both. Of these terms he recognized only terms associated with the molecular equation for photosynthesis and cellular respiration: “oxygen,” “carbon dioxide,” “water,” and “electrons.”
Brandon’s cellular respiration concept map indicated 4 links with words like “organisms,” “oxygen,” “biological energy,” and “mitochondria.” He scored a total of 8 points on this map. In the photosynthesis map he used the terms “plants,” “sun,” “energy,” “photons,” and “chlorophyll.” His photosynthesis map was more interrelated and had 7 links and 1 branch for a score of 15 points.

Brandon’s visual field was more developed when it came to imagery than when it came to personal situations. In his past visual field he visualized running and using oxygen and trees in bright sunlight. In the present visual field he saw himself having air to breathe outdoors on campus with green grass and green trees. His future visual field brought up images of people running, seeds growing, and focusing on green plants. He “has not really thought of this before.”

Based on his concept maps, visual fields, object sorting, and term sorting activities, Brandon’s overall literacy was determined to be nominal for cellular respiration and photosynthesis. His concept maps are in Appendix P and their scoring is in Appendix Q.

Post Lecture Phase. In Brandon’s term sorting activity, he had 71% correct for cellular respiration only words and scored 83% correct for photosynthesis only words. For words that are both cellular respiration and photosynthesis, he scored 36% correct. He had the most difficulty again with words that were related to both. His overall score was 61% correct.

Brandon’s cellular respiration concept map had 9 links, 2 branches, and 4 islands for a total of 16 points. His photosynthesis map had 9 links and 2 branches for a total of 24 points.

Brandon identified his past visual field as trees and light, heterotrophs, and a runner. All were images of photosynthesis and cellular respiration. His present visual field was more of the details of the research. His future visual field was trying to figure out a way to make plants produce more energy by making them more efficient. His insight was “If you know in the future and what you want, you learn how to use the future to get what you want.” Based upon his term
sorting, concept maps, and visual fields, Brandon’s overall literacy level was determined to be nominal for cellular respiration and functional for photosynthesis, which was an improvement over his baseline literacy of nominal for photosynthesis but remained nominal in cellular respiration.

**BDM Cellular Respiration Past Visual Field Phase.** Due to Brandon’s cultural heritage he had prior knowledge about Kimchee, but he was not aware of the details and he was interested. His interest in video games and games in general attracted him to the characters in the scenario. He seemed to absorb the information “like a sponge” and he appeared to be very attentive in the instructional session.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>What are your thoughts about the Kimchee scenario?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandon</td>
<td>Kimchee scenario related to real-life and not just technology.</td>
</tr>
<tr>
<td>Researcher</td>
<td>What is the purpose of the Kimchee scenario?</td>
</tr>
<tr>
<td>Brandon</td>
<td>Chemical reactions and things you cannot see related to things you eat; more real.</td>
</tr>
<tr>
<td>Researcher</td>
<td>Was it interesting?</td>
</tr>
<tr>
<td>Brandon</td>
<td>More interesting.</td>
</tr>
<tr>
<td>Researcher</td>
<td>How did you like the use of characters in the scenario?</td>
</tr>
<tr>
<td>Brandon</td>
<td>Characters are cool.</td>
</tr>
<tr>
<td>Researcher</td>
<td>How does the Kimchee scenario involve cellular respiration?</td>
</tr>
<tr>
<td>Brandon</td>
<td>It is an example of anaerobic respiration. If you do it wrong oxygen gets in and it’s aerobic.</td>
</tr>
<tr>
<td>Researcher</td>
<td>Did you gain familiar knowledge about anaerobic cellular respiration?</td>
</tr>
<tr>
<td>Brandon</td>
<td>Yes.</td>
</tr>
</tbody>
</table>

Brandon also quickly picked up on the use of scenarios and characters to introduce cellular respiration concepts. It seemed that some of the other participants had to get used to the use of characters, and then things went smoothly for the entire group. Since Brandon was accustomed to the use of characters to explain things, he learned more about soil microbes during its introduction in this session. He knew about Kimchee, but did not like Korean food except for Korean BBQ. He was also quick to see the similarities and differences between the Kimchee and soil scenarios.
Brandon had not previously studied photosynthesis and cellular respiration, and his official Energy University biology course this year, which was his freshman year, was his first exposure. He also realized that if knowledge is wrong from the past it is wrong every time you use it. He indicated that as you learn more you get a new starting point. He thought that the instructor could help to give a common past visual field when everyone sees the same reaction. He recognized that past knowledge was built upon and that V. Fields™ was useful to introduce the scenarios and the videos were helpful to explain Kimchee. He thought the videos needed to be just the right length and the right speed to be effective. He did not like traditional PowerPoint® presentations that were “stuffed in text.” He liked the BDM PowerPoint® presentations, and he cited specific reasons.

Brandon probably appreciated the animations, as Sanger and Greenbowe (2000) discovered that animations are most effective in helping students visualize a process. Brandon
thought the BDM strategies would be helpful to his long-term memory. He also believed that the past is “up to the current.” The researcher assumed that all participants would have that perception but many did not, and the researcher therefore checked the perception of each participant.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>How are animated PowerPoints® different than the book presentations?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandon</td>
<td>Effect on long term-memory. Help you remember anaerobic and aerobic.</td>
</tr>
<tr>
<td>Researcher</td>
<td>Did what we did last night contribute to your long-term memory?</td>
</tr>
<tr>
<td>Brandon</td>
<td>It will help in the future. If it becomes a given then anaerobic respiration easier to use in experiments</td>
</tr>
<tr>
<td>Researcher</td>
<td>When did the past visual field ends and the present begin?</td>
</tr>
<tr>
<td>Brandon</td>
<td>Past is up to current. Present is right now.</td>
</tr>
</tbody>
</table>

**BDM Cellular Respiration Present Visual Field Phase.** The first things that came to Brandon’s mind about the last session were compaction of soil, fireflies, and fire light due to ATP and hydrogen ions. He liked the yeast solution in the tube because it “shows how carbon dioxide forces fluid out.” He thought the yeast in the tubes showed more than the bread. He thought writing the equations on the board in relationship to the inverted tube of yeast solution was important and he was able to relate to the demonstrations well.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>How did looking at the chemical reactions on the board with the demonstration material in your presence help you think and learn about cellular respiration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandon</td>
<td>Chemical reactions are good to see in front. If you remember it was like keeping a copy.</td>
</tr>
<tr>
<td>Researcher</td>
<td>How do these demonstrations of yeast in the tube and bread dough involve cellular respiration?</td>
</tr>
<tr>
<td>Brandon</td>
<td>Yeast in the tube is anaerobic - carbon dioxide bread rises and gives off carbon dioxide.</td>
</tr>
</tbody>
</table>

Aerobic microbes in the soil and the need for tilling the soil was explained in the first session and the experiment with uncompressed and compressed soil was done in the present visual field. At the interview the researcher gave Brandon a bottle of disinfectant to spray the soil sample, and to then draw the predicted curved for the rate of respiration of the sprayed soil.
sample. He predicted a flat line because the microbes would die. He also related compressing the soil with a bottle to remove the oxygen to prevent aerobic respiration of the soil microbes. He made the following comment about how the data collecting soil labs helped him to understand cellular respiration.

Researcher: How did soil lab help you to understand about cellular respiration?  
Brandon: See respiration and prove that carbon dioxide is a product.  
Researcher: How did the data collection impact your understanding?  
Brandon: Visual confirmation.  
Researcher: Did viewing the data better help you to understand cellular respiration?  
Brandon: Yes.  
Researcher: What were you thinking as you saw each data point appear on the screen?  
Brandon: At first it was weird. Make a prediction and then see the next point fits the prediction.  
Researcher: How does viewing the graphing of the data point by point help you to understand?  
Brandon: Helps you see the progression.  
Researcher: What is the benefit of seeing the data collected on the screen in real time?  
Brandon: Confirms your prediction.  

The researcher was then interested in how he perceived the various activities over the two BDM instructional sessions. He was very sensitive to the differences in the activities and he has reason supporting his differences.

Researcher: How was its overall presentation of the soil lab different than the bread and yogurt?  
Brandon: Soil lab you saw how you interact and how it changes. The bread lab was typical – static.  
Researcher: How do the different types of presentations (lecture, demonstrations and labs) impact your thinking?  
Brandon: Lecture tells you with words. Demonstrations give you examples to learn. Labs let you do it yourself and see it yourself.  
Researcher: Have you had previous experience with data collection?  
Brandon: Vernier data collection with physics.  

The presentation of cytochromes, protein electron carriers in the electron transport chain, was considered in the discussion. Brandon did not remember having studied cytochromes before the last BDM instructional session. The study of the cytochromes was an example of zooming in
on a specific section of the electron transport chain. We discussed the effects of zooming in on knowledge.

Researcher: Is going from the general concept and zooming in on a specific process helpful? How?

Brandon: An example of one is if you saw today’s lecture on a screen, you would only see a small part but it makes it real. Seeing only part makes things more real and you do not lose the facts.

Researcher: How did your past knowledge influence your understanding of the soil lab?

Brandon: Helped to make predictions.

Since Brandon had much experience with video games, he was very observant and critical of animations. He liked the animated and layered PowerPoint® presentation and the ability to replay them. Craik and Lockhart (1972) showed that elaboration and rehearsal allowed access to long-term memory. The researcher attempted to utilize his animation expertise to analyze the impact of animation on learning.

Researcher: Do the animations help to explain the concept?

Brandon: Yes.

Researcher: How did the PowerPoints® help to explain the concepts?

Brandon: See the hydrogen ion move outside and inside. Makes you see reality.

Researcher: How are the animated PowerPoints® different than the book presentations?

Brandon: Animated PowerPoints® move. See the hydrogen ion go.

Researcher: Do you prefer the book, traditional PowerPoints® or layered PowerPoints® and why?

Brandon: Prefer layered because you see it happen and can replay it.

The researcher also attempted to learn more about his perception of the visual fields. He placed the past as ending now, and many of the other participants had the past ending with high school. The researcher wanted to determine the variation in the participants’ perceptions. When the researcher discussed the overall impact of the BDM session’s activities, he quickly integrated the visual field activities into his comment.

Researcher: When does the past end and the present begin in your thoughts of photosynthesis and cellular respiration?

Brandon: Now.
Researcher: Draw the fields and indicate dominance of the field to you by the size of the field.
Brandon: Big past visual field.
Researcher: How will the activities we did impact your learning?
Brandon: Use the past to make insight.
Researcher: How will the activities we did impact your long-term memory?
Brandon: Make it more a broad spectrum. Remember the original slide and apply it.

BDM Cellular Respiration Future Visual Field Phase. The session items that came to Brandon’s mind first were that jumping beans have larvae in them making them jump, how to animate PowerPoint® presentations, and applications of computer technology to collect and express data. He was very interested in the jumping bean lab and understood the underlying concepts. He related that the jumping showed the effect of respiration.

Researcher: What are your thoughts about the jumping beans compared to the mealworms?
Brandon: Mealworms had more space to move, larva [of jumping beans] were confined inside the bean, gases made them move, jumped showed effect of respiration.

He understood the relationship of jumping and respiration and thought a constant temperature would be necessary for accurate lab results. He also related the use of the metal tin to help “hear” the beans move around. He was able to relate the concentrations of oxygen and carbon dioxide to the jumping of the beans for a multifaceted analysis of cellular respiration in relationship to getting work done.

Researcher: How did changing the temperature help you to understand the importance of constant temperature?
Brandon: Cool, beans stopped moving, warmer made them move more, constant temperature would yield more accurate results.
Researcher: Did making a prediction about the jumping beans and their movement help you understand something about cellular respiration?
Brandon: Cooler place, cooler place slowed down, processes slow down, last longer but respire [respire] less.
Researcher: Were the jumping beans interesting?
Brandon: Yes, bounced a lot, made a lot of noise.
Researcher: What is the purpose of using the metal tin with the jumping beans instead of the mealworms?
Brandon: Amplifies the noise, mealworms make no noise.
Researcher: How did studying jumping beans help you to understand about cellular respiration?
Brandon: Slows down jumping beans when carbon dioxide builds up, and amount of oxygen decreases.

The concept of cytochromes was extended in the instructional session and Brandon remembered that he first learned of cytochromes at the BDM instructional session. He was able to say that he had learned about cytochromes in his past since it was in previous BDM classes. Many participants placed these sessions and experiences into their present and the researcher was interested in his perception. The concept of cytochromes was extended by the addition of information about poisons blocking electron transport, and James Bond video clips on the use of cyanide laced darts was included in the explanation. According to Tulving (1985) the episodic nature would help memory. The short and simple nature of the film allowed for a more appropriate arousal level.

Researcher: How did the study of poisons impact your understanding of cytochromes?
Brandon: Way it was taught made the lesson more relevant, adding more helps reinforce old stuff, makes you feel like your progressing.
Researcher: How did looking at the use of cyanide in James Bond movies impact your understanding of cytochromes?
Brandon: Shows how Hollywood uses science, and relates to cytochromes.
Researcher: Did you like the poison information and do you have any examples to add?
Brandon: Yes helps relate, now know how cyanide kills you.

Since Brandon had much experience with video games, the researcher thought he would have a deep perspective on his own construction of animated PowerPoint® presentations. The researcher directed him to contrast the process of constructing an animated PowerPoint® presentation versus a traditional, unanimated presentation. He concluded that you have to understand the process to make the animation. The animated PowerPoint® presentation that he created is included in Appendix U.
Researcher: What is your previous experience with PowerPoint\textsuperscript® authoring?

Brandon: Basic slides, some transitions.

Researcher: How does your PowerPoint\textsuperscript® presentations help to explain the concepts?

Brandon: Animations help see process, like glycolysis. [The researcher included a few animated PowerPoint\textsuperscript® slides in her presentation, and he refers to this.]

Researcher: Does making animations help you to understand the concept?

Brandon: Yes, it helps comprehension of process.

Researcher: How do you think making animations will help you to remember the concept?

Brandon: Helps you remember process by having to put together, just seeing it again helps you remember too.

Researcher: How is making animated PowerPoints\textsuperscript® different in thought process than making traditional PowerPoint\textsuperscript® slides?

Brandon: You have to know the order, traditional nothing moves while animate ones require more thought, you won't just remember a list.

Researcher: Do you prefer making traditional PowerPoints\textsuperscript® or layered and animated PowerPoints\textsuperscript® and why?

Brandon: Layered PowerPoint\textsuperscript® require more thought, have to understand process.

Brandon had to make a recommendation to the Korean restaurant owner about how to make Kimchee faster and he also had to make a recommendation to Oz, the jumping bean seller, if he should sell the old crop (2003 crop) of jumping beans. He was very interested in including his opinion based on the data he collected.

Researcher: What is the impact of you making a recommendation to the restaurant owner make to your learning and thinking about cellular respiration?

Brandon: Makes it more practical, not just learning but also applying.

Researcher: Were you interested in the new problem of Oz, the jumping bean agent, selling last year’s jumping beans?

Brandon: Makes you wonder what he did with the jumping beans in the meantime. I think he should sell them with a warning and explanation at a reduced price.

Researcher: When does the present end and the future begin in your thoughts of photosynthesis and cellular respiration?

Brandon: Present begins when it happens; future is something that might happen.

Researcher: What is your future visual field with cellular respiration? Give 5 examples.

Brandon: Probably will learn new thing about cellular respiration throughout my academic career, will use them in biology fields later in life, learn to produce ATP synthetically for more seed.
Brandon was very interested in application of the session activities, and his rich background knowledge helped him make associations very quickly, and he seemed to list the most participatory activities as most memorable. He liked the combination of intense visuals in association with hands-on activities.

Researcher: How will the activities we did impact your thoughts of the future?
Brandon: Jumping beans cool slowing down individual processes, cryogenic freezing.

Researcher: What are your deficiencies in cellular respiration, what do you think you know best and what do you think you know least?

BDM Photosynthesis Past Visual Field Phase. Brandon thought the things he would remember the most about the Past Visual Field of Photosynthesis BDM session were: the Junior Mint® chloroplast home study kit, the Elodea air bubble in the inverted tube, biodome, and the moss balls with the data collection. From his childhood he remembered people talking about plants making oxygen and that if you planted a tree you could “save the world.” Brandon was tuned into his surroundings and his activities. He had tendencies to analyze his actions and thoughts and was interested in his own learning and noticed that he was becoming more metacognitive as a result of the BDM sessions and was learning more strategies.

Researcher: How are you becoming more metacognitive? Compare yourself now to before the study began?
Brandon: Aware of the concept, this is a more practical application, more intense.

Researcher: What are some metacognitive strategies that you have learned during this education research project thus far?
Brandon: Coming at it from more than one direction, visual learning, labs different, labs more physical to think about later, use real life examples.

Brandon had not previously studied guard cells or chromatography and found the tangerine model of the guard cells and the chromatography interesting. He took a tangerine to his roommate at the end of the session to tell him about the model. He thought the moss ball
photosynthesis experiments were very effective with the shrimp boat scenario because the moss balls were, as he termed them, “solid balls of photosynthesis;” he smiled as he explained his like of the moss balls. He was fascinated by them and had never seen them before. He was very impressed with the effect of data collection and prediction on his learning. The placement of yourself into a situation allowing better construction and thus better encoding is Propositional Theory (Jahnke & Nowaczyk, 1998).

Researcher: How did the data collection impact your understanding?
Brandon: Seeing made me recall -- data is more real.
Researcher: What is the benefit of seeing the data collected on the screen in real time?
Brandon: Measurable and quantifiable thing.
Researcher: Did viewing the data better help you to understand photosynthesis?
Brandon: Not just saying something happens but actually seeing it happen.
Researcher: Predict the graphs for carbon dioxide produced by moss balls at night and explain.
Brandon: Would be taking in carbon dioxide and graph would go down. Plants put out carbon dioxide through cell respiration.

Brandon had no previous experience with neither Elodea nor moss balls and thought the demonstration of the researcher blowing her carbon dioxide into bromthymol blue with the Elodea had an added value of showing how Elodea is directly related to humans. It is not easy to blow human carbon dioxide into a sensosphere and achieve successful quantitative data collection, but it is easy to do so with bromthymol blue; Brandon noticed the connection.

Researcher: How was the moss ball presentation different than the Elodea with bromthymol blue?
Brandon: Elodea related plants to humans directly [and] plants make oxygen for us.
Researcher: What was the purpose of the Elodea demonstration?
Brandon: Elodea related plants to humans directly. Plants make oxygen for us.

Videos were used to help students develop a past visual field about photosynthesis. Brandon preferred The Grapes of Wrath video to the Victory Garden video and thought the videos helped to show the importance of photosynthesis. He thought the PowerPoint® presentations reinforced what he read and was learning. He personally had interest in
photosynthesis about gene alteration to make nonphotosynthetic organisms photosynthetic. He thought that V. Fields™, the visual fields agent, resembled a cartoon character he had seen.

Brandon also made comments about the dynamic nature of the visual fields. According to Jones (1995) meaningful seeing occurs when the visual fields are dynamic.

Researcher: Is it possible to establish a common past visual field?
Brandon: For a certain time period, but it changes quickly, and people have different perceptions (thinking about class).

BDM Photosynthesis Present Visual Field Phase. Brandon described the things that he remembered and he had a combination of the red mulch experiment and the concepts he learned in the animated PowerPoint® slides. He had both broad and specific items in his list.

Researcher: What 5 things come to your mind when I ask you what you remember about the research session tonight?
Brandon: Diagram of photosystem I and II and PowerPoint®, [sensor experiment with] plant in to red box that reflect light, and [the plant in the] black box with no light reflected don't grow as much, whole thing [experiment] was [about] the accepters, [PowerPoint® slides that showed] hydrogen ion go through ATP synthase, equation is switched around and oxygen comes in to the first part, and carbon is in the back.

Brandon had interest in metacognition and he continued to develop his thoughts and strategies. He began to express his thoughts with detail, and he saw the reward of learning efficiency.

Researcher: “Metacognition refers to the knowledge, awareness and control of one’s own learning.” Have you discovered more strategies or understand more about strategies you have previously described? Explain.
Brandon: Pictures really help, see photosynthesis diagrams, awareness of knowledge helps, what you know before, and change your perception, helps you realize it was wrong and need to get it right.

Researcher: Why is it important and useful for you to be aware of strategies that are effective for you?
Brandon: If you know the strategies that work for you, you can learn more in the same amount of time and have a longer lasting effect.

Brandon thought that the review of bromthymol blue helped him track the carbon dioxide, and the inverted tube of sodium bicarbonate and Elodea was helpful for him to track the
Brandon understood that the spinach disk experiment tracked oxygen production and that the oxygen production was related to the use of light in the light reaction. He made the connection of the light reaction of photosynthesis and oxygen production and he remembered it. He also understood that bromthymol blue tracked the carbon dioxide instead of oxygen.

Researcher Describe the methods, purpose and results of the spinach disk experiment.
Brandon Spinach disk- if it's in the light it floated, black bag it didn't. If it had chlorophyll, water and light it would float, if it floated it had oxygen and it was in light, no light no oxygen so it didn't float.

Researcher How was the spinach experiment similar and different than the bromthymol blue experiment and the bubble experiment?
Brandon Spinach [was] more about the effect of light on it, bromthymol-blue about carbon dioxide faster in light, oxygen in bubble, spinach about light reaction.

Researcher Did you the comparison of bromthymol blue to the computer graph impact your learning of photosynthesis?
Brandon [When bromthymol blue goes from] Yellow to blue, yellow mean there's lots of carbon dioxide, blue is turning to oxygen and carbon dioxide is
going down, it explains the slope of the graph, still think about it in physics terms.

Researcher  How is oxygen produced in photosynthesis?
Brandon  Light on photosystem II breaks apart the water, it's in the first part, [and] oxygen comes out. Water breaks apart.

Brandon remembered and understood the various methods of tracking the progress of photosynthesis and realized that the production of starch was the most indicative since it was at the end and then you are sure the process is complete.

Researcher  How does iodine help to study photosynthesis?
Brandon  Shows you if it has glucose/starch, shows glucose is there and is product of Calvin cycle.

Researcher  What are three ways to track the progress of photosynthesis? Explain.
Brandon  Iodine, carbon dioxide, oxygen.

Researcher  Which is the most indicative the entire process occurred? Explain.
Brandon  Iodine, easier, glucose is at the end.

Brandon thought connecting the Junior Mint® Model of the chloroplast with the process of the light reaction of photosynthesis was helpful. He also saw the connection between tracing the iron filings and the Calvin cycle. He had played the iron filing game of making a face with iron filings on a man before. While in the lab the participants traced the route of carbon dioxide with the iron filings, which encourages more general critical thinking skills (Windschitl & Andre, 1998).

Researcher  How did the Junior Mint® Model from Monday night help prepare you for last night’s class?
Brandon  Junior Mint® Model helped about the lumen, made the lumen and thylakoid connected.

Researcher  Did you like the Junior Mint® Model? Why?
Brandon  Liked it, connected lumen and thylakoid but got confused on stroma.

Researcher  Describe the filings experiment and compare it to Calvin’s studies.
Brandon  Filing represent carbon and goes through guard cell to stroma and then through Calvin cycle, takes part of Calvin's cycle, used isotopes.

Researcher  Did you like the filing activity? Explain.
Brandon  Remind him of face and beard game.

The red mulch experiment was to help the participants relate the wavelength of light absorption to the rate of photosynthesis, and Brandon was successful at doing this. He was also
able to make the specific connection of photosystems absorbing the light to plant growing. He realized that if the plant was absorbing light the level of carbon dioxide would decrease.

Researcher Describe the red mulch experiment?
Brandon Red mulch reflects red light so plant can perform photosynthesis, contrast with black, doesn't reflect any light and can't go to plant and stops photosynthesis because red light is being reflected off the mulch and adsorbed by plant.

Researcher How is it like the Engelmann Experiment?
Brandon If green reflected then plants don't like green light nothing occurred, mulch absorbs, black also bad, red and blue are best (red green and blue in TV).

Researcher Relate the Mulch Experiment to photosystems.
Brandon Photosystem require light to occur, mulch plant in red mulch it still has red light it can still grow. In black there's no light reflected so no light for the plant to grow.

Researcher How did the prediction of the curves impact your learning?
Brandon Have to think about what's going to happen, would carbon dioxide go down or not, have to think about practical applications of the info.

Brandon liked the researcher’s animated PowerPoint® slides, the data collection and prediction very much, and he learned and remembered the details he was presented in them. He also saw the value of building knowledge.

Researcher What was the impact of the PowerPoint® slides to your learning last night?
Brandon PowerPoint® outline[s] the info, one slide I really liked about photosystems. Pictures are more helpful than words. Remember the picture than can fill in words; just words have to fill in picture; board for equation. Carbon dioxide plus hydrogen yields glucose; help showing that oxygen has to come before.

Researcher Predict the graphs for a plant near green mulch.
Brandon No photosynthesis -would reflect light away, line would go down, but not as much if there was red light.

Researcher Do you see the present building on the past in the sessions?
Brandon Yes, have to reference stuff from previous sessions bromthymol-blue and carbon dioxide and if it goes up or down.

The concept mapping was related to his analysis of the visual fields. The things he mapped were in the present and those things he could not map would be in his future. He would try to learn so he could map those items.
Researcher: How does the mapping impact your thoughts and behavior?
Brandon: Behavior- forces you to reevaluate what you know, realize what you know might be wrong and put in the right category, know what you don't know, pay more attention as a result of knowing what you don't know.

Researcher: How has mapping impacted your thought about visual fields and each field?
Brandon: Behavior- forces you to reevaluate what you know, realize what you know might be wrong and put in the right category, know what you don't know, pay more attention as a result of knowing what you don't know.

Researcher: Has mapping helped you to make connections to the visual fields?
Brandon: Present dividing line- evaluation point, what you know so far, and what you still need to learn. at the end you form your own perception, that’s you insight. The more you know the more this vision part grows, what sets apart your vision is that you know some stuff but you still have more to learn.

Researcher: Do you like mapping?
Brandon: I like mapping, it shows what you did wrong and right, and distinguish what you know and what you don't.

Researcher: Do you like the C-map program?
Brandon: Pretty good, like moving pieces -solving puzzle.

Brandon understood that the researcher was concerned about how his perception of the visual field compared to the researcher’s perception and so he was patient with the researcher asking about them once again. The researcher had to assume that the past visual field would increase with the previous session and that the next session was the future.

Researcher: Can you put the last class into your past? Explain.
Brandon: Yes.

Researcher: Can the next session be a part of the future? Explain.
Brandon: Yes, didn't happen yet.

Researcher: Can you accept or understand that I place the next class as becoming part of your past visual field—honestly?
Brandon: Yes.

**BDM Photosynthesis Future Visual Field Phase.** The first things that came to Brandon’s mind were concepts that he was in quest of understanding. As he constructed his previous concept map in the previous interview, he kept track of those concepts that he was not able to map, and he was attentive to these items in the session.
Researcher: What are the first 5 things that come to your mind when I ask you “What new things did you learn today in the research session?”

Brandon: RuBP reacting with rubisco, carbon fixation, weed killers blocking cytochromes [sic], green chromosome, photosystem II and making concept maps, making power sources and organism stuff.

He thought the plant video that was in synchrony with the graphs of fluctuations of light, carbon dioxide, and oxygen graphs was “cool.” He related his experience with the sensor to what he has seen in hospitals that use sensors to track a patient’s stability.

Researcher: Describe what you remember about the plant video with the associated graphs and how we approached the conditions of the plant and the data.

Brandon: Plant video was cool. See video visuals with data brokered. Hospital with patient seeing EKG. It is logical and usual and the same as concept maps and animated PowerPoint®. Breathe. See only. Heard required different ways eyes and that data uses both sides of the brain. Light up and carbon dioxide down and oxygen up; light down and carbon dioxide up and oxygen down.

This video served as an introduction to the digital data collection and analysis lab called “Ecosystem Model for the Ratio of Photosynthesis and Cellular Respiration” (Appendix S). The researcher attempted to determine Brandon’s understanding of the lab by discussing various predictions to specific situations.

Researcher: What were your predictions?

Brandon: See what reacts made you make real applications including light, carbon dioxide and oxygen.

Researcher: What was the impact of making predictions about the situations in the video of the plant help you understand the concepts?

Brandon: Plants last indefinitely. Uses its own reactants to make products. You could think the plant in a jar would die because humans have to rationalize in human terms [and humans would die in a sealed jar]. We are human and we very often think in human terms. Sometimes we even relate the limbs of trees as arms. At night I sometimes have thought that tree limbs look like the arms and [the trees] are scary people. A few movies make trees people.

Researcher: What concepts did we consider about the plant?

Brandon: Concentration of light, carbon dioxide and oxygen.
Brandon had previously been confused that the plant in a closed jar would die, and the BDM Present Visual Field of Photosynthesis instructional session helped him to understand the plant in the jar. Now that the light bulb went on in his head he had thought of colonizing a biodome with just plants. He keeps thinking about his “cool thought” of the plants in a biodome.

Researcher Describe a plant closed in a jar and its metabolic condition? Predict its fate.
Brandon OK it will live. The thought is cool.
Researcher Are your thoughts on the plant in the jar new or the same as you have thought in the past? Explain.
Brandon No, now I understand. I finally understand that a plant can sustain itself.
Researcher Are you comfortable with your present thoughts? Explain.
Brandon Yes, OK. Thought it was cool [to have plant in a sealed jar]. Humans and plants send out air and water. The plant can sustain itself. You know about the biodome?
Researcher Yes.
Brandon We could colonize it with just plants. Send in the plants first and wait.
Researcher That is interesting to relate this at this time. The biodome is a very large sealed jar.

The researcher wanted to ensure understanding and so there was further discussion. He was requested to make predictions to specific situations.

Researcher Predict the carbon dioxide vs. time graph of plants living in a sensosphere with light. Explain.
Brandon Carbon dioxide down.
Researcher Predict the carbon dioxide vs. time graph of plants living in a sensosphere with light and 20 mealworms. Explain.
Brandon Carbon dioxide down less steep.
Researcher Now cut down ½ the plants. Predict the carbon dioxide vs. time graph of ½ the plants living in a sensosphere with light and 20 super mealworms. Explain.
Brandon Carbon dioxide less steep almost level.

The researcher then had Brandon think how these predictions simulated a current situation. He related the herbivore mealworms to the people cutting down trees since they ate vegetation. He did not relate the increase in carbon dioxide and decrease of oxygen to the
reduction of vegetation. There would be more problems than just a lack of plants. He made his predictions based on visualizations.

Researcher  Is this a model for a current situation?
Brandon  Mealworms are herbivores. If the shoe fits wear it.
Researcher  What is the consequence of more animals and less plants?
Brandon  Planet is screwed. Animals make the Earth final. Like Adam and Eve ate the apple and propagated the beginning. Animals last forever; man finite.
Researcher  How could this situation impact plants?
Brandon  Plants consumed by animals. Visualize more animals and fewer plants. Run out of plants.

He was able to relate the various reactions of photosynthesis to the various detection methods and it seems to help him review the reactions with a different emphasis from just looking at the book and it kept his interest. Langer (1989) would think the variety of analyzes would help attention and memory. Craik and Tulving (1975) would consider the variety of analyses as laying a deeper trace for greater recall.

Researcher  What are your thoughts about the DPIP compared to the spinach disks and the bromthymol blue?
Brandon  DPIP – NADP⁺, spinach - oxygen, bromothymol – carbon dioxide. Having 3 examples made me think plant. Cytochrome herbicide -- block off different parts of cytochrome.

Brandon appreciated the studying the various types of plants. He quickly related the variation in the plants to a difference in harvest. He was also able to relate the theory to the application of harvest.

Researcher  Compare and contrast C₃ and C₄ plants.
Brandon  C₃ -- grow in normal conditions. No carbon dioxide use oxygen; oxygen - - to mesophyll break. C₄ - Have that bundle sheath that is separate. Carbon fixation from mesophyll and prevents oxygen fixation. C₃ is grass and C₄ is corn.
Researcher  When is the C₄ pathway critical to the plant and an advantage over the C₃ pathway?
Brandon  During harvest.
Researcher  How are C₃, C₄, and CAM plants similar? Explain.
Brandon  All are plants, photosynthesis, light reaction, Calvin cycle, C₄ and CAM extra.
Researcher: How did studying C\textsubscript{3} and C\textsubscript{4} plants help you learn and remember about photosynthesis?

Brandon: Showed importance of carbon dioxide and fixation. They are different plants with different carbons.

Researcher: Is the extra detail beneficial to your learning and remembering?

Brandon: Yes. If you have been taught differently, you do not learn the same.

Brandon appreciated applications of every kind and he found value in thinking about the applications, which helped him perform meaningful seeing (Jones, 1995). He was most excited about the recent advance in using photosystems for laptop batteries and powering cars.

Researcher: What are your thoughts on the contrast of V. Fields\textsuperscript{TM} using plastic compared to the big science of current research?

Brandon: People know big science is cool stuff. It is the future. Personally, I like the past and future. Past to future. Past is a plant but here we come. Those who need to remember the past can. Past can shape the future.

Researcher: Explain two recent advances in photosynthesis research?

Brandon: Using spinach (photosystem I) power. Using solar energy more effectively. Photosystem II to get water to produce hydrogen. More efficient way to make fuel for cars.

Researcher: How does considering recent research impact your learning and remember of photosynthesis?

Brandon: Has more relevance and cooler and apply cool photosystem to use power cells. Organisms way to make fuel. And hydrogen gas. Nature’s way to make energy to benefit humans.

Researcher: Were you surprised that there is so much current interest in photosynthesis?

Brandon: Knew there were some but few were cool. Did not teach you in school. Could come to organisms for technology. Using memory organisms to store memory. Cool about DNA memory. Some things recorded. Like the research because it is technology against nature. Research from learning formally technology research. Photosystem II to split water. Natures better way. So why make up a harder one. Technology from nature.

Researcher: Are you interested in the research?

Brandon: Yes.

Brandon liked the herbicide studies that helped to explain cytochromes. He very often referred to the herbicide studies during his overall discussions.

Researcher: How are herbicides useful in the study of photosynthesis?

Brandon: Show the importance of cytochromes. How cytochromes are to pressure.
Researcher: How did studying herbicides help you learn and remember photosynthesis?
Brandon: Herbicides block path and made you remember photosynthesis. Had to research path to block hydrogen ions.

Researcher: How did looking at the video of the plant treated with herbicide impact your understanding of photosynthesis?
Brandon: Example of blocks just one part. Plant dies. Cytochrome is effective, strong but fragile [sic].

The red mulch experiment merged a recent research finding with a lab done by the participants. It appeared that the combination of something interesting along with the continuation of current research allowed for a memorable experience consisting of the combination of episodic and semantic memory (Tulving, 1985).

Researcher: How did building on the red mulch information with the phytochomes stimulating growth of the plant above the ground impact your learning about red mulch and photosynthesis?
Brandon: Important way to remember.

Researcher: Predict the carbon dioxide vs. time graph for a tomato plant that is near red mulch.
Brandon: More light reaction more light, more oxygen and more ATP and NADPH and more Calvin cycle and more fixation so carbon decreases.
Researcher: Relate your predicted graph to the various reactions of photosynthesis.
Brandon: The more red light, the more light reaction. The more light reaction, the more Calvin cycle and the more starch.

The researcher discussed with Brandon the possibility of adding an important item to his PowerPoint® presentation that proposed a solution to the farmer’s problem of productivity. He was quick to relate the relationship of the use of a wavelength of light to photosystem II and the need to split water, and thus the need to have adequate water while his PowerPoint® presentation was missing the need of adequate water. Also, the impact of view and creating animations was discussed.

Researcher: Add an important item or concept to your PowerPoint®.
Brandon: Water. There may need to be special irrigation if it is dry.
Researcher: How do your PowerPoints® help to explain the concepts?
Brandon: PowerPoints® are displays of different processes as presented to you. Different boards set up in your mind.
Researcher: Does making animations help to understand the concept?
Brandon: Remember animations of cytochromes and ATP synthase. Seeing hydrogen ions moving helps you to remember -- yes making -- makes all more organized in your mind. You are making so you need this.

Researcher: How do you think making animations will help you to remember the concept?
Brandon: Concept maps [are] static [when] making a diagram. PowerPoint® stages a process of explaining it. It can look cool if it’s animated. Pictures would help a concept map like a PowerPoint®. Good to have [it] animated to start.

Brandon enjoyed a variety of activities preventing fixation and the loss of attention (Langer, 1989). He could see the value of using both concept mapping and animated PowerPoint® presentations in learning so that both sides of the brain are used. He also understood the importance of making a recommendation in the animated PowerPoint® presentation so that the future visual field could be utilized. While this study did not attempt the use of animated concept maps, such a concept map is possible with use of the correct technology tools and may be of sufficient interest to study further. The participant’s response further successfully anticipated the researcher’s next question.

Researcher: Compare and contrast the thought process of making an animated PowerPoint® to making a concept map?
Brandon: Concept maps static and making a diagram. PowerPoint® stages a moving process of explaining it. It can look cool if animated. Pictures would help a concept map like a PowerPoint®. Good to have animated to start.

Researcher: What benefit could come from using both techniques in your study of photosynthesis?
Brandon: Right and left side of the brain even though distant are logical. Use both sides to reinforce it ATP synthase if you do not remember the words you remember the animation.

Researcher: What is the impact of you making a recommendation to the farmers make to your learning and thinking about photosynthesis?
Brandon: Like the future visual field.

Researcher: What is your future visual field with cellular respiration? Give 5 examples.
Brandon: Do research, construction part of photosynthesis used for other things. Carbon fixation, RuBP with oxygen to rubisco. 3-phosphoglycerate. Organism's way of getting rid of carbon dioxide. Learn from photosynthesis to reductase. Plant more trees.
Brandon saw the value of journaling his thoughts on visual fields and that the activities of the session supported the visual fields. He also predicted what he would find easy and difficult to remember to help the researcher pinpoint areas to teach more thoroughly.

**Researcher** Of what use is the visual field worksheet to you?

**Brandon** It makes you realize what you know. Back to previous notes and then forward. Need the present to learn old and new. For me it is similar. What I got taught here [will] resurface [later]. You find the need to learn and the need for future interaction.

**Researcher** How will the activities we did impact your thoughts of the future and learning and remember photosynthesis?

**Brandon** Picture and diagrams help. Photosystems II and I help. Light and photosystems and RuBP and rubisco reinforce it and help. Far out new technology. Photosynthesis is now future. Photosynthesis has application for future learning.

**Researcher** What are your deficiencies in photosynthesis, what do you think you know best, and what do you think you know least?

**Brandon** Best is general process. Deficient in actual things - what happens, why and specific was what enzyme is fuzzy.

**Researcher** List the first five things that come to your mind about the strategies.

**Brandon** Pesticide (did not know too much), data collection, applications, diagrams of photosynthesis, and moss balls.

**Researcher** What would you add to the project?

**Brandon** More about using spinach chips in computers.

**Researcher** What would you remove from the project?

**Brandon** Use nature to make stuff.

**Delayed BDM Instructional Strategy Sessions Clinical Interview.** Brandon said the BDM examples and activities will help him remember the concepts. Brandon also stated that organization, for example concept maps, helps him learn the concepts and understand their complexities.

**Researcher** List the five things that you remember most about the sessions or interviews?

**Brandon** Phrases: splitting of water, photon, weed killers block off cytochromes, spinach, flow charts.

**Researcher** List five things that helped you to learn photosynthesis and cellular respiration most in the project.

**Brandon** Diagrams helped, liked two examples: spinach chip; making hydrogen.
Researcher List the strongest things that you remember most about photosynthesis and cellular respiration.
Brandon In photosynthesis splitting of water.
Researcher List the weakest things that you remember least about photosynthesis and cellular respiration.
Brandon Certain terms: NADP⁺.
Researcher List learning strategies that your use to learn concepts.
Brandon Organizing stuff, dividing into categories.
Researcher How do PowerPoint® presentations impact your learning?
Brandon PowerPoint® helpful because they show info with action.
Researcher Compare animated PowerPoint® presentations to concept maps.
Brandon PowerPoint® teach new info. Concept maps help you organize info.

Concept Map Analysis. Brandon’s cellular respiration Baseline score was 8 and he had nominal literacy. His map was simplistic. He indicated that oxygen was better than no oxygen. His Post Lecture map had a score of 16 and he had nominal literacy. The map was very fragmented, but had no incorrect field. In the Past Visual Field of Cellular Respiration Brandon’s map score was 58 and he had structural literacy. He added fermentation, Krebs cycle, and the use of oxygen to make water. In the Present Visual Field of Cellular Respiration Phase, he scored 101 and had structural literacy level. His visual fields did not have application. The map shows more interconnections. He added the details of pyruvic acid becoming acetyl CoA to enter the Krebs cycle, but fermentation was still isolated. He located more processes in the mitochondria. His map score in the Future Visual Field of Cellular Respiration was 101 and his literacy was multidimensional. He added oxidative phosphorylation, FAD⁺, and NAD⁺ with the Krebs cycle and he attached cytochromes to the electron transport. Brandon’s map score for Delayed Visual Field of Cellular Respiration was 87 with a multidimensional literacy level, which can be compared to the Post Lecture map score of 16. Brandon had added application to his visual fields. Brandon linked fermentation to glycolysis, but he did not use oxygen to make water. He also included the example of pesticides that was not included in the concept bank, which Brandon expressed his enjoyment about learning.
His Baseline Photosynthesis map score was 15 and he had nominal literacy level. He had the information about energy from sun to chlorophyll to produce energy. His Post Lecture map score was 24 and his literacy was nominal. He was not sure how ATP was made, but he was able to show the basics of the light reaction in relationship to chlorophyll. He incorrectly placed the Calvin cycle in the thylakoid and he had chemiosmosis incorrectly linked to the Calvin cycle. He showed the splitting of water to make oxygen, but does not show the production of hydrogen ions and this process is in isolation. His Past Visual Field of Photosynthesis map score was 64 and literacy was structural. He did not understand the light reaction, but included fragmented associations of the concepts. He split water to only generate ATP and did not include the production of the hydrogen ion and oxygen. Brandon did not include carbon dioxide in the Calvin cycle.

Brandon’s Present Visual Field of Photosynthesis map score was 90 and had multidimensional literacy. He included carbon dioxide and the other reactants in the Calvin cycle. Brandon also added photosystem II producing oxygen, ATP, a hydrogen ion, and an electron. Brandon’s visual fields included application. Brandon’s Future Visual Field of Photosynthesis score was 130 and was multidimensional literacy level. Brandon added C₄ and C₃ plants in relationship to the Calvin cycle in moderate detail. He added in the Calvin cycle and producing oxygen. The score on Brandon’s Delayed Visual Field of Photosynthesis map was 75 and he had structural literacy. He did not produce NADPH, and didn’t relate electron transport to chemiosmosis. Also, he didn’t relate the thylakoid or redox reaction to any process.

His Post Strategy Interrelationship of Photosynthesis and Cellular Respiration map score was 154 and his Delayed Interrelationship of Photosynthesis and Cellular Respiration map was 171. Brandon did well in each individual process, except he failed to crosslink the two processes.
together through glucose, water, oxygen and carbon dioxide. In his delayed map Brandon did not produce hydrogen ions, oxygen, or water in the Krebs cycle, nor did he link glucose from the Calvin cycle to glycolysis. But, Brandon did include the use of pesticides blocking cytochromes. He included carbon fixations in the Calvin cycle and the proton pump in chemiosmosis. In both maps he failed to relate the light dependant reaction to the Calvin cycle. In photosynthesis Brandon failed to include application in his visual fields. Selected AP questions were correlated to concept map links that corresponded to the questions. Brandon’s average concept map score was 55% and his average AP question score was 100%. His AP question scores were higher due to his ability to interpret questions and answers.

At the debriefing the researcher was interested in his overall impressions. He thought concept mapping was more helpful than multiple-choice questions for learning.

**Researcher** What is impact of metacognition on success?
**Brandon** It helps, because "knowing how you learn helps you learn in the future. If you know what's wrong you can learn how to make it right. Metacognition is two way learning.

**Researcher** Look at multiple-choice test questions and problems. Comments.
**Brandon** Concept maps are a better indication of knowledge. Multi choice help you guess or eliminate. You can't do that with concept maps. Concept maps help you map the brain more so than multi choice.

**Researcher** Literacy- comments –be sure you have the associated words that go with each term.
**Brandon** it's important to know the terms you can't say it's the thing that does the thing. In contrast if you don't know how to use the terms correctly, it takes too much time to defining things.

**Researcher** Map comparison—comments.
**Brandon** It's good, because it shows parts you are weak on and what parts to improve. The color red is REALLY STRONG! Don't use red! Red is bad! [The researcher used red to code the concepts that were incorrectly mapped or not mapped. He did not like the use of red for correction].

The researcher was interested in his willingness to continue the project if it continued.

The researcher was also interested in his reflection on his current participation.

**Researcher** If the project continues, would you consider being in it?
**Brandon** Ok.
Researcher: What do you think the next step could be?
Brandon: Have a test class. Not too many kids, big groups tend to fall asleep and not pay attention.

Researcher: How could the project be modified for more student success?
Brandon: Keep thinking, because everything can be improved.

Researcher: Rate yourself on a scale of 1-10 with 1 being lowest 10 being the highest.
Brandon: 10. Anything worth doing is worth doing well.

Researcher: Were you a satisfied customer (honest representation of project).
Brandon: It helped me learn more about photosynthesis and cellular respiration.

Researcher: Have you heard any gossip?
Brandon: Moss balls were fun, firefly thing was bad. Late night classes were tiring.

Researcher: What impact does having more background on info have on memory decay?
Brandon: Sometimes it's depressing because other people have learned it. For them the path has already been paved; it just needs to be repaved.

Merged BDM Group Analysis

Description of Participants

This group is termed “merged” because some participants received overall analysis and some received extended analysis. The profile of each participant is in Table 13. All participants received clinical interviews at the baseline, post lecture, post strategies, delayed, and debriefing phases. Participants who received these clinical interviews only, comprised the BDM Overall Analysis Subgroup. Other participants received additional clinical interviews after each visual field of instruction and a separate interview for the integration of photosynthesis and cellular respiration concepts. These participants comprised the BDM Extended Analysis Subgroup. Both groups received 6 hours of instruction with the same content. The difference between the two groups was the number of clinical interviews. Each subgroup contained participants with high and low levels of prior biology knowledge. High prior biology knowledge participants had taken a Biology AP course or Biology International Baccalaureate Course, and had similar scores in math and language ability. 89% of the students in this group had at least a 1290 SAT score and 85% were in the range of 1290 to 1520. Most of the high biology knowledge participants
Table 13

Merged BDM Participant Baseline Profiles

<table>
<thead>
<tr>
<th>Pseudonym</th>
<th>ACT</th>
<th>SAT</th>
<th>Biology AP</th>
<th>Expected Major</th>
<th>PowerPoint® Sensors</th>
<th>P + R comments</th>
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<td>Baxter</td>
<td>32</td>
<td>1290</td>
<td>Bio - 3</td>
<td>Biology Premedicine</td>
<td>Yes, not Vernier</td>
<td>P + R with prompting</td>
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<td>33</td>
<td>1410</td>
<td>Bio - 4</td>
<td>Biology Premedicine</td>
<td>Yes</td>
<td>P+R bad, know charts + diagrams</td>
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<td>1390</td>
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<td>Biology Premedicine</td>
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<td>Brandon</td>
<td>31</td>
<td>1510</td>
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<td>24</td>
<td>1200</td>
<td>NA</td>
<td>Neuroscience Premedicine</td>
<td>No, No</td>
<td>Plant in tube, O₂ diagram</td>
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<td>1470*</td>
<td>NA</td>
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<td>Yes, No</td>
<td>&quot;Show her a picture&quot;</td>
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<tr>
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<td>Light with chlorophyll to make sugar</td>
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<tr>
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<td>1520</td>
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<td>IB</td>
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<td>NA</td>
<td>NA</td>
<td>Biology</td>
<td>Yes, No</td>
<td>Breathe</td>
</tr>
<tr>
<td>Sherlock</td>
<td>29</td>
<td>1330</td>
<td>NA</td>
<td>Biology</td>
<td>Yes, Yes</td>
<td>Grew plant in Biology I class</td>
</tr>
<tr>
<td>Stephanie</td>
<td>22</td>
<td>1080</td>
<td>NA</td>
<td>Biology</td>
<td>Yes, No</td>
<td>Little</td>
</tr>
<tr>
<td>Susie Q</td>
<td>32*</td>
<td>1410</td>
<td>NA</td>
<td>Environmental Biology + Fine Arts</td>
<td>Yes, No</td>
<td>Meaning from life</td>
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<tr>
<td>Sylvia</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>Ecology + Evolution Biology</td>
<td>Yes, No</td>
<td>CD with animations for photosynthesis</td>
</tr>
</tbody>
</table>

Legend:
* = score derived from reference source (Dorans, 1999)]
P = photosynthesis
R = cellular respiration
had taken the Biology AP Exam and have an official AP score of 3 or higher, which is the lowest score the College Board uses for the award of college credit.

**Description of Instruction Area**

The instruction and the laboratory activities were conducted in a conference room in the science building annex on the Energy University campus. The computers and lab equipment were carted to the room from the interview area, assembled for each session, and returned to the interview area after the close of each session. The room was equipped with a digital projector and screen for the participants to view the PowerPoint® presentations and real time data that was being measured at one of the computer stations. Wireless Internet access was available on the campus and in the room. The participants were divided into groups of two and each group shared a laptop computer and sensors. There was no sink in the room but water was available in a nearby restroom.

On one occasion the conference room in the annex was not available and the researcher used another conference room located in the main science building. This conference room was a little larger and had a digital projector and screen available along with the wireless Internet connection. There was a sink located in the conference room, which provided a more convenient water source for the lab activities and cleanup. Although the rooms were crowded, the participants were on the whole cooperative with the conditions.

**BDM Cellular Respiration Past Visual Field Phase**

The session began with the PowerPoint® presentation called Cellular Respiration (Appendix R). The scenario for the visual field agent, V. Fields™ was “Once Upon a Sandy Loam” and included memories about hoeing and plowing soil. Thus the soil microbes were used to introduce aerobic cellular respiration.
Animated PowerPoint® slides illustrated the basics of cellular respiration (endergonic reactions, anaerobic and aerobic conditions, glycolysis always occurs, ATP count). The “Model of Mitochondrion Activity-Home Study Kit” constructed with potatoes (Appendix S) provided a model of morphology of the mitochondria related to its function. Then hot bun mix with live yeast was demonstrated. The participants were attentive throughout.

To illustrate anaerobic respiration, the agent, V. Fields™, introduced Kimchee. A jar of Kimchee was shown to the participants and an accompanying PowerPoint® presentation described the fermentation. The presentation included a thirty second Kimchee commercial and a 1.5 minute original video about the ingredients used to make Kimchee, filmed at a local Korean grocery. The videos were modeled from the format of WebQuest (Dodge, 1997) activities which always establish an interesting story in the beginning of an activity.

The Kimchee story was extended with an innovative experiment and demonstration to capture the participants’ attention. Adele and Pierre, characters in the scenario, explained that a restaurant near campus needed to speed up the process of making Kimchee. The participants compressed the cabbage by pushing down on it with a bottle (Appendix S). Four samples of Kimchee of differing ages were exhibited.

A “Logger Pro™ How To” tutorial (Appendix S) was introduced so that participants could familiarize themselves with “Biology With Computers” and do the basic tasks from the menu such as starting the data collection and determining the slope of a line. The associated lab, “Making Kimchee: Tracking Microbes of the Phyllosphere with Sensor Data Collection” (Appendix S), determines the rate of cellular respiration of Kimchee samples of various ages by using carbon dioxide sensor. Lactic acid concentration was determined with the pH sensor and salt concentration was determined with the conductivity sensor. An old fashioned respirometer was used to demonstrate an alternative method of measuring carbon dioxide.
BDM Cellular Respiration Present Visual Field Phase

The major activities in this instructional session were collecting data with sensors and Logger Pro® software and viewing animated and layered PowerPoint® presentations with the details of the concepts (Appendix R). Quantitative data were collected from Kimchee and soil samples (Appendix S), and qualitative demonstrations were done with bread, ATP, and fireflies (Appendix T). The video tape of the instruction session revealed that the participants were attentive to the activities and were intrigued by the firefly experiment. Participants were asked to predict the slope of the line for Kimchee that was fermenting in the cold.

Researcher: What would you expect the slope of the carbon dioxide graph to be?
Bertha: The slope should be positive but less [than] that [of] the room temperature Kimchee.

Participant interest in the class lesson was important. By the enthusiasm in her response, it was evident that Bertha was very interested in the laboratory exercise.

The lab called “The Falling Bread” (Appendix S), included a scenario about a problem making bread, was demonstrated. “Basic Fermentation BioKit® Student Guide Lab” (Appendix T) tracked fermentation by measuring the height of the carbon dioxide bubble produced by the yeast. “Making Yogurt” (Appendix S) included a scenario to track lactic acid production. A sample of year-old Kimchee was examined. An old fashion respirometer was demonstrated. “The City Park Running Track” video about lactic acid and cramps was followed by a researcher-created PowerPoint® presentation called “Cellular Respiration” (Appendix R) that continued with the topics of glycolysis, fermentation, Krebs cycle mitochondria, electron transport, cytochromes, chemiosmosis, and oxidative phosphorylation.

The scenario in “Picturing Soil Microbes” (Appendix S) focused on a Louisiana sugar farm; the lab explored the rates of respiration for soil microbes in aerobic and anaerobic
conditions. Predictions were made with Logger Pro® at each step along the way. The “Firefly Bioluminescence BioKit® Student Guide Lab” (Appendix T) was also done by the participants during this phase

**BDM Cellular Respiration Future Visual Field Phase**

The future visual field applied the elements of constructing animated knowledge to help solve a problem by using knowledge learned in previous sessions. It was important to keep the interest of the participants so new examples of cellular respiration were used. The rate of respiration was measured for Mexican jumping beans and mealworms in various conditions.

“Cellular Respiration: The Mystery of the Mexican Jumping Bean” (Appendix S) had a scenario about a company that had old jumping beans and was not sure if they should sell them. Participants were asked to make predictions about the rate of carbon dioxide production, the viability of the jumping beans, and to chose the parameters that they wanted to vary. Poisons that interfere with cellular respiration were explained with animated and layered PowerPoint® presentations. One contained a video clip of the James Bond movie *Moonraker* and featured darts laced with cyanide, another contained an online broadcast from the National Institute of Health on mitochondrial diseases. PowerPoint® slides illustrated ATP deficiencies associated with Parkinson and Alzheimer's diseases (Singer, 2003); Noble Prizes awarded for research on cellular respiration; and cognition and behavior articles from a recent *Science* Magazine.

Using a toolbox of template slides and graphics, and techniques from a simple lesson on how to animate objects, participants constructed animated layered PowerPoint® presentations to explain the process of fermentation of Kimchee and the technology used to make and monitor the Kimchee. Turbidity, pH, and conductivity were considered. The participants were surprised that they were able to make their own PowerPoint® immediately after the data collection.
Researcher Open the tool box file and make your PowerPoint®.
Bertha We can use these tools or do we have to make our own?
Researcher Yes, you can use the tools.
Bella Great! That will give us more time to concentrate on the details.
Bunny I have never used animation feature in PowerPoint® before like this.

BDM Photosynthesis Past Visual Field Phase

The basic concepts of photosynthesis, as seen in the Past Visual Field of Photosynthesis Presentation, were presented. In addition animated PowerPoint® slides on the basic concepts, videos, models, a few demonstrations, and data collection were used (see Appendix R). A quick video clip on the dust bowl from *The Grapes of Wrath* movie was used to illustrate the impact of climate on food production in the United States. Another example used was the World War II Victory Gardens. Women were encouraged to grow food while using fewer ration stamps.

A Junior Mint® Chloroplast Model Kit (Appendix S) was given to each participant. The three dimensional model helped students to understand the two dimensional structure seen in electron micrographs of the chloroplasts.

During the “Bromthymol Blue- Photosynthesis and Human Carbon Dioxide Lab” demonstration (Appendix T), carbon dioxide was blown into two tubes of bromthymol blue to obtain a yellow color. Twigs of *Elodea* were added. One tube was placed in the light and the other in the dark. The experiment was also repeated with twigs of *Elodea* placed in water with sodium bicarbonate. These tubes were inverted. All tubes were examined over the course of the session to detect changes. The fluid in the tube in the light eventually returned to its original blue color because the *Elodea* in the light used the carbon dioxide from the solution for photosynthesis; the illuminated inverted tubes had a bubble at the top of the tube due to the accumulation of oxygen.

Guard cells surround the stomata and regulate the exchanges of gasses; were simulated with tangerine sections in a lab called “Study Stomata With Tradescantia” (Appendix T). Fresh
tangerine sections are swollen like guard cells under pressure -- when stomata are open. As sections were exposed to the air they shriveled and, without much pressure, collapsed, thus simulating closed stomata.

Crushed cabbage leaves were subject to paper chromatography to see the separation of the various pigments. The rate of photosynthesis was digitally recorded using “moss balls,” a mutant form of green algae that grows in the shape of large, green, cotton balls. They are good for doing photosynthesis data collection experiments because they lack roots and have a lot of photosynthetic mass. Cabbage plants were also used for the data collection. The moss balls experiment was supplemented with scenarios using Cotille and Boudreaux to help the students relate the experiment to daily life.

**BDM Photosynthesis Present Visual Field Phase**

The Present Visual Field of Photosynthesis reviewed the Past Visual Field of Photosynthesis session. The demonstrations from the previous session were integrated with new activities. Iodine, which stains starch dark blue, was used to provide a qualitative assay of starch production in leaves in light and lack of starch production in dark. An accompanying animated PowerPoint® presentation (Appendix R) increased details to facilitate concept development. Radiographs used by Calvin in his research of the Calvin cycle were simulated using iron filings and a magnet with a plant diagram in the activity called “Radionuclides and Autoradiographs: Applications for Understanding Photosynthesis and Respiration” (Appendix S).

The data collection experiment was called “The Hunt for the Red Mulch” (Appendix S). The rate of photosynthesis of plants grown with red mulch were compared. Red light is reflected from red mulch, while it is absorbed by black mulch. The rate of photosynthesis was digitally determined with the carbon dioxide sensor and Logger Pro®. Like the Engelmann experiment with a prism, this experiment demonstrates that wavelengths in the red part of the spectrum
increase photosynthesis. The session ended with the Lab called “Photosynthesis: The Light Reaction Using Spinach Disks” (Appendix S). Disks of spinach were punched from spinach leaves; air was removed from them; they were placed into a solution of sodium bicarbonate, and placed either in the dark and or the light. Due to lack of oxygen in leaf tissue, the disks sank. When disks were placed in light, oxygen produced during photosynthesis caused them to float.

**BDM Photosynthesis Future Visual Field Phase**

Videos, data prediction, demonstration of DPIP, analysis of current applied research on photosynthesis concepts with instructor-constructed PowerPoint® presentations, and student constructed animated PowerPoint® presentations were used. Further a NASA video of soybeans growing in space, and other videos of herbicide killing a plant, and an infrared time-lapse animation of the seasonal difference in photosynthetic productivity in the northern or southern hemispheres were included.

DPIP is a blue indicator that is used as a surrogate for NADP⁺ in the light reaction of photosynthesis. When DPIP is reduced to DPIPH it becomes colorless. A demonstration of DPIP was used to follow the reduction of NADP⁺ in the light reaction.

The animated PowerPoint® presentations reviewed concepts by explaining C₃, C₄, and CAM plants. Current research on photosystem I from Massachusetts Institute of Technology has been tested to power laptop computers. A current research article described the use of photosystem II for powering cars. Finally, the students were asked to make a recommendation to farmers about the use of red mulch to help increase the productivity of their crops. They constructed layered and animated PowerPoint® presentations with a tool box of images and slide templates (Appendix U).
Visual Fields

The Merged BDM Subgroup did not receive TIVF instruction until Post Lecture. Since all the students attended Cell Biology 101 classes, Post Lecture was a common past visual field for all the research students. All of them had previously relied on memorization to learn new concepts, but as they continued to experience decay in their knowledge, they welcomed a different approach to learning. By the Post Strategy Phase they were able to experience building knowledge with the past, present, and future visual fields. Responses from the BDM Overall Analysis Subgroup illustrate their level of understanding of TIVF.

Researcher    How did you visualize your present experience with photosynthesis and cellular respiration?
Sabrina       Text without any real visualization but also, bright, animated PowerPoints®, performing experiments with computers and plants.
Sylvia         Light has been shed not only on the processes and their steps, but on their greater purpose in each process. They fit into a larger picture. Not just memorized but understood. [I am] Out of breath and thinking oxygen and mitosis.

Sabrina’s comment is the description of BDM, which she had actually experienced. In the sequence below, Shelly explains the changes in learning she has experienced over the various stages of BDM strategies.

Researcher    How did you visualize your present experience with photosynthesis and cellular respiration [at various phases of the research]?
Shelly         Difficult and confusing. Block your head banging. Frustrated with official lectures that were part of the Energy University Course [during Post Lecture Interview].
Shelly         Much clearer! I see myself understanding and making better mental connections between all the information [during Post Strategy Phase Interview].

Sylvia’s progress from Baseline to Post Lecture and to Post Strategy is shown in the dialogue below. She was happy with her progress, and realized that she will remember photosynthesis and cellular respiration because they are “happening at every moment.”
Researcher: How do you visualize your or other people’s future experiences with photosynthesis and cellular respiration?

Sylvia: You wish it will be more default and less vague. Easier to recall goals for yourself [during Baseline Phase Interview].

Sylvia: I imagine it will be like counting or the ABC’s. It will be almost innate. I won’t have to tax my brain trying to remember [during Post Lecture Phase Interview].

Sylvia: As I relate these processes to myself and the world around me, things seem very clear. How can I forget something that is happening at every moment [during Post Strategy Phase Interview]?

The Merged BDM Group was exposed to additional applications in the laboratory activities, giving them a broader future visual field than the Comparison Group. Selected comments below illustrate their new level of understanding. Baxter had thought much about how the researcher had scheduled the delayed interview two weeks after the strategies concluded. He correlated the need to have two weeks to be sure that the item was in long-term memory so that it could enter the past visual field.

Researcher: How did you visualize your present experience with photosynthesis and cellular respiration?

Baxter: I am beginning to see a division in my past and present after two weeks. I can’t really define a present [During Delayed Phase Interview].

Bella remembered first studying photosynthesis in 5th grade. Her development through Post Strategy and Delay is shown in the responses below.

Researcher: From your past what do you visualize about your experiences with photosynthesis and cellular respiration?

Bella: I remember learning about photosynthesis in almost every grade, starting at 5th. I have done relatively well on the tests on photosynthesis [during Post Strategy Phase Interview].

Bella: I have now intensely learned almost every nook and cranny of cellular respiration and photosynthesis. I am confident with cellular respiration and photosynthesis. [Delayed Phase Interview]

Beth experienced much in her Biology AP course as evidenced in this Baseline dialogue. She enjoyed visualization of her past visual field, and she had one of the strongest past visual fields.
Researcher From your past what do you visualize about your experiences with photosynthesis and cellular respiration?
Beth Easiest process - Animation on the computer or the easiest picture from biology [textbook]. [During her Biology AP course, she liked to learn with animations and simple pictures.]
Researcher How do you visualize your present experience with photosynthesis and cellular respiration?
Beth Same way you learned it. Would have to remember words-need to get words - connection between words.
Researcher How do you visualize your or other people’s future experiences with photosynthesis and cellular respiration?
Beth Seeing plants - seeing your cellular respiration.
Researcher How do your visualizations of your past, present, and future will help you understand photosynthesis and cellular respiration?
Beth Best to go over the process and do not have trouble connecting it. Connection is important. Connection is what you see in books to what surrounds you. I had not thought about this before.

Application of knowledge is important. Bertha’s application of knowledge of photosynthesis and cellular respiration is demonstrated in the following comment:

Researcher How do you visualize your present experience with photosynthesis and cellular respiration?
Bertha Depletion of world's oxygen because of chopping down rain forests, thorough understanding of photosynthesis process and can apply to life, apply past techniques of successful learning. I learned how.

BDM provided students insight by visualizations of their past, present, and future visual fields. The clinical interviews helped to reveal the value of the visual fields.

Literacy

Literacy was determined from the map scores, visual field analysis, and clinical interviews. Many participants achieved high enough map scores and validated the applications as part of their learning goals. The Merged BDM Group achieved multidimensional literacy despite low initial scores (Table 10).

Baseline. The Baseline literacy level of the Merged BDM group was a reflection of their high school biology experience. Baseline knowledge was assessed with concept mapping, word
sorting, and visual field analysis. The literacy level for each participant in cellular respiration and photosynthesis was nominal (see Table 9), although three participants were at the functional level in photosynthesis. Although these participants did not have previous Biology AP courses they had a strong biology background. Overall, the merged BDM Group had little knowledge of cellular respiration and photosynthesis. They felt more comfortable with photosynthesis because they had more exposure to photosynthesis than cellular respiration in high school. All had very little application knowledge. Curiously, during interviews, they stated that their knowledge of photosynthesis and cellular respiration was high. Their assessments showed otherwise. The assessment scored the participants’ average biological literacy level as 1 (i.e. nominal literacy) in cellular respiration, and as 1.2 (i.e. marginally above nominal literacy) in photosynthesis.

Post Lecture. All the participants had the same instruction together in the Official Energy University class and by this phase almost all of the participants had either functional or structural literacy. However, two of the participants were still at the nominal level. The participants were able to define or explain biological terms correctly or explain principles and use processes to illustrate them. They had increased their literacy levels in both cellular respiration (2.27) and photosynthesis (2.07).

Researcher How do your visualizations of your past, present, and future will help you understand photosynthesis and cellular respiration?

Susie Q The present greatly helps the future because of detail. But the past does not because of little detail. But past is basic and it makes you want to learn more.

Bridget All go together - photosynthesis has a background as you go from seeing it to knowing about the molecules and the cellular level. Respiration did not have a past - now today will have a past - this is making a past. Future will go more in classes you take deeper in depth. It becomes natural like the alphabet.

Bertha Understanding instead of just memorizing. Memorize and understanding is much better why something comes easy. When it is ineffective then learning the concept will make it more effective. Past was just memory. Previous memory and understanding. Do not know the future. Future will learn from present and apply to future endeavors.
Post Strategy. The Post Strategy Phase was at the end of BDM instruction in cellular respiration and photosynthesis. The participants had all the strategies of BDM and understood the function of their past, present, and future visual fields. By the time the participants reached this phase there was a rise in literacy level and three of the participants were multidimensional in cellular respiration and one was multidimensional in photosynthesis. No participants were nominal and only one participant was functional in photosynthesis.

Researcher From your past what do you visualize about your experiences with photosynthesis and cellular respiration?
Bertha Metacognition linked present and past visual fields from the research study. Childhood: 9th grade biology, AP Biology, research sessions, college biology, growing plants in a bag, and aerating shoes.

Researcher How do your visualizations of your past, present, and future will help you understand photosynthesis and cellular respiration?
Brandon Maybe I want to be involved with concepts remembered and development of those concepts into something greater.

Delayed. The Delayed Phase took place two weeks after Post Strategy. None of the participants experienced decay in their literacy during this time. There were no BDM strategies or instruction between Post Strategy and Delayed but there was a rise in biological literacy. There was an increase in average biological literacy for the group during this time. The majority of the participants reached a level of multidimensional literacy with one achieving structural literacy. This rise was probably due to the participants making applications of what they had learned. This final analysis illustrates the effect of BioDatamation™ strategies on the biological literacy levels of the participants. They reached a biological literacy level of 3.6 in cellular respiration (i.e. significantly higher than structural literacy) which was an increase of more than a full level for the BDM Merged group over their Post Lecture analysis. Their scores were an average of 3.4 (i.e. significantly higher than structural literacy) in photosynthesis, again increasing by more than a full level above their Post Lecture scores.
Researcher: How do you visualize your present experience with photosynthesis and cellular respiration?

Baxter: I am beginning to see a division in my past and present after two weeks I can’t really define a present.

Brandon: We are bringing ideas back and thinking about how we can use them.

Shelly: I see myself understanding and making better mental connections between all the information.

**Biology AP Multiple-Choice Exam Question Analysis**

Selected Biology AP questions that are administered by Educational Testing Service and College Entrance Examination were asked at each phase of the project. The questions were analyzed with and compared at the Delayed Phase. These questions were contained in Biology AP Exams from 1990 (ETS, 1992), 1994, (ETS, 1994) 1999 (ETS, 1999), and 2002 (CEEB, 2004) which were released and published by the College Board, and the following is an analysis based on these examination questions.

Table 14 provides the description of the selected questions and the score analysis for the Biology AP National Group, BDM Group, and Comparison Group scores. For these questions, the Merged BDM Group had an average score of 75.6 and the national average was 41.6. The Merged BDM Group had double the national score on 50% of the questions, and always scored higher than the national score.

The Comparison Group had an average score of 51.8% on the selected questions. Cellular respiration and photosynthesis are fundamental to the study of biology. According to the analysis, the Merged BDM Group had significantly more understanding of basic concepts. The Merged BDM Group scored at least an average of 70% on 66.6% of the questions, where as the Comparison Group scored 70% on only 8.3% of the questions. Of the National Group, 0% of the questions had 70% correct. The Merged BDM Group performed significantly better than the Comparison Group, which is an indication that the BDM learning strategies had a positive effect on their performance.
<table>
<thead>
<tr>
<th>Year/Question/Reference</th>
<th>Concept</th>
<th>% correct</th>
<th>% correct</th>
<th>% correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999/60(ETS, 1999)</td>
<td>Chlorophylls vary in light absorption</td>
<td>33</td>
<td>53</td>
<td>23</td>
</tr>
<tr>
<td>1994/90 (ETS,1994)</td>
<td>ATP synthase is a protein in mitochondria and chloroplasts</td>
<td>56</td>
<td>73</td>
<td>29</td>
</tr>
<tr>
<td>1994/66(ETS, 1994)</td>
<td>ATP hydrolysis coupled to free energy reaction</td>
<td>33</td>
<td>87</td>
<td>30</td>
</tr>
<tr>
<td>1999/41(ETS, 1999)</td>
<td>ATP produced as a result of movement down concentration gradient</td>
<td>67</td>
<td>80</td>
<td>33</td>
</tr>
<tr>
<td>1994/20(ETS, 1994)</td>
<td>CO₂ path to starch</td>
<td>33</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>1999/18(ETS, 1999)</td>
<td>ATP produced in both mitochondria and chloroplasts</td>
<td>44</td>
<td>60</td>
<td>42</td>
</tr>
<tr>
<td>1999/61(ETS, 1999)</td>
<td>ATP hydrolysis coupled to active transport</td>
<td>33</td>
<td>67</td>
<td>46</td>
</tr>
<tr>
<td>1999/84(ETS, 1999)</td>
<td>Calvin cycle incorporates CO₂</td>
<td>67</td>
<td>93</td>
<td>46</td>
</tr>
<tr>
<td>1994/58(ETS, 1994)</td>
<td>Carbohydrate synthesis requires light reaction</td>
<td>33</td>
<td>67</td>
<td>49</td>
</tr>
<tr>
<td>1999/82(ETS, 1999)</td>
<td>O₂ by-product of light reaction</td>
<td>56</td>
<td>73</td>
<td>49</td>
</tr>
<tr>
<td>1999/85(ETS, 1999)</td>
<td>Chemiosmosis is in both</td>
<td>67</td>
<td>87</td>
<td>57</td>
</tr>
<tr>
<td>1994/83(ETS, 1994)</td>
<td>O₂ released from H₂O in photosynthesis</td>
<td>100</td>
<td>87</td>
<td>57</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>75.6</td>
<td>51.8</td>
<td>41.6</td>
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</table>
Comparison Group Analysis

Group Description

This group was termed Comparison Group because they were chosen to be the control group for the research. These participants each received clinical interviews at the Baseline, Post Lecture, Post Strategy, Delayed, and Debriefing Phases. These participants received 6 hours of instruction, which was the same amount of instruction time received by the experimental group. The Comparison Group contained participants with high and low levels of prior biology knowledge. Table 15 shows the characteristics of the Comparison Group. High prior biology knowledge participants had taken a Biology AP course or Biology International Baccalaureate Course, and the researcher interviewed them to determine the quality of the course. These students were approximately equal in math and language ability. Energy University has a narrow range of SAT scores for acceptance. Most students in this group had at least a 1260 SAT score and 67% were in the range of 1260 to 1320. Most of the high biology knowledge participants had taken the Biology AP Exam and have an official AP score of 3 or higher, which was the lowest score the College Board uses for the award of college credit. From the literacy data in Table 9, the Comparison Group had a higher average literacy than the merged BDM group for both cellular respiration and photosynthesis in the Baseline and Post Lecture Phases.

Instructional Sessions

There were six hours of instruction and each session was two hours. The sessions were a combination of laboratories and discussion. The activities were hands-on and encouraged understanding and not memorization, but lacked BDM learning strategies and the infrastructure of the visual fields.

The first hour of instruction began with a review of difficult questions from the Official Energy University Second Introductory Biology Class Exam on photosynthesis and cellular
Table 15

Comparison Group Participant Baseline Profiles

<table>
<thead>
<tr>
<th>Pseudonym</th>
<th>SAT</th>
<th>Bio. AP</th>
<th>Expected Major</th>
<th>Experience with PowerPoint®</th>
<th>Experience with Sensors</th>
<th>Experience with photosynthesis + cellular respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nancy</td>
<td>1300*</td>
<td>Bio – 3</td>
<td>Biology</td>
<td>Yes</td>
<td>No</td>
<td>Phosphorylation, Electron Transport, and DPIP</td>
</tr>
<tr>
<td>Natalie</td>
<td>1310</td>
<td>Bio – 3</td>
<td>Chemistry</td>
<td>Yes</td>
<td>No</td>
<td>DPIP confusing not enough time</td>
</tr>
<tr>
<td>Natasha</td>
<td>1310</td>
<td>Bio – 4</td>
<td>Premedicine – sports</td>
<td>Yes</td>
<td>Yes</td>
<td>DPIP labs, charts, cycles</td>
</tr>
<tr>
<td>Nick</td>
<td>1420*</td>
<td>Bio - No Exam</td>
<td>Chemical Engineering - MD / Ph.D.</td>
<td>Yes</td>
<td>Yes</td>
<td>Electron Transport + ATP</td>
</tr>
<tr>
<td>Neka</td>
<td>1300</td>
<td>NA</td>
<td>Biology</td>
<td>Yes</td>
<td>No</td>
<td>Draw diagram + look at plants</td>
</tr>
<tr>
<td>Nicole Sonia</td>
<td>1220*</td>
<td>NA</td>
<td>Biology</td>
<td>Yes</td>
<td>No</td>
<td>lab, visual terms</td>
</tr>
<tr>
<td>Niomi</td>
<td>1260</td>
<td>NA</td>
<td>Chemistry</td>
<td>Yes</td>
<td>Yes</td>
<td>Do not remember chlorophyll</td>
</tr>
<tr>
<td>Norma Jean</td>
<td>1320</td>
<td>NA</td>
<td>Neuroscience + Premedicine</td>
<td>Yes</td>
<td>Yes</td>
<td>Diagrams + answered questions</td>
</tr>
<tr>
<td>Norman</td>
<td>1300</td>
<td>NA</td>
<td>Biomedical Engineering + Premedicine</td>
<td>Yes</td>
<td>Yes</td>
<td>Light + energy chloroplasts</td>
</tr>
<tr>
<td>Average</td>
<td>1300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend:
NA = Not available
Bio. = Biology

respiration. The format of the session was similar to a focus group, and the topic was how to get a better understanding of cellular respiration and photosynthesis. The researcher used the dry
erase board to explain the answers with diagrams and notes. Some of the questions that were discussed concerned the following:

Many participants were confused about why yeast doesn’t secrete pyruvic acid directly. The answer pertained to making more ATP and NADH and regenerating NAD⁺. The researcher used a diagram to show how the regeneration of NAD⁺ was required for glycolysis.

ATP in glycolysis is produced as a result of substrate level phosphorylation. The answers included ATP being produced in chemiosmosis, the mitochondria and the Krebs cycle. The discussion of the answer included the cytoplasm being the location of glycolysis. We discussed that you could have eliminated some answers because they were false. The mitochondria is not the location of glycolysis and the Krebs cycle does not occur in glycolysis. The researcher wanted to know why there was so much confusion about this question that seemed straightforward.

Researcher  Why do you think this question was difficult?
Neka   The diagram at the end of the chapter made it seem that all the process were part of one.
Researcher  Some other participants had mentioned that diagram at the post lecture interviews.
Niomi  I thought that if I memorized the diagram, I could answer any question about cellular respiration. It is not that easy.
Researcher  There needs to be understanding to have long-term memory of concepts, and here it seems that memorization has not helped you remember even in the short term since the diagram was so complex.

We discussed the need to have background to understand the diagrams in a college textbook. The researcher showed the participants an introductory level high school biology textbook, Biology (Miller, 2002) and the complexity of diagrams. The researcher suggested looking at the basics along with the more complex.

Researcher  Did many of you bring your high school biology textbooks with you to college?
Natalie  I thought about it but figured the book for the course would have everything in it. Boy, does it have everything in it. There is so much
sometimes that I do not understand anything. I like to start with the simple. I like your idea of looking at high school books.

Two questions concerned the bridge between glycolysis and the Krebs cycle and the answer involved the conversion of pyruvic acid to acetyl CoA (Coenzyme A). Again it seemed that some of the problems arose from the complex diagrams and awareness of this step. Another question concerned the structure and function of ATP synthase. The question included a description of the flow of hydrogen ions through a cylinder that rotated and the participants had to relate this to ATP synthase.

Natasha Each thing makes sense, but I do not understand where everything fits together.

Researcher Does making the concept maps or looking at diagrams help you to see how things fit together?

Natasha I need to be careful with the diagrams because they are so complex. The concept maps help me to add some things each time. I think the maps help.

The researcher and the participants discussed the importance of reading the book, at least some of the time, prior to the lecture to get a background on the concepts. The participants who had AP felt they had a background to most concepts and they had something to build their knowledge on. Whereas the students who had a limited background in high school biology were finding things difficult and time-consuming.

Researcher Those of you who have had a limited background in biology, do you read the book prior to lecture?

Norma Jean The book is so complicated that I sink as I read it. I need to know something when I go to the lecture, but our textbook is difficult. I think I am going to get a high school book to review so I can figure out the big picture before I read the big course textbook.

The researcher showed the participants the book, Biology (Campbell & Reece, 2002) and then passed a few around so that they could look at the diagrams on photosynthesis and cellular respiration. They all agreed that this book had excellent diagrams and they could see what they where looking for. The Energy University course used the textbook Biology (Raven, Johnson,
Losos & Singer, 2005) and the students thought the diagrams in this book were difficult to understand.

The next part of the session involved the researcher demonstrating the making of yogurt and tracking its progression with the change in pH due to the production of lactic acid during fermentation. The process was explained on the dry erase board along with the demonstration. Making bread was also demonstrated and the progress of the fermentation was tracked with the rising of the bread. Then there was discussion about the bread and yogurt.

- **Researcher**: How do you know the conditions for the yeast are good?
- **Nick**: The bread would rise faster.
- **Researcher**: What is the course of energy for glycolysis? Think about the ingredients in bread.
- **Nomi**: It must be the flour.
- **Natalie**: The flour is made of starch which is a polysaccharide and polysaccharides are made of glucose that can be used in glycolysis.

The second hour of the session was doing the lab “Basic Fermentation BioKit® Student Guide Lab” by Carolina Biological Supply (Appendix T). The BDM group also did this experiment. The students were given the “Student Guide: Basic Fermentation BioKit®.” It included the procedure, a table for the data, a graph for the data, and questions. The participants read the lab and were divided into three groups. Each group used a different concentration of sugar or a different sugar (10% sucrose, 5% sucrose, and 5% glucose and water for the control). The solution was placed in a vial and inoculated with yeast. The vial was full and was inverted and placed into a larger vial. The length of the gas column was measured every 5 minutes for 45 minutes, recorded in the table, and graphed. The groups shared their data to compare their results. About 15 minutes into the experiment the researcher asked the following question.

- **Researcher**: How are things going with the experiment?
- **Natasha**: I am so surprised that so much gas is produced so quickly. Our tube is almost all full of gas.
Nancy: I have water and yeast and nothing has happened. It is sort of boring, but I like looking at the others. I like to get results.

Researcher: You are getting results. What are you establishing with your experiment?

Nancy: You need sugar to have fermentation.

Researcher: Yes. Your boring experiment is important for us all to see.

The students enjoyed watching and measuring the gas column. Some were frustrated by the bubbles because it was difficult to see where the gas column ended and the solution began.

The next part of the session used old fashioned respirometers to track the aerobic cellular respiration of various organisms. In the Biology AP Laboratory 5: Cell Respiration (Appendix T). The students skimmed the lab and the researcher explained the most important aspects of the lab on the dry erase board by asking them questions.

Researcher: If we are working with aerobic organisms, what gases are involved in the reaction compared to the reaction in anaerobic organisms?

Nick: Aerobic has oxygen and carbon dioxide; anaerobic does not have oxygen.

The researcher then helped them to understand the purpose of potassium hydroxide to precipitate the carbon dioxide in the respirometer so that only the consumption of oxygen would be followed. The emphasis was on the removal of the carbon dioxide as a solid so that only the oxygen gas would affect the volume in the tube. The researcher showed them a carbon dioxide and oxygen sensor that is used to track the changes in carbon dioxide and oxygen. The researcher explained that this technology was quick, but expensive. The lab was set up for the group of nine. They chose to test warm mealworms vs. cold mealworms. The data were collected and then discussed. They noticed that it was difficult to read the pipets to see the change in volume, but they thought doing the lab was interesting. The metamorphosis of the mealworms was discussed and how the beetle is in the adult stage. An animation from *The Biology Place* (Pearson, 2005) for AP Lab 5 was viewed and discussed. The participants enjoyed the animation about the cricket and cellular respiration.
There was a discussion about how the mealworms were using up the oxygen in the tube of the respirometer. The researcher posed the question of what would happen if a plant was placed in a respirometer with potassium hydroxide. There was much discussion about how the plant would make oxygen and then it was finally realized that the plant would also use the oxygen for cellular respiration. If a plant was put in a respirometer with potassium hydroxide, the plant would both use and make oxygen in the light, but only use oxygen in the dark. The conclusion was that plants do both cellular respiration and photosynthesis and that all organisms do glycolysis. Germinating and nongerminating seed respiration was also discussed.

There was also a discussion about using 10% sucrose because it has the fastest rate of cellular respiration. The yeast enzymes are more suited for sucrose than glucose.

The fourth hour session began with an analysis on the difficult photosynthesis questions from the participant’s official second course exam. The first question considered was whether photosynthesizing plant cells have mitochondria. Only one participant’s answer was no and she said that the chloroplast produced ATP as well as glucose. The correct answer was yes because plants have mitochondria to supply the plant with energy to power cell activities. Some students were confused about where ATP was produced and how it was used. The researcher used the dry erase board to explain that the ATP for photosynthesis was produced in the chloroplasts in the light reaction and that the mitochondria produced energy for the other activities of the cell.

Basic questions concerning the location of the light reaction and Calvin cycle and the nature of what the light reaction produced were discussed. Many basic concepts of photosynthesis were also dealt with. Some were confused that chlorophyll was located in the thylakoid membranes. Another question concerned the production of ATP in both the mitochondria and the chloroplasts via chemiosmosis which was naturally a difficult concept for
the students to grasp. On the dry erase board, the researcher showed how the glucose in cellular respiration was the source of hydrogen ions for chemiosmosis and that the hydrogen ions present in water were the source of hydrogen ions in photosynthesis.

The participants worked on a brief lab report on aerobic and anaerobic cellular respiration as they watched the respirometers. They used the Lab Report Format created by the researcher (Appendix S). They worked in groups of three or four and divided the written sections among the group members. They had an option of using either Microsoft® Word® or Microsoft® PowerPoint® for the format. The lab report was to focus on the Basic Fermentation BioKit Experiment of anaerobic fermentation with yeast and to include some contrasting information about aerobic cellular respiration that was learned in the Biology AP Cellular Respiration Lab. At first the participants were hesitant about doing the lab report because they indicated some bad experience in their previous college lab reports. They appreciated the rubric and the permission to make some modifications. The researcher requested that they include at least three points about what would happen if the experiment was done at colder temperatures. There was a discussion about how students have time to reflect and to think about concepts as they write the lab report.

One group used Microsoft® Word® and the other group used Microsoft® PowerPoint® for the report and both are included (Appendix U). They enjoyed the option of format and the opportunity to work in groups. They thought the review was useful and they were grateful for the lack of pressure to produce a report that was very restrictive and highly competitive. They thought that restrictive and competitive lab reports were good on occasion but not on a weekly basis, as they are assigned. Upon completion of the reports the groups discussed the reports.

After the lab reports were complete, the session continued with a demonstration of bromthymol blue and Elodea (Appendix T). The researcher exhaled into the bromthymol blue
using a straw and the solution turned from blue to yellow in color. The Elodea was placed in the yellow solution and placed in the light. The researcher used the dry erase board to explain that as the Elodea used up the carbon dioxide in photosynthesis, the solution would return to blue. The Elodea was also placed into a solution of sodium bicarbonate, inverted and placed in the light. A bubble was formed in the tip of the tube. DPIP was also demonstrated to show the function of NADP⁺ reductase. On the dry erase board the reaction of DPIP⁺ (blue in color) forming DPIPH (clear in color) was explained. Chromatography was also done by all the participants and the Rf values were determined (Appendix T). There was a discussion about how cars can be powered with photosystem II.

The following concerns the fifth and sixth hours of instruction:

The participants performed a lab called “Photosynthesis: The Light Reaction Using Spinach disks,” (Appendix S). The participants read the lab and began to punch the spinach disks. The researcher explained the lab using the dry erase board. This lab tracked the production of oxygen from the photosystem II of the light reaction of photosynthesis. The oxygen is removed from the disks and when the disks are placed in the light, the oxygen causes the disk to be buoyant and to float to the top. The ones in the dark do not do the light reaction and do not produce oxygen and, thus, do not float. There was a discussion about how spinach is better than other types of leaves. The DPIP demonstration is related to the spinach disk experiment. The participants use the digital camera to take pictures of the disks that float. The chromatography experiment was continued and various plants, Tennessee Chinese Pepper, cucumber, spinach, purple cabbage, Wandering Jew, and tomato were used to analyze the different pigments in the various leaves. The principles of chromatography were discussed. The low Rf values of chlorophylls a and b were compared to the other pigments. The diversity of
pigments in the various plants allows for plants to live in various locations with different amounts of light. The advantages of C₄ plants was also discussed in relationship to diversity. Participants continued to collect the data from spinach lab. Biology AP Laboratory 12, Dissolved Oxygen and Aquatic Primary Productivity (Appendix T), was demonstrated and discussed. The relevance of algae and the use of screens to modify the amount of light and thus the amount of productivity were discussed. The issues of temperature and dissolved oxygen with respect to the viability of fish was discussed. The researcher used these topics to relate the importance of photosynthesis to the participants.

**Visual Fields**

The Comparison Group was introduced to the TIVF during Baseline interviews. The class and interviews from the semester’s start to Post Lecture interview was a common past visual field for all the students in the research, since they all attended Cell Biology 101 class. During the Baseline interviews and at Post Lecture, they spoke more about photosynthesis than cellular respiration. The researcher believes this was due to the fact that they never really studied cellular respiration in high school and had a very limited knowledge of it. Cellular respiration does not appear in the students’ responses until Post Strategy, since it was the first time they actually understood the process. Nick briefly mentioned the cellular respiration process in Post Lecture but it was probably due to his Biology AP background.

The students often used the term “jumbled” to indicate their level of confusion. This mostly occurs in the Baseline and Post Lecture. In Post Strategy and Delayed they refer more to their mind being “less jumbled” to indicate more organization and more understanding.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>How do you visualize your present experience with photosynthesis and cellular respiration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natasha</td>
<td>Jumbled in my head. Too much of it during the last few days. (Post Lecture)</td>
</tr>
<tr>
<td>Natasha</td>
<td>Starting to now change. (Post Strategy)</td>
</tr>
</tbody>
</table>
Nancy said at the Delayed interview that it will “become less jumbled even more specific. Mapping makes sense to me.” At the level of Post Strategy most students understood relationships rather than trying to memorize processes. Natalie described it as, “Hands-on experience with emphasis on understanding rather than memorization.”

This group rarely referred to application of photosynthesis and cellular respiration to their daily lives and research. Their lack of awareness of application contributed to them not achieving multidimensional literacy. The Comparison Group received hands-on instruction that encouraged understanding and not memorization, but it lacked the infrastructure of the visual fields and BDM learning strategies.

**Literacy**

**Baseline Phase.** Like the Merged BDM Group, the participants had little knowledge of cellular respiration and photosynthesis. They felt more comfortable with photosynthesis because they had more exposure to photosynthesis than cellular respiration in high school. They also had very little application knowledge. Although in the interviews they felt that their knowledge of photosynthesis and cellular respiration was high, their assessments showed otherwise. The Baseline Phase biological literacy analysis of the Comparison Group (as shown in Table 9) showed them universally at the nominal level in cellular respiration, while in photosynthesis four (evenly spaced between AP and nonAP) were at the functional level and five were at the nominal level yielding a mean score of 1.4.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>How do you visualize your present experience with photosynthesis and cellular respiration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nick</td>
<td>From my past high school to the present, I have no knowledge of photosynthesis and respiration. I have not studied them. I have learned some things along the way reading about medicine.</td>
</tr>
<tr>
<td>Nancy</td>
<td>Knowledge of it from last year is short term or gone. Presently, I do not know much. I learned it well. I am thinking and remembering.</td>
</tr>
</tbody>
</table>
Post Lecture Phase. This phase marked the end of cellular respiration and photosynthesis instruction in the Cell Biology 101 class. At the end of this phase, three members of the Comparison Group had increased their level of literacy to the structural level in cellular respiration while four had done so in photosynthesis. All of the other participants were at the functional level with no participants at the nominal literacy level. The Comparison Group had, at this time, an average biological literacy scores of 2.3 in cellular respiration and 2.4 in photosynthesis.

Researcher  How do you visualize your present experience with photosynthesis and cellular respiration?
Natasha   It is jumbled in my head. There was too much of it during the last few days. I will study from the book.
Norma Jean Learn it well enough to do well and not forget it the next day that would help future biology courses.

Post Strategy Phase. This period marked the end of the instruction in which they learned about the past, present, and future visual fields. There was a rise in group literacy level during this time with four participants at the structural level and five participants at the functional level in cellular respiration. In photosynthesis there were six participants at the structural level and three participants at the functional level.

Researcher  How do you visualize your or other peoples’ future experiences with photosynthesis and cellular respiration?
Norma Jean Know it well enough to do well on those parts of the MCAT. More in depth understanding. More detailed knowledge. Learned more biochemistry. I will ace sections of the MCAT with more in depth understanding of cycles and less confusion of little parts with more detailed knowledge.
Neka   Perhaps someone can figure out how to use in cars and address environmental issues.

Delayed Phase. The Delayed Phase took place two weeks after the Post Strategy Phase. Most participants experienced some decay in their subject knowledge during this time. At the time of the delayed evaluation, only one participant had retained a structural biological literacy
level while all but one other had remained at or fallen to a functional biological literacy level; the remaining participant had fallen to a nominal level. In photosynthesis, two participants maintained a structural literacy level while the remainder had remained at or fallen to a functional level. The overall literacy level average for the Comparison Group was 1.9 in cellular respiration and 2.2 in photosynthesis.
SUMMARY AND CONCLUSION

This study focused on teaching basic concepts of cellular respiration and photosynthesis using three technology-based curriculum components, collectively termed BioDatamation™ (BDM), and the Theory of Interacting Visual Fields™ to supplement traditional lecture presentations. The three components of BDM were: 1. WebQuest-style activities (Dodge, 1997; Watson, 1999) that used stories, animations, and hands-on laboratory demonstrations; 2. real-time data collection activities that monitored living systems under controlled conditions with electronic sensors, coupled with computers that allowed for simultaneous data display and analysis; 3. student constructed animated presentations on photosynthesis and cellular respiration, developed using commercially available animation programs, that required participants to integrate their knowledge and to propose solutions to problems.

The researcher developed laboratories (e.g., Making Kimchee: Tracking Microbes With Sensors, The Hunt for Red Mulch, Picturing Soil Microbes, Making Yogurt: The Heat Is On) and animations in the form of video and layered PowerPoint® presentations. Examples of the laboratories are in Appendix S and the PowerPoint® presentations in Appendix R.

By using layered and animated PowerPoint® slides, the first component allowed for knowledge from the past visual field to be integrated into the present visual field. It was hypothesized that this approach would lead to less cognitive overload, facilitate hierarchical organization of concepts, and improve recall. The second component engaged students in setting up experiments, predicting results, observing data output, and rapid hands-on data analysis. The quick repeatable experiments produced a computer graphic and provided almost immediate gratification. The third component, during which students constructed their own animated PowerPoint® presentation, required individual interpretation. Each student had to rearrange words and images in space, think in layers, and apply concepts to daily life.
The study group consisted of 24 volunteers recruited from an introductory level course in General Biology at a major American research university. Fifteen participants received BDM instruction in six phases (Cellular Respiration Past Visual Field, Cellular Respiration Present Visual Field, Cellular Respiration Future Visual Field, Photosynthesis Past Visual Field, Photosynthesis Present Visual Field, and Photosynthesis Future Visual Field). This group was called the Merged BDM Group. Of these fifteen, eight were selected for in depth individual analysis and this subgroup was called BDM Extended Analysis Subgroup. The Comparison Group consisted of nine participants and received traditional instruction. The average SAT score for the BDM Extended Analysis Subgroup was 1394, and 1300 for the Comparison Group. Each group had both students with and without an AP course background, and all had approximately equal biology knowledge at the Baseline and Post Lecture stages. Interviews were conducted after each of the six phases. During interviews, students created concept maps and visual fields diagrams with the researcher, and discussed BDM strategies.

The researcher designed mixed quantitative and qualitative assessment methods. The quantitative component consisted of an analysis of multiple-choice questions from 263,267 examinations from the 1990, 1994, 1999, and 2002 Biology Advanced Placement Examinations. Problem concepts were identified, (e.g. Where does the water come from? Do both plants and animals perform cellular respiration?). The original video clips, animations, classroom demonstrations, and laboratory exercises comprising the BDM strategy were developed to address concepts where students showed serious deficiencies. See Appendices R, S, and T for details concerning the content of BDM.

“Value added” is stipulated to mean the increase of knowledge and long-term memory of concepts. Applying the Theory of Interacting Visual Fields™, “value added” is correlated with
an improvement in biological literacy. The case study methods of Yin (2003) were used to assess knowledge construction and to determine the taxonomy of a BDM learner. The taxonomy of a BDM learner includes technology, metacognitive strategies, and the three visual fields as the major components.

The research was centered on a main research question and three subquestions. The following are the answers to the questions as determined from the current research.

The main research question was: What was the value added by each of the three instructional technology-based curriculum components comprising the BioDatamation™ strategy to selected introductory college biology students’ conceptual understanding and conceptual integration of the processes of photosynthesis and cellular respiration?

The value added to the Merged BDM Group learning was an increase of knowledge and long-term memory of the concepts and very often (59% for cellular respiration and 64% for photosynthesis) an improvement in biological literacy to the level of multidimensional biological literacy with the use of the Theory of Interacting Visual Fields™. The Comparison Group had 0% achieve multidimensional biological literacy for cellular respiration and photosynthesis.

The overall value added to cellular respiration literacy in the Merged BDM Group between Post Lecture and Post BDM Strategy instruction was 39% to cellular respiration and 43% to photosynthesis. There was also a value added over the Delayed Phase. The value added between Post Strategy and the Delayed Phase was 13% for cellular respiration and 13% for photosynthesis. The average change in biological literacy in photosynthesis and cellular respiration between Post Lecture and the Delayed Phase was 62%. The value added over the two week delay seems to have occurred because the participants had time to use their knowledge in daily life and to see more examples of its application. During instruction of cellular respiration,
there was the largest value added during the past visual field and present visual field instruction periods and participants had the greatest change in biological literacy in these periods. During photosynthesis instruction there was the largest value added between the Post Lecture analysis and the past visual field analysis. There was little value added to literacy between the present visual field and the future visual field for both cellular respiration and photosynthesis. From the clinical interviews, it seems that the students thought the value added to their knowledge during these phases was added to long-term memory due to the interaction with and application of the concepts.

In contrast to the Merged BDM Group was the Comparison Group, which was taught with traditional strategies, which lacked the infrastructure of BDM strategies. There was a 4% increase in knowledge of cellular respiration and a 9% increase in photosynthesis between the Post Lecture and the Post Strategy Phases. There was a decay in biological literacy between the Post Strategy and the two week Delayed Phase of -23% for cellular respiration and -17% for photosynthesis. The average decay in biological literacy for photosynthesis and cellular respiration between Post Lecture and Delayed Phase was -20%. Participants in the Comparison Group were not exposed to concept applications and only one participant reached multi-dimension literacy. In the absence of awareness of application, the participants did not use concepts outside of instruction. Lack of use prevents rehearsal which is instrumental to memory.

The taxonomy of the BDM learner uses tools including technology, metacognitive strategies, and all visual fields to learn. The TIVF is used in conjunction with technology and metacognitive strategies to maximize meaningful learning.

Additional subquestions were what value does each of the following curriculum components add to students’ existing conceptual understanding and integration of the process of photosynthesis and cellular respiration:
1. WebQuest–style activities (Dodge, 1997; Watson, 1999) that use stories, animations, and carefully designed hands-on live biological experiences that together serve to introduce and exemplify the constructs of photosynthesis and cellular respiration.

These components allowed for animated prior knowledge in the past visual field and detailed content knowledge construction in the present visual field through animated layered encoding of concepts which laid a deeper trace. Visual explanation of the custom BDM animated and layered PowerPoint® slides and data collection allowed for hierarchical organization, less cognitive overload and greater recall.

2. Real-time data collection inquiry experiences (Brasell, 1990) using living systems and electronic sensors coupled with real-time display and analysis with calculators/computers.

This component allowed participants to animate detailed content knowledge and allowed participants to set up experiments, predict results, observe, and perform hands-on data analysis to relate the concept to the data. It was quick, repeatable, and produced a personalized graphic and immediate gratification. It was an individual experience.

3. Scientifically valid, student-constructed, real-world based, photosynthesis and cellular respiration animations using commercially available animation programs, and demonstration of these animation products to peers.

Application of knowledge to achieve practical solutions to a problem allowed participants to think in layers, to think out the process, and to apply concepts to daily life. The decision making required interpretation of the concepts. The construction of an animated PowerPoint® presentation utilized layering that required participants to think out the process by rearranging words and images in space which allowed for hierarchical organization of knowledge. Proposing solutions to problems required participants to apply the concepts to real life.
The limitations of the study include: small sample size, full professor as instructor, college population atypical of larger American public universities, highly selective admissions, and short duration of the units on photosynthesis and cellular respiration. The study was not designed to take into account the fortuitous unexpected finding that traditional chalk or dry erase board use could be considered animated presentation. Despite this oversight, this study indicates that use of random animation does not have the synergistic effect of BDM animations.

Future research includes the determination of the generalization of BDM strategies with visual fields to other biology themes, other sciences, and other disciplines. Other research would implement BDM based instruction as the sole input, whether it could have remote delivery and with varying levels of technology.

BDM research addresses the NRC concern that, “The ways in which most future research biologists are educated are geared to the biology of the past, rather than to the biology of the future” (NRC, 2003, p. 1). BDM research demonstrated that gaining integrative knowledge through the implementation of the BDM Theory of Integrated Visual Fields™ with BDM technology-scaffolded instructional components ensures both increased retention and continued development of concept application. The BDM participants now see the world through biology concepts.
REFERENCES


APPENDIX A:

LSU IRB APPLICATION WITH APPROVAL FORM
IRB #: 2690  LSU Proposal #: ____________  Revised: 06/11/2003

LSU INSTITUTIONAL REVIEW BOARD (IRB) for HUMAN RESEARCH SUBJECT PROTECTION
578-8692 FAX 6792
Office: 203 B-1 David Boyd Hall

APPLICATION FOR EXEMPTION FROM INSTITUTIONAL OVERSIGHT

Unless they are qualified as meeting the specific criteria for partial or full Institutional Review Board (IRB) oversight, ALL LSU research/education involving living human subjects, or samples or data obtained from humans, directly or indirectly, with or without their consent, must be approved or exempted in advance by the LSU IRB. This form helps the PI determine if a project may be exempted, and is used to request an exemption.

Instructions: Complete this form.

Exemption Applicant: If it appears that your study qualifies for exemption send:

(A) Two copies of this completed form,
(B) a brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts A & B),
(C) copies of all instruments to be used. If this proposal is part of a grant proposal include a copy of the proposal and all recruitment material.
(D) the consent form that you will use in the study
to: ONE screening committee member (listed at the end of this form) in the most closely related department/discipline or to IRB office.

If exemption seems likely, submit it. If not, submit regular IRB application. Help is available from Dr. Robert Mathews, 578-8692, irb@lsu.edu or any screening committee member.

Principal Investigator  Jewel J. Reuter  Student? Y Y/N

Ph: 504-606-1039  E-mail jewelreuter@earthlink.net  Dept/Unit Curriculum and Instruction

If student, name supervising professor Jim Wandersee  Ph: 225-578-2346

Mailing Address LSU, Dept. of Curriculum and Instruction, 223-P Peabody Hall, Baton Rouge, LA 70803  Ph: 225-578-2346

Project Title Using the BioDatamation Strategy to Learn Introductory College Biology: Value-Added Effects on Selected Students' Conceptual Understanding and Conceptual Integration of the Processes of Photosynthesis and Respiration

Agency expected to fund project None

Subject pool (e.g. Psychology Students) Biology Students

Circle any "vulnerable populations" to be used: (children <18; the mentally impaired, pregnant women, the aged, other). Projects with incarcerated persons cannot be exempted.

I certify my responses are accurate and complete. If the project scope or design is later changed I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted.

PI Signature  Date 3/16/04 (no per signatures)
Part A: DETERMINATION OF "RESEARCH" and POTENTIAL FOR RISK

This section determines whether the project meets the Department of Health and Human Services definition of "research" and if not, whether it nevertheless presents more than "minimal risk" to humans that makes IRB review prudent and necessary.

1. Is the project a systematic investigation designed to develop or contribute to generalizable knowledge?

(Note "systematic investigation" includes "research development, testing and evaluation"; therefore some instructional development and service programs will include a "research" component).

☐ YES

☐ NO

2. Does the project present physical, psychological, social or legal risks to the participants reasonably expected to exceed those risks normally experienced in daily life or in routine diagnostic physical or psychological examination or testing? You must consider the consequences if individual data inadvertently become public.

☐ YES Stop. This research cannot be exempted—submit application for IRB review.

☒ NO Continue to see if research can be exempted from IRB oversight.

3. Are any of your participants incarcerated?

☐ YES Stop. This research cannot be exempted—submit application for IRB review.

☒ NO Continue to see if research can be exempted from IRB oversight.

Part B: EXEMPTION CRITERIA FOR RESEARCH PROJECTS

Research is exemptable when all research methods are one or more of the following five categories. Check statements that apply to your study:

☒ 1. In education setting, research to evaluate normal educational practices.
The research must also comply with all of the following:

□ a) It is directly conducted or approved by the head of a US Govt. department or agency.

□ b) It concerns only issues under usual administrative control (48 Fed Reg 9268-9), e.g., regulations, eligibility, services, or delivery systems;

□ c) Its research/evaluation methods are also exempt from IRB review.

6. For research not involving vulnerable volunteers [see "2 & 3" above], do food research to evaluate quality, taste, or consumer acceptance.

The research must also comply with one of the following:

□ either that

□ a) the food has no additives;

□ b) the food is certified safe by the USDA, FDA, or EPA.

NOTE: Copies of your IRB stamped consent form must be used in obtaining consent. Even when exempted, the researcher is required to exercise prudence in protecting the interests of research subjects, obtain informed consent if appropriate, and must conform to the Ethical Principles and Guidelines for the Protection of Human Subjects (Belmont Report), 45 CFR 46, and LSU Guide to Informed Consent; (Available from OSP or http://app1022.lsu.edu/osp/osp.nsf/$Content/LSU%20IRB%20Documents)

HUMAN SUBJECTS SCREENING COMMITTEE MEMBERS can assist & review:

COLLEGE OF ARTS AND SCIENCES:

Dr. Lezman * (Psych) 578-4118 Dr. Nelson (Mass C) 578-6686
Dr. Geiselman * (Psych) 763-2695 Dr. Archambeault (Soc Wk) 8-1374
Dr. Beggs (Socio) 578-1119 Dr. Rose (Soc Wk) 578-1015
Dr. Honeycutt (Speech) 578-6676 Dr. Keenan* (Hum Ecol) 578-1708
Dr. Dixit (Comm Sc./Dis) 578-3938 Dr. Belleau (Hum Ecol) 578-1535

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<td>Dr. Kleiner (Middleton) 578-2217</td>
<td>Dr. Biswas (Marketing) 578-2217</td>
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<td>Dr. Culross (Education) 578-2254</td>
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<td>Dr. Landin* (Kinesiol) 578-2916</td>
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<td>Dr. MacGregor (ELRC) 578-2150</td>
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<td>Dr. Munro* (Curric &amp; I) 578-2352</td>
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(* = IRB member)
APPENDIX B:

LSU IRB APPROVED ABSTRACT OF STUDY
Abstract of Study

Project Title:
Using the BioDatamation™ Strategy to Learn Introductory College Biology: Value-Added Effects on Selected Students' Conceptual Understanding and Conceptual Integration of the Processes of Photosynthesis and Respiration

Investigators:
Student Principle Investigator: Jewel Reuter, Doctoral Candidate of Science Education, LSU; Faculty Supervisor/Principle Investigator, Dr. James H. Wandersee

Description of Study:

A) Purpose of the study:
The purpose of the research is to study how students learn photosynthesis and cellular respiration and to determine the value added to the student's learning by each of the three technology learning strategies (animated concept presentations and WebQuests, data collection and student constructed animations) of the BioDatamation™ Program. Photosynthesis and cellular respiration are normal parts of the course.

B) Description of the Subjects:
The subjects are 16 underclassman students enrolled in an introductory level General Biology course at a four-year college that is a major American research university and is a member of the Association of American Universities. The University is accredited by the Commission on Colleges of the Southern Association of Colleges and Schools to award bachelor's, master's, and doctoral degrees. The university is also accredited by the Louisiana State Department of Education.

C) Justification for Using This Subject Population:
This is the population of students that study introductory level college biology.

D) Subject Recruitment Procedures:
All 16 students in an introductory college level biology course will be invited to volunteer to participate in the study. Interviews will be conducted to select four students of high and four of low academic ability instructed with the BioDatamation™ learning strategies and interviews. Also, a second group of eight students of similar academic profile will be selected for evaluation with pre and post BDM interviews, but they will not receive BDM instruction.

E) Detailed Description of the Procedures to Be Used:
Eight students will be involved in six phases of BioDatamation™ instructional activities and interview after each phase, and another eight students will meet for six phases of non-BioDatamation™ activities and interviews. Pseudonyms will be used to identify them during the interviews. The interviews will include the student's creation of concept maps, visual field diagrams and narrated PowerPoint presentation. Pseudonyms will always be used for identification. There will be a total of nine sessions each lasting two hours.
F) Description of the Procedures for Obtaining Consent of Subjects or of Parents/Guardians and Assent of Minor Subjects:
Students will receive a letter/consent form describing the research, risks/benefits, procedures, etc. The information consent form will be review with the student in class, and the students will sign the consent form after they are selected.

G. Description of the Procedures to Be Used to Protect the Identity and Privacy of the Subjects
All students will be recorded and reported using pseudonyms in place of their names. All video and data collected will remain in possession of the investigator. At the completion of the project, subjects will be asked, but not required to grant the investigator permission to use video segments in academic presentations, which may or may not include the subject's likeness.

H. Procedures to Be Used in the Study
Eight students will be involved in six phases of BioDatamtion™ instructional activities and interview after each phase, and another eight students will meet for six phases of non-BioDatamtion™ activities and interviews. Pseudonyms will be used to identify students during the interviews. The interviews will include the student's creation of concept maps, visual field diagrams and narrated PowerPoint® presentation. Pseudonyms will always be used for identification. There will be a total of ten sessions each lasting two hours. Six sessions will involve instructional activities and interviews and four other sessions will involve interviews to determine the knowledge of the students immediately before and immediately after class instruction, to determine the students' understanding of the relationship of photosynthesis and cellular respiration immediately after the study and after a delay of the study.

I. Debriefing Procedures
At the end of the study, students who were interviewed will be provided copies of concept maps that they constructed during the interviews. All students will be thanked for their participants, and the use of their data will again be explained, explaining their protection of privacy.

J. Any Potential Risks to Subjects and Measures to Be Used to Minimize Risks
The only possible risk involved is if the identity of the student would be revealed and they were embarrassed. All student data will be given pseudonyms or numbers to protect their identity.

Project Director: Student Investigator: Jewel J. Reuter, Doctoral Candidate of Biology Education, LSU, telephone number: (504) 606-1039, e-mail address: jewelreuter@earthlink.net; Advisor: Dr. James H. Wandersee, Professor of Biology Education, LSU, telephone number: (225) 578-2348, e-mail address: jwander@lsu.edu.

Purpose of the Research: The purpose of the research is to study how students learn photosynthesis and respiration and to determine the value added to the student's learning by each of the three technology learning strategies (animated concept presentations and WebQuests, data collection and student constructed animations) of the BioDatamation™ Program.

Procedures for the Research: There will be two groups of eight students Dr. Joan Bennett’s General Biology class of Tulane University. One group will be involved in six phases of BioDatamation™ instructional activities and interview after each phase. Pseudonyms will be used to identify them during the interviews. The interviews will include a survey, the student's creation of concept maps, visual field diagrams and narrated PowerPoint presentation. Pseudonyms will always be used for identification. There will be a total ten sessions each lasting two hours. The other group of eight students will meet for the same amount of time and will be presented non-BioDatamation instructional activities and interview sessions. The interviews will include a survey, the student's creation of concept maps and visual field diagrams.

Potential Risks: There are no medical, personal, social or academic risks anticipated in this study. The only possible risk involved is if your identity and performance would be inadvertently revealed and you would feel embarrassed. The possibility of this occurring is approximately 0% since you and all participants will be given a pseudonym or number as identification to protect your identity. Participants are welcome to contact the researcher at any time to discuss concerns about perceived risks. Your grade in this course or any other will not be adversely affected by participation in this project.

Potential Benefits: As a result of this study students will have a better understanding of the concepts of photosynthesis and respiration. Students will also increase their technology skills and have a better understanding of the learning process.

Alternative Procedures: There are no alternative procedures for collecting these data. Your participation is entirely voluntary and you may withdraw consent and terminate participation at any time without consequence.

Protection of Confidentiality: Some sessions will be videotaped for the purpose of data collection. These videos and all data collected will be in the sole possession of the student.
investigator named above. Transcriptions and all subsequent analysis and public presentations of
the data (in journals and presentations) will use identifying pseudonyms.

The study has been discussed with me and all my questions have been answered. I may direct
additional questions regarding study specifics to the investigators. If I have questions about
subjects' rights or other concerns, I can contact Robert C. Mathews, Chairman, LSU Institutional
Review Board, (225) 578-8692. I agree to participate in the study described above and
acknowledge the researchers’ obligation to provide me with a copy of this consent form if signed
by me.

*I have been fully informed of the above-described procedure with its possible benefits and risks
and I give my permission for participation in the study.*

____________________________________  ________________________________
signature                                                                 printed name

____________________________________
date
APPENDIX C:

LSU IRB INTERVIEW PROTOCOL
INTERVIEW PROTOCOLS

Phase 1 (Pre-Interview Preparation)
Quantitative analysis of Biology AP Exam multiple choice item analysis to help to determine misconception.

Phase 2 (Introduction/Baseline- Interview A)
The following data are gathered at the beginning of the course before photosynthesis and respiration are taught to the class and is administered to all 16 participants.

1. Introductions about the BDM study.
2. Provide agenda and information about the study.

Steps 3-6 pertain to the details of the clinical interviews.
-Pre (baseline) Individual Interview- Photosynthesis and respiration and their relationship and pre-visual field measurement determined by Individual Interviews as outlined below (45 min/student)

3. Think-aloud initial activity to determine literacy level: material sorting tasks (Bread, piece of wood, head of cabbage, yogurt, doodle bugs, cup of water, flash light, cup of soil, plant in a jar with top close tightly, animal in a jar with top close tightly, jar of Kimchee, Ziplock® bag label with oxygen, Ziplock® bag label with carbon dioxide, mushroom, red bean) (10 min)
   A. Sort the objects into living or at one time living and non-living and explain why.
   B. Sort the objects into categories of photosynthesis and respiration and explain why.

4. Term sorting task and modified co-concept mapping using dragging and dropping of terms on a computer screen using graphic software (10 min)

**Overall Terms**

**Cellular Respiration:** fermentation, cellular respiration, glycolysis, ATP, redox reaction, glucose, oxygen, carbon dioxide, water, glycolysis, Krebs Cycle, electron transport, chemiosmosis, NAD⁺ → NADH, ATPase, dehydrogenase, oxidative phosphorylation, substrate level phosphorylation, endergonic and exergonic reactions, aerobic and anaerobic, alcoholic fermentation, lactic acid fermentation, biosynthesis

**Photosynthesis:** autotrophy, heterotrophic, chlorophyll, mesophyll, chlorophyll, carbon dioxide, water, light, glucose, oxygen, water, splitting of water, photophosphorylation, ATP, NADPH, electromagnetic spectrum, Visible light, photons, action spectrum, excitation, photosystems, reaction center, primary electron acceptor, photosystem I, photosystem II, thylakoid, G3P, Rubisco, Calvin cycle

A. Choose the concepts that you recognize from the left side of the screen.
B. Give a simple oral definition of each term.
C. Now we will create a map that shows how you think about the concepts and how they are related. We will begin with the most general idea on too and then take the others and group them under the most general idea to work our way to the most specific ideas.
D. Now type a linking work between each pair of words that tells the relationship between the terms.
E. Are there any change that you would like to make in you map (arrangement, concepts or links).
5. Interpreting situation with the chloroplast and mitochondria models.
A. Compare and contrast the parts of the chloroplast and the mitochondria for the photosynthesis and respiration interview.
B. For the respiration interview

6. Using the Visual Field Mapping Instrument
Visualizing is a mental image of what you know or understand.
A. From the past what do you visualize about your experiences with photosynthesis and respiration?
B. How do you visualize your present experience with photosynthesis and respiration?
C. How do you visualize your or other people’s future experiences with photosynthesis and respiration?
D. How do your visualizations the past, present and future help you understand photosynthesis and respiration concepts?

7. Students take Photosynthesis and Respiration Survey which is included in this IRB.
8. Pre-BDM Introduction Instruction to briefly explain concept mapping, visual fields, WebQuests, data collection and PowerPoint.

Phase 3 (Knowledge After Class Presentations- Interview B)
The above will be repeated with all participants after the normal class material on photosynthesis and respiration are presented.

Phases 4 – 10 (BDM Phases of Instruction and Interviews C- I)
The following summarizes the BDM instructional content and student tasks. In phases 4 -10 there will be BDM instruction and then interviews that follow the interview protocol of Phase 2 steps 3 -6. Only those eight students that receive BDM instruction will participate in these phases.
The following is a summary of phases 4 – 10:

Phase 4 (Respiration Past)
>Pre BDM Respiration Interview
> Past Visual Field Respiration Individual Instruction (WebQuest and brief videos) (1 hour maximum/student)
> Past Visual Field Respiration Individual Interviews as outlined above (1 hour/student)

Phase 5 (Respiration Present)
> Present Visual Field Respiration Individual Instruction (data collection and brief videos) (1 hour maximum/student)
> Present Visual Field Respiration Individual Interviews as outlined above (1 hour/student)

Phase 6 (Respiration Future)
> Future Visual Field Respiration Individual Instruction (animated and annotated student PowerPoints related to a real world problem) (1 hour maximum/student)
> Future Visual Field Respiration Individual Interviews as outlined above (1 hour/student)
Phase 7 (Photosynthesis Past)
> Past Visual Field Photosynthesis Individual Instruction (WebQuest and brief videos) (1 hour maximum/student)
> Past Visual Field Photosynthesis Individual Interviews as outlined above (1 hour/student)

Phase 8 (Photosynthesis Present)
> Present Visual Field Photosynthesis Individual Instruction (data collection and brief videos) (1 hour maximum/student)
> Present Visual Field Photosynthesis Individual Interviews as outlined above (1 hour/student)

Phase 9 (Photosynthesis Future)
> Future Visual Field Photosynthesis Individual Instruction (animated and annotated student PowerPoints related to a real world problem) (1 hour max./student)
> Future Visual Field Photosynthesis Individual Interviews as outlined above (1 hour/student)

Phase 10 (Post Photosynthesis and Respiration Relationship Knowledge and BDM Analysis)
> Post (final)- Photosynthesis and respiration relationship and post-visual field measurement determined by Individual Interviews as outlined above (45 min/student)
> Analysis of BDM learning strategies (45 min/student)

Phase 11 (Delayed Post Instruction)
> Respiration, photosynthesis, relationship of respiration and photosynthesis and visual field measurement, overall comments about BDM learning strategy individual interview (1 hour/student)

This phase will be administered to the group that receives BioDatamation™ instruction and the group that does not receive instruction.
Questionnaire

Directions:
- You are to asked to answer the following questions for research purposes. Answer in the question is optional, but your responses will better help us understand how student learn photosynthesis and respiration.
- Your responses will not affect your exam grade in any way.
- Circle your choices directly in this sheet.
- It may be helpful to make notes and diagrams in the margins to help you think about the question.
- Do not answer questions that you have not read.

1. A student using a light microscope observes a cell and correctly decides that it is a plant cell because
   A. ribosomes are visible
   B. an endoplasmic reticulum can be seen
   C. a cell membrane is present
   D. it has a large central vacuole
   E. centrioles are present
   **Explain why your answer is correct.**
   _______________________________________________________________________
   _______________________________________________________________________
   _______________________________________________________________________
   _______________________________________________________________________
   _______________________________________________________________________

2. Oxygen consumption can be used as a measure of metabolic rate because oxygen is
   A. necessary for ATP synthesis by oxidative phosphorylation
   B. necessary to replenish glycogen levels
   C. necessary for fermentation to take place
   D. required by all living organisms
   E. required to break down the ethanol that is produced in muscles
   **Explain why your answer is correct.**
   _______________________________________________________________________
   _______________________________________________________________________
   _______________________________________________________________________
   _______________________________________________________________________
   _______________________________________________________________________

3. During respiration, most ATP is formed as a direct result of the net movement of
   A. potassium against a concentration of gradient
   B. protons down a concentrations gradient
   C. electrons against a concentration gradient
   D. electrons through a channel
   E. sodium ions into the cell
   **Explain why your answer is correct.**
   _______________________________________________________________________
   _______________________________________________________________________
   _______________________________________________________________________
   _______________________________________________________________________
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4. Which of the following pathways for the transformation of cellular energy most likely evolved first?
   A. Cyclic photophosphorylation
   B. Citric acid (Krebs) cycle
   C. Calvin cycle
   D. C₄ photosynthesis
   E. Glycolysis
   **Explain why your answer is correct.**

5. On a sunny day, the closing of stomata in plant leaves results in
   A. a decrease in CO₂ intakes
   B. a shift from C₃ photosynthesis to C₄ photosynthesis
   C. an increase in transpiration
   D. an increase in the concentration of CO₂ in mesophyll cells
   E. a increase in the rate of production of starch
   **Explain why your answer is correct.**

6. Process in which O₂ is released as a by-product of oxidation-reduction reactions
   A. Glycolysis
   B. Krebs cycle (citric acid cycle)
   C. Calvin cycle (light-independent reactions of photosynthesis)
   D. Light-dependent reactions of photosynthesis
   E. Chemiosmosis
   **Explain why your answer is correct.**

7. Process in which CO₂ is released as byproduct of oxidation-reduction reactions
   A. Glycolysis
   B. Krebs cycle (citric acid cycle)
   C. Calvin cycle (light-independent reactions of photosynthesis)
   D. Light-dependent reactions of photosynthesis
   E. Chemiosmosis
8. Process in which carbon from CO₂ is incorporated into organic molecules
A. Glycolysis
B. Krebs cycle (citric acid cycle)
C. Calvin cycle (light-independent reactions of photosynthesis)
D. Light-dependent reactions of photosynthesis
E. Chemiosmosis

**Explain why your answer is correct.**


9. Process found in both photosynthesis and cellular respiration
A. Glycolysis
B. Krebs cycle (citric acid cycle)
C. Calvin cycle (light-independent reactions of photosynthesis)
D. Light-dependent reactions of photosynthesis
E. Chemiosmosis

**Explain why your answer is correct.**


10. Process in which sugar is oxidized to pyruvic acid
A. Glycolysis
B. Krebs cycle (citric acid cycle)
C. Calvin cycle (light-independent reactions of photosynthesis)
D. Light-dependent reactions of photosynthesis
E. Chemiosmosis

**Explain why your answer is correct.**


11. What is your past biology experience in high school?
12. What is your intended degree major?

13. What are your career goals and explain why you selected your career choice?

14. Comments about the above questions.
APPENDIX E:

LSU IRB CONSENT FORM

Project Director: Student Investigator: Jewel J. Reuter, Doctoral Candidate of Biology Education, LSU, telephone number: (504) 606-1039, e-mail address: jewelreuter@earthlink.net; Advisor: Dr. James H. Wandersee, Professor of Biology Education, LSU, telephone number: (225) 578-2348, e-mail address: jwander@lsu.edu.

Purpose of the Research: The purpose of the research is to study how students learn photosynthesis and respiration and to determine the value added to the student's learning by each of the three technology learning strategies (animated concept presentations and WebQuests, data collection and student constructed animations) of the BioDatamation™ Program.

Procedures for the Research: There will be two groups of eight students Dr. Joan Bennett’s General Biology class of Tulane University. One group will be involved in six phases of BioDatamtion™ instructional activities and interview after each phase. Pseudonyms will be used to identify them during the interviews. The interviews will include a survey, the student's creation of concept maps, visual field diagrams and narrated PowerPoint presentation. Pseudonyms will always be used for identification. There will be a total ten sessions each lasting two hours. The other group of eight students will meet for the same amount of time and will be presented non-BioDatamation instructional activities and interview sessions. The interviews will include a survey, the student's creation of concept maps and visual field diagrams.

Potential Risks: There are no medical, personal, social or academic risks anticipated in this study. The only possible risk involved is if your identity and performance would be inadvertently revealed and you would feel embarrassed. The possibility of this occurring is approximately 0% since you and all participants will be given a pseudonym or number as identification to protect your identity. Participants are welcome to contact the researcher at any time to discuss concerns about perceived risks. Your grade in this course or any other will not be adversely affected by participation in this project.

Potential Benefits: As a result of this study students will have a better understanding of the concepts of photosynthesis and respiration. Students will also increase their technology skills and have a better understanding of the learning process.

Alternative Procedures: There are no alternative procedures for collecting these data. Your participation is entirely voluntary and you may withdraw consent and terminate participation at any time without consequence.
Protection of Confidentiality: Some sessions will be videotaped for the purpose of data collection. These videos and all data collected will be in the sole possession of the student investigator named above. Transcriptions and all subsequent analysis and public presentations of the data (in journals and presentations) will use identifying pseudonyms.

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Chairman, LSU Institutional Review Board, (225) 578-8692. I agree to participate in the study described above and acknowledge the researchers’ obligation to provide me with a copy of this consent form if signed by me.

I have been fully informed of the above-described procedure with its possible benefits and risks and I give my permission for participation in the study.

____________________________      ______________________________
signature                                                             printed name

___________________________
date
APPENDIX F:

EU IRB REQUEST AND APPROVAL LETTER
REQUEST FOR EXPEDITED IRB REVIEW

INSTRUCTIONS: This form may be submitted to request an expedited IRB Review if the research being conducted corresponds with one or more of the categories listed on the attached page. Please indicate on page 2 the category in which the project qualifies and write a justification in the space provided below explicitly indicating how the project corresponds to the designated expedited category. A completed protocol form, along with copies of survey instruments, interview schedules, etc., must be submitted with this form. Failure to submit these supporting documents will only delay a decision. The decision to expedite review will be made by representatives of the Institutional Review Board.

Project Title: Using the BioDatamation(TM) Strategy to Learn Introductory College Biology

Signatures of Energy University Officials

Date: 3-31-04

Signature of Faculty Advisor (if applicable)

Justification/Explanation: See category E7.

Energy University IRB Mailing Information
REQUEST FOR EXPEDITED IRB REVIEW

Research activities involving no more than minimal risk, and in which the only involvement of human subjects will be in one or more of the following categories (carried out through standard methods) may be reviewed by the Institutional Review Board through expedited review procedure, authorized in §46.110 of CFR Part 46 (see Footnote). Expedited review also may be used for minor changes of previously approved research during the period (of one year of less) for which the approval is authorized.¹

Under an expedited review procedure, the review will be conducted by the IRB chair or by the chair and one designated IRB reviewer. In reviewing the research, the reviewers may exercise all of the authorities of the IRB except that the reviewers may not disapprove the research. A research activity may be disapproved only after review in accordance with the non-expedited procedure set forth in §46.108(b).

Please checkmark the applicable category²

☐ (A3) Prospective collection of biological specimens for research purposes by noninvasive means. Examples: (a) hair and nail clippings in a nondisfiguring manner; (b) deciduous teeth at time of exfoliation or if routine patient care indicates a need for extraction; (c) permanent teeth if routine patient care indicates a need for extraction; (d) excreta and external secretions (including sweat); (e) uncannulated saliva collected either in an unstimulated fashion or stimulated by chewing gumbase or wax or by applying a dilute citric solution to the tongue; (f) placenta removed at delivery; (g) amniotic fluid obtained at the time of rupture of the membrane prior to or during labor; (h) supra- and subgingival dental plaque and calculus, provided the collection procedure is not more invasive than routine prophylactic scaling of the teeth and the process is accomplished in accordance with accepted prophylactic techniques; (i) mucosal and skin cells collected by buccal scraping or swab, skin swab, or mouth washings; (j) sputum collected after saline mist nebulization.

☐ (B4) Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.) Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subject's privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual.

☐ (C5) Research involving materials (data, documents, records, or specimens) that have been collected, or will be collected solely for nonresearch purposes (such as medical treatment or diagnosis).
(D6) Collection of data from voice, video, digital, or image recordings made for research purposes.

(E7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

(F8) Continuing review of research previously approved by the convened IRB as follows: (a) where (i) the research is permanently closed to the enrollment of new subjects; (ii) all subjects have completed all research-related interventions; and (iii) the research remains active only for long-term follow-up of subjects; or (b) where no subjects have been enrolled and no additional risks have been identified; or (c) where the remaining research activities are limited to data analysis.

Footnote 1: Expedited review procedures do not apply to research: (1) involving prisoners, fetuses, pregnant women, other dependent populations, or human in vitro fertilization; (2) involving children except for research limited to observations of public behavior when the investigators do not participate in the activities being observed; (3) in which identification of participants and/or their responses would reasonably place them at risk of criminal or civil liability or be damaging to their financial standing, employability, insurability, reputation, or be stigmatizing, unless reasonable and appropriate protections will be implemented so that risks related to invasion of privacy and breach of confidentiality are no greater than minimal.

Footnote 2: Energy University’s Statement about invasive procedures.
REQUEST FOR EXPEDITED IRB REVIEW, Energy University, page 4

Answer all items. Failure to include the requested information and documentation will prevent IRB consideration of your protocol.

Project Title: Using the BioDatamation(TM) Strategy to Learn Introductory College Biology

1. Purpose of the proposed study?

The purpose of the research is to study how students learn photosynthesis and respiration and to determine the value added to each student's learning by each of the three technology learning strategies (animated concept presentations and WebQuests, data collection and student constructed animations) of the BioDatamation(TM) Program. Photosynthesis and respiration are normal parts of the course.

2. Describe participant population and procedures for recruiting participants.
   (Attach a copy of any letter or other material used to solicit institutional and/or individual participation.)

   The subjects are 16 underclassman students enrolled in introductory level General Biology course (Cell-101). The entire class will be invited with a verbal announcement to volunteer to participate in the study. Interviews will be conducted to select eight students of high and eight of low academic ability and the details of the research will be provided in written form to each student interviewed. All participants will be 18 years or older.

3. Is this study a complete replication or extension of a prior study? Yes ☐ No ☑
   (If yes, provide the approval number, investigator name, and date of the original study.)

4. Will subjects' name or other identifiers potentially enabling an individual's identity be required? (If yes, fully describe procedures to be used to insure subjects' confidentiality. Except in Category 2 or 4, exempt research need not be anonymous, if reasonable protections of confidentiality are made.) Yes ☐ No ☑
5. Check the appropriate box for each of the following questions. If the answer to any item in #5 is "yes", then the research is not appropriate for exempt status. In this instance, please follow the procedures for "non-exempt, non-expedited" research.

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<td>Does the research involve minors?</td>
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<td>b.</td>
<td>Does the research involve fetuses, pregnant women, or in-vitro fertilization?</td>
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<td>c.</td>
<td>Does the research involve any dependent populations (e.g. prisoners)?</td>
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<td>d.</td>
<td>Will participants be subject to any physical or psychological stress beyond that associated with normal social interactions and discourse?</td>
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<td>e.</td>
<td>Will participants be subject to more than minimal physical or psychological risk?</td>
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<td>Will participants be tested or observed without their knowledge or consent?</td>
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<td>g.</td>
<td>Will participants be deceived or misinformed in any way?</td>
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6. Does the principal investigator or any other person responsible for the design, conduct, or reporting of this research have any economic interest in, or act as an officer or director of, any outside entity whose financial interests would reasonably appear to be affected by the research (If "yes", please explain. Use separate sheet if necessary)

No

7. Are you applying for, or currently receiving, support for this research from the National Institutes of Health? (If "yes", please provide for each individual identified as "key personnel" a description of education completed in the protection of human subjects. Use separate sheet if necessary.)

No

- Attach complete copies of any instruments (e.g., questionnaires, interviews) and stimuli which will be used with participants.

- Attach complete copies of information to be distributed to subjects regarding the purpose of the study, description of risk(s), procedures by which participants may contact investigators with questions and gain access to findings.

- Include a copy of the actual "consent form(s)" to be used when obtaining participant's agreement to participate (and allow audio or audio taping).

NOTE: If tacit or implicit consent is to be used, please describe procedures and provide documentation indicating how subjects will be apprised.
APPENDIX G:

EU IRB CONSENT FORM
Energy University – Photon USA
Institutional Review Board for Human Research
Consent Form

Study Name:
Using the BioDatamation™ Strategy to Learn Introductory College Biology: Value-Added Effects on Selected Students' Conceptual Understanding and Conceptual Integration of the Processes of Photosynthesis and Respiration

Researchers and Contact Information:
Dr. Lucia Crickson, Energy University, Department of Cell and Molecular Biology, Energy University, telephone number: (XXX) XXX-XXXX, e-mail address: lcrickson@energy.edu
Jewel J. Reuter, Doctoral Candidate of Biology Curriculum and Instruction, LSU, telephone number: (504) 606-1039, e-mail address: jewelreuter@earthlink.net

Purpose of the Study:
The purpose of the research is to study how students learn photosynthesis and respiration and to determine the value added to the student's learning by various learning strategies.

Description of What Participation Involves:
There will be two groups of eight students from Dr. Lucia Crickson’s General Biology class of Energy University. Each group will be involved in six phases of instructional activities and interviewed periodically. Pseudonyms will be used to identify students during the interviews. There will be approximately eleven sessions each lasting not more than two hours, and the total hours will be approximately 15 to 20 hours per student to complete the research study. The interviews will include surveys, the student's creation of concept maps and visual field diagrams.

This research will be conducted in Helix Hall Suite 4000 outside of the scheduled times of Dr. Crickson's General Biology class and will not interfere with any scheduling or course content. Participants will be reimbursed at the rate of $7.00 per hour of contact time. Participants must be 18 years or older to participate, and will have scheduling choices. Participation will be limited to the Fall, 2004 semester. Participants will be required to provide information concerning your age, previous grade point averages, and SAT and/or ACT scores.

Participation is Voluntary:
Participation is voluntary and participants may withdraw participation at any time without loss of credit or monetary remuneration.

Answering Participant Questions:
Researchers are available to answer participant questions and contact information is provided above.

Protection of Confidentiality:
Sessions will be videotaped for the purpose of data collection. Neither the participant’s name or any other identifying information will be associated with the audiotape (videotape) or the
transcript. Transcriptions and all subsequent analysis and public presentations of the data (in journals and presentations) will use identifying pseudonyms. Details are provided in The Consent to Audio- or Video-Taping and Transcription.

**Any Potential Risks to Subjects and Measures to Be Used to Minimize Risks:**
This study will not interfere with the participants' performance in General Biology. Participants will not be exposed to any harmful chemicals or have to perform any dangerous tasks.

**Potential Benefits:** As a result of this study, participants will have a better understanding of the difficult concepts of photosynthesis and respiration. Participants will also increase their technology skills and have a better understanding of the learning process. Participants be compensated in cash (Federal minimum wage rate) as well as a stipend award at the completion of the project at the semester’s end if there is full participation as described above.

**Debriefing Procedures at End of Study:**
At the end of the study at a scheduled session, participants who were interviewed will be provided copies of concept maps that they constructed during the interviews. All participants will be thanked for their participation, and the use of their data will again be explained, explaining their protection of privacy. Their comments about the data will be recorded.

I understand the basic procedure of this study, and am aware that I may discontinue participation at any time. I hereby give my consent to participate.

________________________________________  ______________________________
Participant's Signature    Date

I have personally discussed the research procedure, and any possible risks, with the above named individual. I am satisfied that s/he understands the information provided.

________________________________________  ______________________________
Researcher's Signature    Date
APPENDIX H:

EU IRB NOTICE OF RESEARCH PROJECT
Biology Education Research Project
with Biology-101 Class (Professor Crickson’s Section)

Study Name:
Using the BioDatamation™ Strategy to Learn Introductory College Biology: Value-Added Effects on Selected Students’ Conceptual Understanding and Conceptual Integration of the Processes of Photosynthesis and Cellular Respiration

Researchers and Contact Information:
Dr. Lucia Crickson, Energy Department of Cell and Molecular Biology, Energy University, telephone number: (XXX) XXX-XXXX, e-mail address: lcrickson@energy.edu.
Jewel J. Reuter, Doctoral Candidate of Biology Curriculum and Instruction, LSU, telephone number: (504) 606-1039, e-mail address: jewelreuter@earthlink.net

Purpose of the Study:
The purpose of the research is to study how students learn photosynthesis and respiration and to determine the value added to the student's learning by various learning strategies.

Description of What Participation Involves:
There will be two groups of eight students from Dr. Crickson’s General Biology class of Energy University. Each group will be involved in six phases of instructional activities and interviewed periodically. Pseudonyms will be used to identify students during the interviews. There will be approximately eleven sessions each lasting not more than two hours, and the total hours will be approximately 10 to 20 hours per student to complete the research study. The interviews will include surveys, the student's creation of concept maps and visual field diagrams.

This research will be conducted in Helix Hall, Suite 4000 outside of the scheduled times of General Biology class and will not interfere with any scheduling or course content. Participants will be reimbursed at the rate of $7.00 per hour of contact time. Participants must be 18 years or older to participate, and will have scheduling choices. Participation will be limited to the Fall, 2004 semester. Participants will be required to provide information concerning your age, previous grade point averages, and SAT and/or ACT scores.

Participation is Voluntary:
Participation is voluntary and participants may withdraw participation at any time without loss of credit or monetary remuneration.

Answering Participant Questions:
Researchers are available to answer participant questions and contact information is provided above.

Protection of Confidentiality:
Sessions will be videotaped for the purpose of data collection. Neither the participant’s name or any other identifying information will be associated with the audiotape (videotape) or the transcript. Transcriptions and all subsequent analysis and public presentations of the data (in
journals and presentations) will use identifying pseudonyms. Details are provided in The Consent to Audio- or Video-Taping and Transcription.

**Any Potential Risks to Subjects and Measures to Be Used to Minimize Risks:**
This study will not interfere with the participants' performance in General Biology. Participants will not be exposed to any harmful chemicals or have to perform any dangerous tasks.

**Potential Benefits:** As a result of this study participants will have a better understanding of the difficult concepts of photosynthesis and respiration. Participants will also increase their technology skills and have a better understanding of the learning process. Participants will be compensated in cash (Federal minimum wage rate) as well as a stipend award at the completion of the project at the semester’s end if there is full participation as described above.

**Debriefing Procedures at End of Study:**
At the end of the study at a scheduled session, participants who were interviewed will be provided copies of concept maps that they constructed during the interviews. All participants will be thanked for their participation, and the use of their data will again be explained, explaining their protection of privacy. Their comments about the data will be recorded.

---

**Research Orientation Meetings**

If you are considering participation in the research project, please attend one of these meetings:

**Times:**  
Thursday, August 26, 2004 from 4:00 PM to 4:45 PM  
Friday, August 27, 2004 from 3:00 to 3:45 PM

**Location:**  
4000 Helix Hall, Suite 4000 (Dr. Crickson’s Laboratory)

If you are unable to attend the meetings, please contact Jewel Reuter at (504)606-1039 or at jewelreuter@earthlink.net as soon as possible.
APPENDIX I:

EU APPLICATION FOR STUDENT PARTICIPATION
Application for Participation in Biology Education Research Project
with Cell-101 Class (Professor Crickson’s Section)

If you are interested in participating in this Biology Education Project, please provide the following information.

You must be in Cell-101 (Dr. Crickson’s Section) for Fall 2004, and at least 18 years of age to participate.

Selection interviews will be used to pick the participants and are required for participation. The researchers will contact you for an interview time. When all the participants are selected, the selection interviews will terminate and you will be contacted as to your participation in the project.

If you have any questions, please contact Jewel Reuter at (504) 606-1039 or at jewelreuter@earthlink.net.

Name  ____________________________________________________________

Telephone number (dorm) ________________________________

Telephone number (cell) ________________________________________

E-mail address(es) ____________________________________________

________________________________________________________________

Best date and time for selection interview over the next week:

_________________________________________________________________
APPENDIX J:

EU CONSENT FORM TO AUDIO- OR VIDEO- TAPING
CONSENT TO AUDIO- OR VIDEO-TAPING & TRANSCRIPTION

Study Name: Using the BioDatamation™ Strategy to Learn Introductory College Biology: Value-Added Effects on Selected Students' Conceptual Understanding and Conceptual Integration of the Processes of Photosynthesis and Cellular Respiration

Researchers: Dr. Lucia Crickson, Energy Department of Cell and Molecular Biology, Energy University; and Jewel J. Reuter, Doctoral Candidate of Biology Curriculum and Instruction, LSU

I understand that this study involves the audiotaping (videotaping) of my interview with the researcher. Neither my name or any other identifying information will be associated with the audiotape (videotape) or the transcript. Only the researcher(s) will be permitted to listen (view) to the tapes.

I understand that the tapes will be transcribed by the researcher and erased once the transcriptions are checked for accuracy. Transcripts of my interview may be reproduced in whole or in part for use in presentations or written products that result from this study. Neither my name nor any other identifying information (such as my voice or picture) will be used in presentations or in written products resulting from the study.

I further understand that immediately following the interview I will be given the opportunity to have the tape erased.

Please check one of each pair of options.
A. _____ I consent to have my interview taped.
   _____ I do not consent to have my interview taped.
B. _____ I consent to have my taped interview transcribed into written form.
   _____ I do not consent to have my taped interview transcribed.
C. _____ I consent to the use of the written transcription in presentations and written products resulting from the study, provided that neither my name nor other identifying information will be associated with the transcript.
   _____ I do not consent to the use of my written transcription in presentations or written products resulting from the study.
D. The above permissions are in effect until December 31, 2008. On or before that date, the tapes will be destroyed.

__________________________________    ____________________
Participant's Signature        Date

I hereby agree to abide by the participant's above instructions.

__________________________________                     ____________________
Investigator's Signature        Date
APPENDIX K:

EU IRB QUESTIONNAIRE
Questionnaire

Directions:
- You are to asked to answer the following questions for research purposes. Answer in the question is optional, but you responses will better help us understand how student learn photosynthesis and respiration.
- Your responses will not affect your exam grade in any way.
- Circle your choices directly in this sheet.
- It may be helpful to make notes and diagrams in the margins to help you think about the question.
- Do not answer questions that you have not read.

1. A student using a light microscope observes a cell and correctly decides that it is a plant cell because
   A. ribosomes are visible
   B. an endoplasmic recticulum can be seen
   C. a cell membrane is present
   D. it has a large central vacuole
   E. centrioles are present
   **Explain why your answer is correct.**


2. Oxygen consumption can be used as a measure of metabolic rate because oxygen is
   A. necessary for ATP synthesis by oxidative phosphorylation
   B. necessary to replenish glycogen levels
   C. necessary for fermentation to take place
   D. required by all living organisms
   E. required to break down the ethanol that is produced in muscles
   **Explain why your answer is correct.**


3. During respiration, most ATP is formed as a direct result of the net movement of
   A. potassium against a concentration of gradient
   B. protons down a concentrations gradient
   C. electrons against a concentration gradient
   D. electrons through a channel
   E. sodium ions into the cell
   **Explain why your answer is correct.**
4. Which of the following pathways for the transformation of cellular energy most likely evolved first?
A. Cyclic photophosphorylation
B. Citric acid (Krebs) cycle
C. Calvin cycle
D. C₄ photosynthesis
E. Glycolysis

**Explain why your answer is correct.**

5. On a sunny day, the closing of stomata in plant leaves results in
A. a decrease in CO₂ intakes
B. a shift from C₃ photosynthesis to C₄ photosynthesis
C. an increase in transpiration
D. an increase in the concentration of CO₂ in mesophyll cells
E. an increase in the rate of production of starch

**Explain why your answer is correct.**

6. Process in which O₂ is released as a by-product of oxidation-reduction reactions
A. Glycolysis
B. Krebs cycle (citric acid cycle)
C. Calvin cycle (light-independent reactions of photosynthesis)
D. Light-dependent reactions of photosynthesis
E. Chemiosmosis

**Explain why your answer is correct.**

7. Process in which CO₂ is released as byproduct of oxidation-reduction reactions
A. Glycolysis
B. Krebs cycle (citric acid cycle)
C. Calvin cycle (light-independent reactions of photosynthesis)
D. Light-dependent reactions of photosynthesis
E. Chemiosmosis

**Explain why your answer is correct.**

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

8. Process in which carbon from CO₂ is incorporated into organic molecules
A. Glycolysis
B. Krebs cycle (citric acid cycle)
C. Calvin cycle (light-independent reactions of photosynthesis)
D. Light-dependent reactions of photosynthesis
E. Chemiosmosis

**Explain why your answer is correct.**

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

9. Process found in both photosynthesis and cellular respiration
A. Glycolysis
B. Krebs cycle (citric acid cycle)
C. Calvin cycle (light-independent reactions of photosynthesis)
D. Light-dependent reactions of photosynthesis
E. Chemiosmosis

**Explain why your answer is correct.**

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

10. Process in which sugar is oxidized to pyruvic acid
A. Glycolysis
B. Krebs cycle (citric acid cycle)
C. Calvin cycle (light-independent reactions of photosynthesis)
D. Light-dependent reactions of photosynthesis
E. Chemiosmosis

**Explain why your answer is correct.**

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

11. What is your past biology experience in high school?
12. What is your intended degree major?

13. What are your career goals and explain why you selected your career choice?

14. Comments about the above questions.
APPENDIX L:

EU IRB INTERVIEW PROTOCOLS
INTERVIEW PROTOCOLS

Phase 1 (Pre-Interview Preparation)
Quantitative analysis of Biology AP Exam multiple choice item analysis to help to determine misconception.

Phase 2 (Introduction/Baseline- Interview A)
The following data are gathered at the beginning of the course before photosynthesis and respiration are taught to the class and is administered to all 16 participants.

1. Introductions about the BDM study.
2. Provide agenda and information about the study.

Steps 3-6 pertain to the details of the clinical interviews.
-Pre (baseline) Individual Interview- Photosynthesis and respiration and their relationship and pre-visual field measurement determined by Individual Interviews as outlined below (45 min/student)

3. Think-aloud initial activity to determine literacy level: material sorting tasks (Bread, piece of wood, head of cabbage, yogurt, doodle bugs, cup of water, flash light, cup of soil, plant in a jar with top close tightly, animal in a jar with top close tightly, jar of Kimchee, ziplock bag label with oxygen, ziplock bag label with carbon dioxide, mushroom, red bean) (10 min)

A. Sort the objects into living or at one time living and non-living and explain why.
B. Sort the objects into categories of photosynthesis and respiration and explain why.

4. Term sorting task and modified co-concept mapping using dragging and dropping of terms on a computer screen using graphic software (10 min)

Overall Terms

**Cellular Respiration:** fermentation, cellular respiration, glycolysis, ATP, redox reaction, glucose, oxygen, carbon dioxide, water, glycolysis, Krebs Cycle, electron transport, chemiosmosis, NAD$^+$ $\to$ NADH, ATPase, dehydrogenase, oxidative phosphorylation, substrate level phosphorylation, endergonic and exergonic reactions, aerobic and anaerobic, alcoholic fermentation, lactic acid fermentation, biosynthesis

**Photosynthesis:** autotrophy, heterotrophic, chlorophyll, mesophyll, chlorophyll, carbon dioxide, water, light, glucose, oxygen, water, splitting of water, photophosphorylation, ATP, NADPH, electromagnetic spectrum, Visible light, photons, action spectrum, excitation, photosystems, reaction center, primary electron acceptor, photosystem I, photosystem II, thylakoid, G3P, Rubisco, Calvin cycle

A. Choose the concepts that you recognize from the left side of the screen.
B. Give a simple oral definition of each term.
C. Now we will create a map that shows how you think about the concepts and how they are related. We will begin with the most general idea on too and then take the others and group them under the most general idea to work our way to the most specific ideas.
D. Now type a linking word between each pair of words that tells the relationship between the terms.
E. Are there any change that you would like to make in you map (arrangement, concepts or links).

5. Interpreting situation with the chloroplast and mitochondria models.
   A. Compare and contrast the parts of the chloroplast and the mitochondria for the photosynthesis and respiration interview.
   B. Pins were used to track the path of the protons.

6. Using the Visual Field Mapping Instrument
   Visualizing is a mental image of a what you know or understand.
   A. From the past what do you visualize about your experiences with photosynthesis and respiration?
   B. How do you visualize your present experience with photosynthesis and respiration?
   C. How do you visualize your or other people’s future experiences with photosynthesis and respiration?
   D. How do your visualizations the past, present and future help you understand photosynthesis and respiration concepts?

7. Students take Photosynthesis and Respiration Survey which is included in this IRB.

8. Pre-BDM Introduction Instruction to briefly explain concept mapping, visual fields, WebQuests, data collection and PowerPoint.

**Phase3 (Knowledge After Class Presentations- Interview B)**

The above will be repeated with all participants after the normal class material on photosynthesis and respiration are presented.

**Phases 4 – 10 (BDM Phases of Instruction and Interviews C- I)**
The following summarizes the BDM instructional content and student tasks. In phases 4 -10 there will be BDM instruction and then interviews that follow the interview protocol of Phase 2 steps 3 -6. Only those eight students that receive BDM instruction will participate in these phases.

The following is a summary of phases 4 – 10:

**Phase 4 (Respiration Past)**
> Pre BDM Respiration Interview
> Past Visual Field Respiration Individual Instruction (WebQuest and brief videos) (1 hour maximum/student)
> Past Visual Field Respiration Individual Interviews as outlined above (1 hour/student)
Phase 5 (Respiration Present)

> Present Visual Field Respiration Individual Instruction (data collection and brief videos) (1 hour maximum/student)
> Present Visual Field Respiration Individual Interviews as outlined above (1 hour/student)

Phase 6 (Respiration Future)

> Future Visual Field Respiration Individual Instruction (animated and annotated student PowerPoints related to a real world problem) (1 hour maximum/student)
> Future Visual Field Respiration Individual Interviews as outlined above (1 hour/student)

Phase 7 (Photosynthesis Past)

> Past Visual Field Photosynthesis Individual Instruction (WebQuest and brief videos) (1 hour maximum/student)
> Past Visual Field Photosynthesis Individual Interviews as outlined above (1 hour/student)

Phase 8 (Photosynthesis Present)

> Present Visual Field Photosynthesis Individual Instruction (data collection and brief videos) (1 hour maximum/student)
> Present Visual Field Photosynthesis Individual Interviews as outlined above (1 hour/student)

Phase 9 (Photosynthesis Future)

> Future Visual Field Photosynthesis Individual Instruction (animated and annotated student PowerPoints related to a real world problem) (1 hour max./student)
> Future Visual Field Photosynthesis Individual Interviews as outlined above (1 hour/student)

Phase 10 (Post Photosynthesis and Respiration Relationship Knowledge and BDM Analysis)

> Post (final)- Photosynthesis and respiration relationship and post-visual field measurement determined by Individual Interviews as outlined above (45 min/student)
> Analysis of BDM learning strategies (45 min/student)

Phase 11 (Delayed Post Instruction)

> Respiration, photosynthesis, relationship of respiration and photosynthesis and visual field measurement, overall comments about BDM learning strategy individual interview (1 hour/student)

This phase will be administered to the group that receives BioDatamation™ instruction and the group that does not receive instruction.
APPENDIX M:

VISUAL FIELD PERCEPTION MAP HEURISTIC™
Visual Field Perception Map Heuristic™
Visual Field Worksheet

Past Visual Field
Learned Experience

Future Visual Field
Projected Experience

Present Visual Field
Immediate Experience

Vision
Insight

Adapted from Jones, 1995
APPENDIX N:
BIODATAMATION™ LEARNING STRATEGIES FOR IRB FORMS
BioDatamation™ Learning Strategies Analysis Video

Click on the file called BDMVIDEO in the list of files to view the video (4min., 4 sec.).

The video concerns using data collection to establish the Present Visual Field for Photosynthesis.
Difficult Concepts and Consequences to Learning Cellular Respiration

Jewel Reuter and Jim Wandersee
Louisiana State University
© 2003

Energy Sources

- **Difficult Concept:**
  Identifying organic molecules as energy sources of heterotrophs.

- **Consequence to Learning:**
  Failure to recognize molecules other than glucose can be used in cellular respiration.

```
Proteins → Carbohydrates → Fats
```
Cellular Level

- **Difficult Concept:**
  Conceptualizing the cellular level of respiration.

- **Consequence to Learning:**
  Failure to realize that there is **cellular respiration** and to assume cellular respiration is only breathing respiration.

Cellular Respiration vs Breathing

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{net 36ATP} \]

Aerobic Cell

Individual Cells **Do Aerobic Cellular Respiration**
Cellular Respiration vs Breathing

Human Breathing
Breathing is a mechanism of bringing air into and out of the body.

Anaerobic Vs. Aerobic

- **Difficult Concept:**
  Distinguishing between anaerobic and aerobic cellular respiration processes.

- **Consequence to Learning:**
  Failure to understand anaerobic and aerobic processes in cellular respiration and the location in the cell of the processes.
**Anaerobic Conditions**

\[ C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{net } \text{36ATP} \]

\[ C_6H_{12}O_6 \rightarrow 2CO_2 + 2\text{CH}_3\text{CH}_2\text{OH} + \text{Net 2 ATP} \]

**Anaerobic Yeast Cell**

---

**Aerobic Conditions**

\[ \text{C}_6\text{H}_8\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{net 36ATP} \]

**Aerobic Cell**
**Chemiosmosis**

- **Difficult Concept:**
  Understanding concept of chemiosmosis-
  - protons move down the concentration gradient to produce ATP.
  - chemiosmosis occurs in both photosynthesis and cellular respiration.

- **Consequence to Learning:**
  Since students do not understand chemiosmosis, they do not understand how most ATP is formed.
Structure of Mitochondrion

Krebs Cycle: Produces H⁺ in Matrix
Chemiosmosis:
Formation of H⁺ Concentration Gradient

H⁺ Diffuses Across ATP Synthase: ATP is Produced
ATP Synthase

- **Difficult Concept:**
  Understanding that ATP synthase is located in the mitochondrial and chloroplast membranes and is an enzyme made of protein.

- **Consequence to Learning:**
  Since students do not understand the structure and function of ATP synthase, they do not understand the final production of ATP.

A Closer Look at Concentrating H⁺ to Create a Gradient

Outer Membrane

Matrix

H⁺

Krebs Cycle

Produce
Oxygen and Production of ATP

- **Difficult Concept:** Understanding role of oxygen in cellular respiration and how oxygen is needed for oxidative phosphorylation.

- **Consequence to Learning:** Failure to recognize the relationship of oxygen and production of ATP and that anaerobic respiration produces less energy (ATP) than aerobic respiration.

\[ \text{O}_2 \quad \text{ATP} \]

A Closer Look at ATP Production

- **Outer Membrane of Mitochondrion**
- **ATP Synthase**
- **Matrix**
- **ADP + Pi**
- **H\(^+\) Reduces Oxygen**
- **To Produce**
- **Water + ATP**
Step by Step Process

- **Difficult Concept:**
  Understanding that there are many steps to cellular respiration and glucose is not the only molecule to trace through the process.

- **Consequence to Learning:**
  - Failure to relate
  - *relate glucose consumption to oxygen consumption.*
  - *relate pyruvic consumption acid and oxygen consumption.*
  - *failure to link concepts.*

Relationship of Concentrations

![Diagram showing the relationship between concentration (µg/l) of glucose, oxygen, pyruvic acid, ATP, and time (μs).]
Carbon Cycle

- **Difficult Concept:**
  Understanding of how cellular respiration produces carbon dioxide and photosynthesis uses it.

- **Consequence to Learning:**
  *Failure to understand how the Krebs Cycle produces carbon dioxide and how the Calvin Cycle uses it.
  *Thus, there is a failure to understand the carbon cycle.

Plants Perform Respiration

- **Difficult Concept:**
  Understanding why plants need oxygen.

- **Consequence to Learning:**
  Failure to understand that plants must perform cellular respiration to produce ATP for cell activities.
Application of Respiration to Daily Life

- **Difficult Concept:**
  Understanding application of overall fermentation concepts.

- **Consequence to Learning:**
  Failure to recognize that yeast are living organisms capable of metabolic process such as fermentation.

Example: Kimchee
Example: Rising of Yeast Bread

Regulation

- **Difficult Concept:**
  Regulation of cellular respiration.

- **Consequence to Learning:**
  Failure to understand that cellular respiration has control mechanisms.
Reactions Need Energy

- **Difficult Concept:**
  Endergonic cellular processes are coupled to hydrolysis of ATP.

- **Consequence to Learning:**
  Failure to understand how and why ATP is utilized by cells.

Example: Reactions That Need Energy

**Glyceraldehyde-3-Phosphate**

Endergonic Uses ATP

1. **Endergonic Uses ATP**
   - ATP
   - Phosphoenolpyruvate
   - Pyruvate kinase
   - Pyruvate

2. **Endergonic Uses ATP**
   - ATP
   - Phosphoglycerate kinase
   - 2-phosphoglycerate
   - Phosphoglycerate mutase
   - 3-phosphoglycerate
   - Triose phosphate isomerase
   - 1,3-bisphosphoglycerate
   - Glyceraldehyde-3-phosphate dehydrogenase

3. **Endergonic Uses ATP**
   - ATP
   - Phosphoglycerate kinase
   - 2-phosphoglycerate
   - Phosphoglycerate mutase
   - 3-phosphoglycerate
   - Triose phosphate isomerase
   - 1,3-bisphosphoglycerate
   - Glyceraldehyde-3-phosphate dehydrogenase
1. A) Attach Temperature sensor to Channel 1 of the CBL.

B) Press **ON** on calculator keyboard and **START** on CBL.
C) Press APPS on calculator keyboard. (See large image below.)

D) Select DATAMATE from the list. Press CLEAR to reset the program.

E) Select SETUP (1). Channel 1 should be temperature.

F) Toggle down to Mode to select MODE and hit ENTER. (See large image in C for an image of the Down Toggle Button.)

G) Select TIME GRAPH (2).
H) Select CHANGE TIME SETTINGS (2).

I) For time between samples —TYPE 2 and hit ENTER.

J) For number of samples— TYPE 60 and hit ENTER.

K) Select OK (1) twice.

L) Place thermometer into the water and begin to stir.

M) Select START (2) and you will begin to collect data. **Stir for 10 sec, add the ice and continue to stir.** When data collection is finished a graph will appear.

N) Press ENTER to return to the main screen.

O) Select ANALYZE (4).

P) Select STATISTICS (4).
Q) Move cursor to the end of the flat portion of the graph where the temperature begins to decrease by toggling, and press ENTER. This will be the LEFT BOUNDARY. Then move the cursor to the end of the curve where the temperature begins to level off at the bottom of the curve. This will be the RIGHT BOUNDARY.

![Left Boundary]

![Right Boundary]

R) Now press ENTER to get the statistics.

```
MEAN: 13.829
MIN: 5.971
MAX: 24.767
STD DEV: 6.295
```

***Record Your Statistics for Your Ice Melt Here***
S) Press ENTER to return to ANALYZE OPTIONS.

T) Select RETURN TO MAIN SCREEN (1).

U) Select ANALYZE (4).

V) Select CURVE FIT (2).

W) Select LINEAR (CH1 VS. TIME) (1).

You will then see $Y = A \cdot X + B$. $A$ is the slope and $B$ is the $Y$ intercept.

(Note: This is the OVERALL rate at which the water cooled. It takes into consideration the baseline room temperature data at the beginning before the cooling began.)

*****Record the OVERALL Rate at Which Your Water Cooled*****

*****Explain Your Answer*****

X) Press ENTER - You will see the graph with the curve fitted to it.

Y) Press ENTER to return to ANALYZE OPTIONS.

Z) Select RETURN TO MAIN SCREEN (1).
2. Selecting a region of the graph and determine the slope of only that region. Determine only the rate at which the water RAPIDLY cooled. To do this you need to determine the slope of the line from the time you added the ice until the cooling slowed down. You need to remove the baseline temperature data and the data when the water slowly approaches its melting point (at thermal equilibrium).

A) Select GRAPH (3) from the MAIN SCREEN.

B) Press ENTER.

C) Press SELECT REGION (2).

D) You will see the graph. Toggle to the LEFT BOUNDARY (that will remove the baseline data). Hit ENTER to SELECT the LEFT BOUNDARY.

E) Toggle to the RIGHT BOUNDARY (this will remove the data when the water slowly approaches its melting point. Hit ENTER to SELECT the RIGHT BOUNDARY. Now you have ONLY the data of the rapid cooling of the water.

F) Press ENTER.

G) Select MAIN SCREEN (1).

H) Select ANALYZE (4).

I) Select CURVE FIT (2).

J) Select LINEAR (CH1 VS TIME) (1).

K) You will then see Y = A*X + B. (A is the slope and B is the Y intercept.)

Note: This is the ONLY the rate at which the water RAPIDLY cooled. It does NOT take into consideration the baseline room temperature data at the beginning before the cooling began and the data when the water slowly approaches its melting point.

*****Record ONLY the Rate at Which Your Water RAPIDLY Cooled *****

*****Explain Your Answer*****
## Alternative Conceptions

<table>
<thead>
<tr>
<th>Alternative Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Only glucose molecules can be used in cellular respiration.</td>
</tr>
<tr>
<td>B. Cellular respiration is only breathing respiration.</td>
</tr>
<tr>
<td>C. All organisms need oxygen.</td>
</tr>
<tr>
<td>D. Glycolysis does not occur in the anaerobic cytoplasm.</td>
</tr>
<tr>
<td>E. There is no change in concentration of pyruvic acid with consumption of oxygen.</td>
</tr>
<tr>
<td>F. Krebs Cycle is the oxidation of sugar to pyruvic acid.</td>
</tr>
<tr>
<td>G. Chemiosmosis is a cellular process coupled to hydrolysis of ATP. Chemiosmosis occurs in glycolysis.</td>
</tr>
<tr>
<td>H. ATP synthesis only occurs in the mitochondria or chloroplast but not in both.</td>
</tr>
<tr>
<td>I. Fermentation is the use of carbon dioxide instead of oxygen. Fermentation is related to aerobic cellular respiration. More energy is produced during anaerobic fermentation.</td>
</tr>
<tr>
<td>J. Calvin Cycle releases carbon dioxide.</td>
</tr>
<tr>
<td>K. Plants do not need oxygen.</td>
</tr>
<tr>
<td>L. There is no negative feedback in respiration.</td>
</tr>
</tbody>
</table>
## Alternative Conceptions About Cellular Respiration

by Jewel Reuter and Jim Wandersee  
Louisiana State University  
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### Difficult Concept

| Identifying organic molecules as energy sources of heterotrophs. | -Only glucose molecules can be used in cellular respiration. |
| Conceptualizing the cellular level of respiration. | -Cellular respiration is only breathing respiration. |
| Understanding role of oxygen in cellular respiration and how oxygen is needed for oxidative phosphorylation. | -More energy is produced during anaerobic fermentation.  
-All organisms need oxygen. |
| Distinguishing between anaerobic and aerobic cellular respiration processes and the location in the cell of the various processes. | -Glycolysis does not occur in the anaerobic cytoplasm.  
-Krebs Cycle is the oxidation of sugar to pyruvic acid. |
| Understanding concept of electron transport and associated chemiosmosis and how most ATP is produced. | -Chemiosmosis occurs in glycolysis. |
| Understanding that ATP synthase is needed in aerobic respiration, is located in the mitochondrial and chloroplast membranes and is an enzyme made of protein. | -ATP synthesis only occurs in the mitochondria or chloroplast but not in both. |
| Understanding that there are many steps to cellular respiration. | -There is no relationship of the rate of glucose consumption to oxygen consumption.  
-There is no change in concentration of pyruvic acid with consumption of oxygen. |
| Understanding carbon cycle (cellular respiration produces carbon dioxide and photosynthesis uses it). | -Calvin Cycle releases carbon dioxide. |
| Understanding why plants need oxygen (plants must perform cellular respiration to produce ATP for cell activities). | -Plants do not need oxygen.  
-Photosynthesis is the plant’s form of respiration.  
-Plants do not respire. |
| Regulation of cellular respiration. | -There is no negative feedback in respiration. |
| Endergonic cellular processes are coupled to hydrolysis of ATP. | -Chemiosmosis is a cellular process coupled to hydrolysis of ATP. |
| Understanding application of overall fermentation concepts. | -Fermentation is an aging process.  
-Fermentation is the use of carbon dioxide instead of oxygen.  
-The rate of fermentation does not vary directly with temperature.  
-Yeast are dead when you use them/yeast are enzymes.  
-Fermentation is related to aerobic cellular respiration. |
What’s Happening with the Data While Making Kimchee?

By Jewel Reuter and Jim Wandersee
Louisiana State University ©2003

What is the community of microbes that live on the leaves called?

Phyllosphere
Make a labeled diagram of the phyllosphere community of microbes.

Cabbage Leaf

Bacterium of Phyllosphere

Describe the anaerobic bacteria of phyllosphere that live in the brine.

- Are Extreme Halophiles
- That live and reproduce in salty solutions called brine.

Brine solutions are:
- High in salt concentration
- Anaerobic, lack oxygen

Brine

O₂

Salt + Water from cabbage
Very salty solutions create anaerobic conditions.

Why does the brine solution increase in turbidity (cloudiness) as the Kimchee ferments?
There is more bacteria: phyllosphere reproduction.

Salty, anaerobic conditions with moderate temperatures allow for reproduction of anaerobic extreme halophile phyllosphere bacteria cause the increase in turbidity.

How does the turbidity change over time?

- Few Bacteria
- 1 Day Growth
- 7 Days Growth
- Many Bacteria

How is turbidity determined?
- Colorimeter
- Turbidity Sensor
- OR
How are salt concentration and temperature determined?

- Conductivity Sensor:
  -- Determines the conductivity
  -- which indicates the salt concentration

- Temperature Sensor
  -- Determines the Temperature

Why does the brine solution get bubbly?
CO₂ (gas) is one product of heterofermentation.

C₆H₁₂O₆ → CO₂, lactic acid, ethanol and net 2 ATP

Visualizing Carbon Dioxide Production

Carbon dioxide gas accumulates to create bubbles.
What is the set-up for determining the rate of carbon dioxide production?

Carbon Dioxide Sensor and Sensosphere

CBL 2 and Calculator

Why does concentration of $\text{CO}_2$ change in the sensosphere?

$\text{CO}_2$ accumulates in brine and then diffuses into sensosphere.
Predict the change in oxygen concentration during fermentation?

I predict **NO CHANGE** in $[O_2]$ since fermentation is anaerobic and does **NOT** use $[O_2]$.

Why does the pH decrease? Part 1

- **Anaerobic Bacterium**
- $[\text{C}_6\text{H}_{12}\text{O}_6]$: Produces $\text{CO}_2$, lactic acid, ethanol and net 2 ATP
Why does the pH decrease? Part 2

- Also, some CO₂ reacts with water to produce carbonic acid.

How are changes in acidity tracked?

- pH 0 - 14

  OR

  - pH Paper (Changes Color)
  - pH Sensor (digital readings)

  pH 7
  pH 5
  pH 4
  pH 2
What’s Happening with Kimchee to Keep It Running?
1) Start-->Programs-->PowerPoint
2) Select Blank Presentation (OK)
3) Select Blank Slide (OK)
4) Insert --> Text Box

Insert is critical for slide composition. Select text box.

Make text box to size and type entities and text. The text box must be selected to type text. To select the text box, click on it and you will see the small squares around the box.
5) Insert --> Picture

![Picture menu](image1)

6) To add another slide
   Insert-->New Slide

7) To add a background or design

![Background and design options](image2)
8) For slide transitions, animations and recording narrations go to:

9) From Slide Show go to Custom Animation.

To find Draw Custom Path: Custom Animation --> Add Effect --> Motion Paths --> Draw Custom Path
10) Views as you work and present

- View --- Normal to make Slide.
- Slide Sorter for mini view of all slide and ability to drag to position.
- Slide Show to see it as a presentation.

The views are also available on the left side of the task bar near the Start button.
APPENDIX O:

BIOLOGY AP EXAM QUESTION ANALYSIS
Title Page

Title: Understanding Photosynthesis and Cellular Respiration: N= 263,267

Type of Manuscript: Research Article

Number of Characters in the Manuscript: without spaces- 53,093 and with spaces- 62,876

Shortened Running Title: Understanding Cellular Energy

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Key Words: photosynthesis, cellular respiration, understanding, Biology AP, secondary, concept maps, concept and data analysis maps, difficult concepts, cognitive categories, conceptual distance, physical science knowledge, history
ABSTRACT
This research study centered on analyzing high school students’ understanding of photosynthesis and cellular respiration by using data from multiple-choice items of 263,267 student exams from the four most recently released Advanced Placement Biology Examinations, as well as from previous bioeducational research. This study introduced the use of concept and data analysis maps that illustrate the hierarchical relationship of concepts and utilizes reference numbers with sublevel letters to analyze the level of conceptual difficulty and to identify possible paths for assessment or teaching these concepts. Results indicated that the topic of photosynthesis is the most difficult to master, followed by the interrelationship of photosynthesis and cellular respiration, and cellular respiration. The most difficult concepts for the students tested were thylakoid structure, the role of light and chlorophyll, carbon fixation, hydrolysis of ATP, electron transport and chemiosmosis. Beyond the identification of these difficult concepts, this research offers possible paths for teaching and assessing those troublesome concepts via the study's concept and data analysis maps of photosynthesis and cellular respiration. It also demonstrates that gaining integrative knowledge of photosynthesis and cellular respiration merits greater attention during instruction.
INTRODUCTION

The concepts of photosynthesis and cellular respiration are basic to the understanding of many biology concepts, and the new recommended curriculum in *Bio2010: Transforming Undergraduate Education for Future Research Biologists* (National Research Council [NRC], 2003) identifies photosynthesis and cellular respiration as central themes of biology. "Living things are far from equilibrium. They utilize energy, largely derived from photosynthesis, which is stored in high-energy bonds or ionic concentration gradients. The release of this energy is coupled to thermodynamically unfavorable reactions to drive biological processes" (NRC, 2003, p. 32).

Students have difficulty understanding photosynthesis and cellular respiration. “The breadth and complexity of biology, the interconnectedness of the knowledge at many different levels, and the invisible nature of many key processes make biology a particularly difficult subject to teach and to learn” (Wandersee, Fisher, & Moody, 2000, p. 30), and this is particularly true for the concepts of photosynthesis and cellular respiration. There has been a call to use research based education studies for improving instruction. “Research work in science education is a special area of scholarship within the scientific enterprise” (Novak, 1963, p. 3). Novak continued to explain that research in science education has the same goals as other fields of science, “to advance the conceptual schemes which have been developed to explain events in the universe about us” (Novak, 1963, p. 3). Also, *Teaching on Solid Ground: Using Scholarship to Improve Practice*, emphasized the need for research based education studies. “We are convinced that when work on teaching and learning is truly scholarly, the knowledge it contains has the power to positively affect the practice of instruction” (Weimer, 1996, p.11).

The content of the AP Biology course is described in the Course Description for AP Biology (CEEB, 2003) publications and is determined from questionnaires to professors of colleges that regularly receive the most AP students. The AP Biology Examinations represent the topics covered by the survey group and assess advanced placement students’ performance. “Primary emphasis in an AP Biology course should be on developing an understanding of concepts rather than on memorizing terms and technical details” (CEEB, 2003, p. 4). The course description booklet also defines themes, topics and concepts. “This booklet defines themes as overarching features of biology that apply throughout the curriculum. Topics are the subject areas in biology and concepts are the most important ideas that form our current understanding of a particular topic” (CEEB, 2003, p. 4). The description booklet provides an example of concept versus a discrete fact that is directly related to cellular respiration. “An example of a
topic is ‘cellular respiration.’ In a conceptual approach to this topic, for example, it is important to understand how membranes couple ATP synthesis to the energy release by electron transport. This key concept stands above discrete ‘facts,’ such as the role of a particular cytochrome in electron transport” (CEEB, 2003, p. 4). The booklet further explains that the theme of “energy transfer” would help students to connect diverse topics such as cellular respiration and ecosystem dynamics and that the AP Biology Examination is increasingly placing more emphasis on themes and concepts and less on discrete facts.

Over the years comments in various publications have indicated that the AP Biology Examination emphasizes rote memorization rather than in-depth understanding (Klymkowsky, Garvin-Doxas, and Zeilik, 2003, NRC, 2002, Wood, 2002), but the comments have not been specifically quantified or qualified. The CEEB has attempted to respond to the criticism with statements as indicated above, but without explaining specific examination examples or providing statistical analysis of the multiple-choice questions.

**Characterization of Exam Items**

Multifaceted characterization of exam items was an important component in the analysis of the Biology AP Examination. The researchers identified level of abstraction or cognition, conceptual distance, level of physical science and historical reference of discovery of the concept as the components to the characterization.

**Level of Abstraction or Cognition Characterization Component**

*How People Learn: Brain Mind Experience, and School* (NRC, 2000), was written by a committee that included cognitive scientists, psychologists, and experts in research on education, and they considered the ways students are taught and the way they learn the concepts being taught. One major finding of the study was that a deep foundation of factual knowledge, an
understanding of facts within a contextual framework, and organization of knowledge in ways that facilitate retrieval and application helps students to develop confidence doing inquiry activities. Conceptual understanding is critical in biology education and this report substantiates its importance, and his research study analyzes the use of AP Biology Examination to help to better determine the difficulties in understanding photosynthesis and cellular respiration.

Bloom (1981) created a taxonomy for categorizing level of abstraction or cognition of questions that commonly occur in educational settings, and his taxonomy was used in the development of the method that used values of 1-6 for identifying the level of question abstraction as part of the question characterization. Bloom’s taxonomy includes the following six categories from least abstract to most abstract: knowledge, comprehension, application, analysis, synthesis, and evaluation. Table 1 briefly describes the categories and the values that the researchers assigned each category for a means of analysis. The lowest category, knowledge, was assigned a value of 1 and the highest cognitive category, evaluation, was assigned a value of 6. The taxonomy provides a useful structure in which to categorize the abstraction level of the test questions. It has been suggest that the AP Biology Examination has mostly rote memory questions, and this taxonomy is useful for classifying the photosynthesis and cellular respiration multiple-choice test questions. Formal and accurate analysis is vital for effective instruction by instructors who are concerned with being congruent with the AP Biology Examination. For example, if the AP Biology Examination questions are not rote, and the instructors and students involved in testing prepare for rote questions, difficulties would probably arise because meaningful analysis of the concepts would be excluded from instruction.
**Conceptual Distance Characterization Component**

Not only was the category of the level of abstraction important, but the conceptual distance was identified as a factor. Griffard (1999) and Griffard and Wandersee (2001) described various gaps, missing knowledge, that could occur in learning photosynthesis. Their research determined that if a gap was present, the learner filled in the gap very often with incorrect information and this process identifies a source of the development of alternative conceptions. Griffard found the following to be possible types of gaps: inability to distinguishing two concepts correctly, inability to identify categories, inability to determine propositions (linking phrases) that link concepts which were conceptually close, inability to link conceptually distant concepts, inability to interrelate sets of distant, but interrelated concepts, inability to recognize the relative significance of a concept. From Griffard's description of gaps categorization of conceptual distance was developed by the researchers. Conceptual distance was determined from the distance of the concepts and propositions that were required to understand and to answer the questions. If the question concerned a concept and a contingent proposition, it was classified as conceptually close and a value of 0 was assigned for purpose of analysis. If the question concerned concept and propositions that were not contingent, it was classified as conceptually distant and assigned a value of 1 for purposes of analysis. Distinguishing distant concepts, identifying categories, linking distant concepts with propositions, relating sets of distant concepts were all classified as conceptually distant. Table 1 summarizes conceptual distance.

**Physical Science Characterization Component**

Physical Sciences are important components in biology education. Photosynthesis and cellular respiration are concepts that require integrated knowledge of chemistry.
(NRC, 2003) emphasizes the importance of integrating physical sciences in the teaching of biology. “Modern biology is becoming more dependent on the physical sciences (chemistry and physics) and engineering in multiple ways. First, as the analysis of biological systems advances at the cellular and molecular levels the distinction between the physical and biological sciences blurs and essential biological processes are most fruitfully treated in terms of their physical properties” (NRC, 2003, p 11). This research study analyzes the AP Biology Examination multiple-choice questions that concern photosynthesis and cellular respiration to determine the examinations emphasis on chemistry and to determine if the examinations is congruent with the findings of the NRC that is also considered in this research.

Following the emphasis on physical science as describe by Bio2010 (2003), the researchers developed a scale for determining physical science knowledge required to understand and to answer questions. The following are the physical science knowledge levels were identified and used to categories questions:

Level 0, none, lack of physics and chemistry knowledge
Level 1, low level that require only definitions
Level 2, medium level that requires basic knowledge of simple introductory processes (simple reactions and motion)

Level 3, high level that required advanced knowledge of advanced processes (redox reactions and thermodynamics)

Values of 1-3 were assigned to the various levels for extended analysis. Table 1 summarizes the physical science knowledge level, Bloom's taxonomy for cognitive categories and conceptual distance to show the relationships of these factors that were used in
characterization of the questions. The questions were involved and required a variety of
evaluation tools to allow for a more complete categorizations of the questions.

**Historical Reference of the Discovery of Component**

Wandersee (1986) establish the positive relationship between alternative conceptions and
mistakes that occur in the discovery of the concept through history. For example he explains
how von Helmont incorrectly said that water was the only requirement to make food in 1648,
(Wandersee, 1986), and Wandersee’s research with students showed the same alternative
conception. In the current research, it appeared to the researchers that there could be a
relationship between gaps and recently concepts. Recently discovered concepts are not always
very familiar to instructors that did not receive formal instruction on those concepts. This
research considers the situation of recent discoveries related to student understanding and
alternative conceptions.

If there was a mistake in history, then there were usually similar alternative conception in
learners (Wandersee, 1986) and if there is a gap and the gap is usually filled incorrectly and is a
source of alternative conceptions. Gap research of Wandersee and Griffard (2001) indicated
that, if there were gaps, the gaps would usually be filled incorrectly and thus misconceptions
formed. The researchers related the history and gap information to hypothesize that if a concept
was recently discovered, it would often have a gap due to the lack of knowledge of it.

**Uses of Released AP Biology Examinations**

The current research analyzes a sample of photosynthesis and cellular respiration
multiple-choice questions by reviewing all multiple-choice questions from the four most recently
released AP Biology Examinations. AP Biology Examinations are released approximately every
four to five years to the public. Usually, the released examinations are used to help familiarize
both high school and university instructors with the content of the examination. The high school
instructor is concerned with content and exam format so that they can prepare students for the
examination and the university instructors are concerned with content and rigor to help
determine the amount of advance placement credits to be awarded.

This research study extends the above common possible uses of the released examinations and considers the characterization level of the multiple-choice items with the researchers’ newly developed data analysis method. This method utilizes concept maps to organize and to display the data from the item analysis of questions pertaining to photosynthesis and cellular respiration of 263,257 student examinations from United States and other countries that took the 1990, 1994, 1999 and 2002 AP Biology Examinations, to help identify learning difficulties with photosynthesis and cellular respiration from the unorganized data.

**Development of Concept and Data Analysis Mapping, A New and Integrated Data Analysis Method**

Quick review of the multiple-choice questions may overlook the current conceptual level of questions in more recent AP Biology Examination compared to those at the start of the AP Program. Also, the use of tables of statistics about the exam results alone does not reveal the interconnections of concepts, lacks the description of the necessary analysis of concepts that require students to extend their thought beyond rote memory of information in the questions and answers, and does not reveal how the data of all the questions from the various years has covered the various concepts of photosynthesis and cellular respiration.

This research study’s careful analysis of the AP Biology Examination questions, concept relationships and item analysis data of photosynthesis and cellular respiration items indicates that the data is useful for pinpointing student difficulties, possible problems in instruction, provides
the big picture of how the various learning difficulties interconnect, and shows that the data have been commonly underutilized. The results of the analysis of AP Biology Examination multiple-choice items of cellular respiration was first used by the authors at the National Association of Biology Teacher's Convention in 2003 (Reuter and Wandersee, 2003) to identify particular learning difficulties and to develop technology applications that were useful for teaching cellular respiration.

Visual display of the examination’s data has been traditionally statistical tables. Tufte’s theory of information design (1990, 1997, 2001) indicates the importance of the excellent visual display of data to allow for clear and consistent analysis and the application of concept mapping provides a graphic solution to the multiple-choice data analysis of the AP Biology Released Examinations that extends the data analysis of the statistical tables.

Ausubel, Novak, and Gowin began to develop concept maps in the early 1970’s and concept maps have become vital tools in education research. One of the 1990 issues of the Journal of Research in Science Teaching had a special issue devoted to concept maps and one article included 100 references related to concept maps (Alkunifed and Wandersee, 1990). Concept maps have been shown to be useful tools for evaluating conceptual understanding (Markham, Mintzes, and Jones, 1994; Martin et al., 2000; Novak, 1990; Thompson and Mintzes, 2002; Wallace and Mintzes, 1990). Concept maps support Ausubel’s theory of meaningful learning (Novak, 2002), which underlies the hierarchical structure of the concept map (Hoz, Bowman, and Chacham, 1997) and are used in instruction to help students learn and in educational research to help determine understanding, alternative conceptions and gaps (areas that knowledge is missing) in learning.

As the researchers analyzed the AP Biology Examination statistical data in relationship to
the biology concepts of the items, the researchers discovered the effective use of concept maps for showing the relationships of the statistical item analysis to the concepts which extended the statistical data analysis. The researchers have developed and introduced a new application of concept maps for extended analysis of the AP Biology Examination statistical data that can help to identify gaps and difficulties in learning. The new analysis application was named concept and data analysis map, and it utilizes reference numbers with sublevel letters to analyze the level of conceptual difficulty and to identify possible paths for assessment or teaching these concepts.

**Purpose of the Research**

This research study analyzes the AP Biology Examination data to determine possible improvements in teaching and to go beyond the use of data for awarding college credit and help extend previous and future educational research efforts. For example, a qualitative study of Griffard and Wandersee (1999) that involved case studies of 12 students showed that there were gaps in learning photosynthesis and these gaps were filled with alternative conceptions. The analysis of the quantitative item analysis of data from 263,267 examinations has identified learning difficulties that support the findings of the case studies of Griffard and Wandersee (1999). The various research supports each other and allows for triangulation.

*Mapping Biology Knowledge* (Wandersee, Fisher, and Moody, 2000) describes the problems that exist in biology education, and concept maps help to display the knowledge of the learner (Novak, 2003, Allen and Tanner, 2003). The new technique of displaying quantitative AP item analysis data integrated within concept and data analysis map as used in the research of this article helps to reveal the knowledge of 263,257 students in a hierarchical analysis.

This research study considers the comprehensive nature of the AP Biology Examination, the cognitive categories of questions, the conceptual distance levels of the questions, the level of
physical science knowledge, the historical reference of discovery of the component, the indications of the item analysis data of the photosynthesis and cellular respiration for teaching, and four questions to help improve instruction:

1) Which poses the greatest difficulty for students, photosynthesis or cellular respiration?
2) Which aspects of photosynthesis are most problematic?
3) Which aspects of cellular respiration are the most problematic?
4) How well do students integrate the concepts of photosynthesis and cellular respiration?

METHODS

Assessing student learning is important and various qualitative and quantitative methods have been summarized by Sunburg (2002). There is also mixed methods approaches that integrate both qualitative and quantitative techniques (Tashakkori and Teddlie, 2003). This research study uses forms of mixed methods called qualitizing and quantizing data. Research based education follows either qualitative, quantitative, or mixed methods, for the research format. Most qualitative studies have depth of information but usually involve a small sampling and thus analysis of few participants. Dancy and Beichner (2002) call for the need for formal research over normal classroom feedback and considered qualitative research techniques, and various qualitative and quantitative methods have been summarized by Sunburg (2002). Most quantitative studies involve a relatively large sample and thus analysis of many participants. Mixed methods allows for a combination of both depth and breadth by careful combination of the two methods (Tashakkori and Teddlie, 2003). The research design for this study was mixed methods, which allows for the strengths of qualitative and quantitative methods.
Characterization of Questions / Concepts and Qualitizing Data

The quantitative component of this research study is based on the analysis of multiple choice item analysis of 263,267 examinations from the 1990, 1994, 1999 and 2002 Biology Advanced Placement Examinations (ETS 1990, 1994, 1999 and CEEB 2004). The items that concerned photosynthesis and cellular respiration concepts were identified and analyzed. There were a total of 51 items identified from the 4 tests that had a total of 480 multiple-choice questions. Each photosynthesis and cellular respiration question was assigned a number for research identification. The identification numbers of each question was used to identify the location of the multiple choice item on various concept data and analysis maps. Letters (e.g. a, b, c, d) were included with numbers, when the concepts or propositions were conceptually distant and thus required a path of numbers to track the thought process. The letters helped to identify conceptual distance and the levels of the concept hierarchy necessary to answer the question. The color helped to identify concepts that were most and least problematic.

The numbers were color coded according to percentage of correct answers. Questions that were answered correctly that were in a particular range were coded as follows:

- red: 20 - 39 % correct
- orange 40-49% correct
- blue: 50- 59% correct
- purple: 60-69% correct
- green: 70 -75% correct

Each photosynthesis and cellular respiration question was qualitatively characterized for: cognitive categories with Bloom’s taxonomy, physical science knowledge, conceptual distance and presence of other constructs (thermodynamics, community of matter, evolution, plant
physiology and animal physiology). Table 1 summaries these characteristics and also shows the quantitative value assigned to some of the characteristics. Assigning quantitative values to the characteristics allowed for descriptive statistical analysis of the qualitative characteristics, such as averages, percentages, and graphical analyses, and this is a mixed methods technique for analyzing data to allow for better triangulation.

Concept and data analysis maps were created with the concepts, propositions, and the data. First a traditional concept map was created. Boxes that contained concepts were connected with lines that had proposition phrases that related the concepts. The maps were developed to have an hierarchical structure. Onto these concept maps color coded numbers that represented concepts from the AP Biology Examinations were layered onto the traditional concept map to transform it into a concept and data analysis map.

First the carbon cycle concept and data analysis map was created and analyzed to determine the most problematic concepts. The Calvin cycle, light reaction of photosynthesis, Krebs cycle, and electron transport concepts were identified as the most difficult concepts, and more detailed maps were created for each of these concepts (Figures 6-8).

Historical Relationships

The very highest and lowest data (the outlier data) were identified according to the percentage of students that answered questions correctly. The concept was identified and historical information matched to it in a table.

Triangulation with Previous Research

Previous research of college students' learning difficulties with photosynthesis and cellular respiration was correlated to the AP Biology Examination results. A full literature review was done on previous photosynthesis and cellular respiration educational research. The
concepts that were included in both the AP Biology Examination and the educational research were analyzed with a matrix to determine the overall relationship.

**Sampling**

The quantitative item analysis of the AP Biology Examinations from 1999, 1994, 1990, and 2002 (ETS 1990, 1994, 1999 and CEEB 2004) which involved the entire population of test takers for those years. The educational research was gathered from various peer review journals.

The units of analysis was the students’ conceptual framework for photosynthesis and cellular respiration of students who participated in the study. The focus of the study was to identify the knowledge representation map in the form of a concept and data analysis map.

**Analysis**

Basic statistical analysis was done to determine the profile of photosynthesis and cellular respiration on questions and the percentage of correctly answered questions. Mixed methods analysis of qualitizing (Tashakkori and Teddlie, 2003) the quantitative data was used. The researcher took the quantitative AP Biology Examination data and analyzed the questions and the item analysis of the answers. The photosynthesis and cellular respiration questions were identified and organized according to various descriptors. The questions and answers were coded to determine meaning and to relate the meaning to the statistics, which is a form of data qualitization. Qualitizing the data allows description for the conceptual level and alternative conceptions from the quantitative data. The qualitized data were then plotted on a traditional concept map of photosynthesis and cellular respiration with color coded numbers to locate the question concept. The number refers to a particular concept and the color refers to percent score, red being the lowest scoring questions and green being the highest scoring questions. Table C is an example of the qualitized quantitative data from the 1990, 1994, 1999, and 2002 AP Biology
Examinations. A profile of knowledge of the conceptions that was derived from this qualitized data. The quantized data was then graphically analyzed (Figures 1-4). The quantitized data helped to extend the analysis of the concept and data analysis maps.

The test items were in qualitative format and were quantized to help determine a quantitative profile of the concepts in the items. The researchers then use triangulation between the data from previous research studies, which are predominately qualitative studies, with the qualitized data from AP Biology Examination and this is an example of mixed data analysis. Historical analysis of the concepts of the statistically high and low outlier questions and a matrix (Table 4) was prepared to assist the analysis.

RESULTS

Characterization of AP Biology Photosynthesis and Cellular Respiration Questions

The photosynthesis and cellular respiration questions were analyzed with respect to Bloom's taxonomy for categories of cognition, conceptual distance, level of physical science knowledge, and historical reference of discovery. The following summarizes the results.

Bloom's Categories in the Cognitive Domain

Figure 1 is a bar graph that shows the distribution photosynthesis and cellular respiration questions with respect to Bloom’s categories in the cognitive domain. Each of Bloom's categories was assigned a level and a numerical value to allow quantizing of the data. The lowest cognitive level was assigned the value 1 and the highest level, evaluation, was assigned a value of 6. Table 1 summaries the above. The majority, 47.1% of the questions are comprehension, level 2. The average level for the questions was 2.59 out of a possible 6 with a standard deviation is 1.12. The graph indicates there are few rote, application, evaluation and synthesis questions, and mostly comprehension and analysis questions.
**Conceptual Distance and Bloom's Categories in the Cognitive Domain**

Figure 2 is the characterization of AP Biology photosynthesis and cellular respiration questions using the conceptual distance model for Bloom's categories in the cognitive domain. This allows further analysis of the data by relating conceptual distance, the distance of the concepts and propositions within a question, with the cognitive level of the question. The levels of conceptual distance were assigned values of 0-1 so that the data could be quantized. A value of 0 indicates conceptual closeness and a values of 1 indicates distance. Table 1 summaries the above. A thorough analysis of the all questions show that only 17.8% of the all the questions are conceptually close, level 0, which related contingent concepts and propositions. Even for rote learning there are many conceptual distance question. Only 9.85 of the rote category questions were conceptually close and only 7.8 % of the comprehension category questions were conceptually close. Most of the questions involved conceptual distance, which is coded with a value of 1 and thus required consideration of concepts that were not contingent to their propositions. The average conceptual distance of all questions is 0.823 with a standard deviation of 0.385. The value of 0.823 indicates that most of the questions required students to consider concepts and propositions were distant.

**Physical Science Knowledge Level and Bloom's Categories in the Cognitive Domain**

Figure 3 is the characterization of AP Biology photosynthesis and cellular respiration questions using physical science (chemistry and physics concepts) understanding levels for Bloom's categories in the cognitive domain. The levels of physical science required to understand and to answer a question ranged from none to high. Values were assigned to each level to allow quantizing of the data. None was assigned a value of 0, low 1, medium of 2 and high of 3. Table 1 summaries the above. The figure shows that high levels of physical science
understanding were predominately required for all categories of questions. Of the 51 questions analyzed, 45% required a physical science understanding of level 3, which indicates the need to understand beyond the basic definitions of common physical science to answer the questions. The average physical science knowledge was 2.14 with a standard deviation of 0.917. Also, specifically 45% of the questions required knowledge of thermodynamics. The graph also shows that the only cognitive category that had more conceptually close concepts was knowledge.

**Physical Science Understanding Level and Conceptual Distance**

Figure 4 is the characterization of AP Biology photosynthesis and cellular respiration questions using the Conceptual Distance Description for each Physical Science Understanding Levels. The figure shows that most questions involved conceptual distance (value of 1) and high levels physical science knowledge (level 3) to understand and to answer the questions. The graph indicates the overall positive relationship between conceptual distance and physical science understanding. Questions that lacked physical science knowledge were exclusively conceptually close, and those questions that required high levels (level 2) of physical science knowledge were mostly.

The major focus of this study was to determine if photosynthesis or cellular respiration were more difficult for students to understand, and to analyze the problems specific to the study of photosynthesis and cellular respiration and to the integration of the concepts of photosynthesis and cellular respiration concepts. The following is an analysis of AP Biology Examination data that specifically concerns the learning difficulties of photosynthesis and cellular respiration and the interrelationship of photosynthesis and cellular respiration.
**Greater Difficulty: Photosynthesis or Cellular Respiration**

Figure 5 is the carbon cycle data Concept and Data Analysis Map, a composite map of carbon cycle concepts and related AP Biology Examination data. It shows the concepts and the data for both photosynthesis and cellular respiration.

Figure 5 lacks green coded numbers but had many red coded numbers in the photosynthesis section of the carbon cycle. This indicated that none of the photosynthesis concepts ranked in the high outliers of better understanding (70 - 85% understanding) but had the most poorly understood questions. All question code numbers that are of high understanding are coded with green and lowest understanding red and orange.

Upon observation of the lack of photosynthesis questions that had green coding in Figure 5, Table 2 was prepared to show the details of the relationship of the most difficult and least difficult questions and the percent answered correctly. Of the most difficult questions (20 - 49% correct, the red and orange coded number) 52.3% of those were photosynthesis conception, 28.6% were integrated photosynthesis and only 19.0% were cellular respiration concept questions. Photosynthesis questions were obviously the most abundant. Of the least difficult questions that were indicated by the highest percent correct scoring questions 100% were cellular respiration concepts and 0% interrelated photosynthesis and cellular respiration. It was obvious that students were more successful with the cellular respiration questions and least successful with the photosynthesis questions and integrated photosynthesis and cellular respiration concept questions using both the concept and data analysis map and related matrices. Table 2 also includes the overall averages for the various concepts and photosynthesis has the lowest average. Both the overall and outlying high and low scores indicate that photosynthesis questions were the most difficult for students, as indicated in Table 2.
Most Problematic Aspects of Photosynthesis Concepts

Figure 5 indicated the most problematic aspects of those tested with this study's four-year AP Biology sample, and the overall results were indicated above in the description of the most difficult concepts of the carbon cycle. Figure 5 indicated the most problematic aspects of photosynthesis was the fixation of carbon, the relationship between the fixing of carbon and production of organic molecules and the light reaction in relationship to the Calvin Cycle.

Additional concept and data analysis maps, Figures 6 and 7 were created to help analyze these most difficult concepts of photosynthesis, and Table 3 summaries the results. No photosynthesis questions scored in the highly understood category. Table 3 summaries the above.

Carbon Cycle

The lowest understanding in the carbon cycle is the areas of red and orange numbers. Figure 6 is a concept and data analysis map that shows the details of the Calvin Cycle concept and the associated AP Biology Examination data. The major learning difficulties as identified with the diagrams are:

- the difference of C₃ and C₄ plant fixation of carbon in the Calvin Cycle (3a and 3b with 27% correct)
- the fixation of carbon dioxide with the distant concept of the synthesis of starch (9a and 9b with 40% correct)
- carbon dioxide and water are need to make the plant grow, increase in number of organic molecules (12a, 12 b, and 12c with 44% correct)
- the involvement of the stomata for diffusion of carbon dioxide to increase the yield of photosynthesis (13 a and 13 b with 44% correct)
• the fact that the chloroplast evolved from a photoautotrophic prokaryote (15a and 15b with 44% correct)
• the Calvin Cycle related to incorporating carbon dioxide into organic molecules (17a, b, c with 46% correct)
• the products light reaction of photosynthesis and their use in the carbohydrate producing reactions (20a, b, c, and d with 46% correct)
• the site of glucose synthesis is the chloroplast (31a and 31b with 55% correct)
• carbon fixation is more efficiently by a C₄ plant instead of a C₃ plant (36 with 59% correct).

Light Reaction

The relationships of concepts across the light reaction were difficult and Figure 7 is a concept data map that shows the details of the light reaction of photosynthesis. The function of light and chlorophyll in relationship to the production of oxygen from water and the use of the light reaction products in the Calvin Cycle were the most difficult concepts. The following are difficulties in learning as indicated by the test results:

• the presence of thylakoid membrane and not the chloroplast structure in prokaryotic photosynthetic organisms (1a and b with 22% correct)
• the use of different color wavelengths by different colors of chlorophyll molecules (2 with 23%, the chloroplasts related to ATP production (11a and b with 42% correct)
• the need of water and carbon dioxide for photosynthesis and plant growth (12 a and b with 44% correct)
• the splitting of water related to production of the Calvin cycle (12a,12b, and 12c with 44% correct)
• the light reaction products that are used in carbohydrate synthesizing reactions., (20a, 20b, 20c, and 20d with 46% correct)

• that oxygen is a by-product of the light-independent reaction of photosynthesis (21 a and b with 48% correct)

• Oxygen released during photosynthesis comes from H₂O instead of CO₂, chloroplast and light are required to change the color of DPIP (24 a, b and c with 53% correct)

• the most important difference between the light-dependent and independent reactions of photosynthesis is that the light dependent reactions produce ATP And NADPH and the light-independent reactions use the energy stored in ATP and NADPH (29a and 29b with 55% correct)

• light reaction producing oxygen (21a and 21b with 49% correct)

• the relationship of cytochromes and the creation of the H⁺ gradient in chemiosmosis, (25a and 25b with 53% correct). Table 3 summaries the above.

**Most Problematic Aspects of Cellular Respiration**

Figure 8 shows the details of electron transport and chemiosmosis in relationship to the Krebs cycle in a concept and data analysis map. The function of protons in chemiosmosis, electrons in electron transport, and use of ATP appear to be the most difficult. As summarized in Table 3, the major learning difficulties as identified with the diagram are:

• The most ATP is formed as the result of protons moving down a gradient (7a, b and c with 33% correct)

• the hydrolysis of ATP is needed for negative free energy reactions (5a and 5b with 30% correct)
• the Krebs cycle produces of FADH₂ that then enters the electron transport chain at a lower level than electron entering the beginning of the chain (8a, 8b and 8c with 38% correct)
• NAD⁺ is an intermediate electron carrier in glycolysis and the Krebs cycle (14a and 14b with 44% correct)
• the hydrolysis of ATP is coupled with reactions such as active transport (16a and 16b with 46% correct)
• with oxygen more ATP is produced during cellular respiration (19a, 19b with 48% correct)
• ATP can act as an allosteric inhibitor (23a and 23b with 51% correct)
• the most important consequence of electron transport chain is that an electrochemical (proton) gradient is formed (25a and 25b with 53% correct)
• negative feedback can cause the rate of pyruvic acid to fluctuate (30a and 30b with 55% correct)
• metabolic breakdown of glucose yields less energy with fermentation than during aerobic respiration (32a and 32b with 56% correct),
• electron transport occurs in a double membraned organelle (33 with 56% correct)
• the most ATP is produced during electron transport and chemiosmosis in aerobic respiration (34a, b, c, and d with 56% correct).

Integration of Photosynthesis or Cellular Respiration Concepts

Twenty percent of the questions required the integration of concepts from photosynthesis and cellular respiration. The common use of ATP synthase, electron transport, and relation of
carbon dioxide in the Krebs and Calvin Cycles are the most difficult concepts. Students had difficulty understanding the following:

- ATP synthase is a protein located both in the mitochondrial and chloroplast membranes (4a and 4b with 29% correct)
- the need for the hydrolysis of ATP to power positive free energy reactions (5a and 5b with 30% correct and 46a and b with 45% correct)
- cytochromes were membrane-bound electron carriers found in electron transport of both aerobic respiration and photosynthesis (6a and 6b with 31% correct)
- ATP is produced in mitochondria and chloroplasts (11a, 11b, 11c and 11d with 42% correct)
- carbon dioxide was produced in the Krebs cycle and not the Calvin cycle or the light-dependent reactions of photosynthesis (26a, b, and c with 53% correct)
- organic molecules instead of carbon dioxide were used by heterotrophs in the carbon cycle (27a and 27b with 54% correct)
- chemiosmosis instead of glycolysis was found in both photosynthesis and cellular respiration (35a and 35b with 57% correct).

Table 3 summaries the above.

**Relationship of Photosynthesis and Cellular Respiration to Other Themes**

Some questions relation photosynthesis and cellular respiration to other themes and there was some difficulty: plant physiology related to stomata opening and diffusion of carbon dioxide (13a and 44b) evolution of chloroplasts and glycolysis (15 and 18), consumption of oxygen and the cardiovascular system (49). Table 3 summaries the above.
Relationship of Recent Discoveries to the Outliers

Table 4 shows the relationship of history to the percentage of questions that are answered correctly. The table shows the high and low outlier questions. The low outlier questions of the knowledge or comprehension category had a common history factor of more recently discovered. 80% of the outlier questions concerned concepts that were discovered from 1955 to 1973, and 100 the high outlier questions were all discovered from 1930 to 1948. Table 4 summaries the outlier questions and discovery of the concepts.

The following were concepts related to their discoveries that composed the low outlier questions:

- difference in carbon fixation in C\textsubscript{3} and C\textsubscript{4} plants (3a and 3b with 27% correct) and the discovery of the Hatch-Slack pathway in 1966 (Taiz and Zeiger, 1998)
- the fact that ATP synthase is an enzyme in the inner wall of the mitochondrial and chloroplast membranes (4a and 4b with 29% correct) and the discovery of ATP synthase by Racker in 1960 (Nelson and Cox, 2000) and the function of ATP synthase was discovered by Boyer, Walker and Skou in 1973, Walker and Skou in 1997 (Boyer, Walker, and Skou, 1997)
- the relationship of chemiosmosis and production of ATP related to the flow of electron down the concentration gradient (5a and 5b with 33% correct) and its discovery by Mitchell in 1961 (Mitchell, 1978)
- the Krebs cycle produces of FADH\textsubscript{2} that then enters the electron transport chain at a lower level than electron entering the beginning of the chain, (8a, 8b and 8c with 38% correct) and Crane's discovery of ubiquinone and plastiquinone's function in the electron transport chain during 1955-1959.
• the hydrolysis of ATP and coupling the energy to a positive free energy reaction and the discovery of this by Lipmann in 1942 (Lehninger, 1975). Note this one does not follow the relationship of recent discovery and low scores since it was discovered in 1942 and the question is the reason 80% of the questions followed the recent history and low score relationship.

The following is a summary of the question that had high scores and are related to discoveries that were not recent, earlier than 1955:

• Definition of glycolysis to be glucose convert to pyruvic acid (46 with 72% correct) and the discovery of the Embden-Meyerhof pathway by Embden and Meyerhof in 1930 (Lehninger, 1975)

• Mitochondria is the organelle that requires oxygen (48a and 48b with 78% correct) and its discovery by Lehninger and Kennedy on 1948 (Lehninger, 1975)

• ATP energy is transfer to do cellular work (50a and 50b with 82% correct) and its discovery by Lipman in 1941 (Leninger, 1975)

• Mitochondrion is the organelle that produces ATP (51a and 51b with 85% correct) and its discovery by Lehninger and Kennedy in 1948 (Lehninger, 1975)

It appears that the more recently discovered concepts of carbon fixation in C₃ and C₄ plants, ATP synthase, electron transport and related chemiosmosis are the least understood. It takes time for the information about new discoveries to be communicated to the scientific community, for the information to be included in text book and for people to gain familiarity with it. For example Mitchell discovered chemiosmosis in 1961 but did not receive the Nobel prize until 1978 (Mitchell, 1978). Boyer, Walker and Skou discovered the function of ATP synthase in 1971 and they won Nobel Prize in Chemistry in 1997.
Relationship of Previous Research and AP Biology Exam Data

Table 5 shows the relationship of previous research to the data of the AP Biology Exams. The table shows that the AP Biology Exam supports previous research as follows:

- more general questions were answered least correctly (Eisen and Stavy, 1988) and more students answering questions about photosynthesis producing glucose (55% correct) and less correctly answering questions organic molecules (44% correct)
- uncertain of how oxygen is produced and not able to link photosynthesis together physical and chemical processes (Hazel and Prosse, 1994) and the AP Biology Examinations had an average of 50% on the role of oxygen and 33% on the role of the stomata
- the difficulty that students had with water and carbon dioxide as reactants of photosynthesis to make carbohydrates (Wandersee, 1986) and the AP Biology Examinations had 5 questions with an average of 48% that supported Wandersee's findings
- the gaps in learning associated with the development of alternative conceptions research of Griffard and Wandersee (2001) and indicated problems with distinguishing concepts such as fixation (question numbers, 3, 36 and 42 with an average of 50.7%), identifying categories such as molecules (question numbers 12, 13 and 17), propositions missing (question number 10 at 41%), conceptual distant of carbon dioxide becoming organic material (question numbers 12, 17, 20 and 46 with an average of 49.8%), gaps in constructs such as thermochemistry (question numbers 2, 3, 5, 6, 7, 8, 14, 16, 18, 21, 24, 25, 26, 28, 32, 34, 36, 41, 44, 45, 49, 50 with an average of 51.6%)) and community of matter (question numbers 9, 12 and 17 with an average of 43.3%).
DISCUSSION

The first consideration of the research was the characterization of the AP Biology photosynthesis and cellular respiration multiple choice items. The use of Bloom's cognitive domain categories, conceptual distance, physical science knowledge and the concept and data analysis maps helped to ensure a comprehensive analysis.

The use of Bloom's cognitive domain categories helped to establish one basic dimension of the question. A one dimension characterization of the questions could have been misleading to characterize the questions level as only comprehension because it would have neglected to consider the other dimensions or factors involved in the questions and in the concepts of photosynthesis and cellular respiration. The method of using cognitive domain categories, conceptual distance and physical science knowledge was useful for revealing the various aspects of the questions and the related concepts.

The conceptual distance of the question which was based on the knowledge gap studies of Griffard and Wandersee (2001) helped to relate the issue of conceptual distance of the conceptions and the related test questions. The physical science knowledge rating was developed specifically to help measure the level of physical science knowledge required to answer questions which has been a concern of the NRC (NRC, 2003).

Quantizing the cognitive domain categories, conceptual distance measure and the physical science knowledge required by the learner for the understanding of the questions and the concepts allowed for comparison of the data with descriptive statistics and bar graphs to see the relationship of the various components. This is the first research to review the AP Biology Examination items with these various analyses methods. The analysis of the question structure
and content was useful for analyzing the hierarchical concepts of photosynthesis and cellular respiration.

Analysis of the conceptual distance of the knowledge to understand and to answer the questions (which is displayed in Figure 2) helped to show that most questions required conceptual distance to answer the questions. In particular, 83% of the questions that were classified as comprehension required conceptual distance and the conceptual distance adds the level of abstraction and difficulty of the question. The use of conceptual distance helped to example the hierarchical nature of the concepts from both the assessment and teaching of these concepts. Learners are required to make distant relationships even with the most basic concepts of photosynthesis and cellular respiration, and Figures 5 help to show the conceptual distance be using small letters with the code number to help track the conceptual distances that are require for the various questions.

Bio2010 (NRC, 2003) indicate the importance of physical science concepts in the learning of biology. The results of this study are congruent with the findings revealed in Bio2010. The majority of the questions required a high level of physical science understanding to understand and answers the questions which added to the abstraction and difficulty of the questions, and this would have be overlooked if only Bloom's cognitive categories were used to characterized the questions. Figure 4 shows that most to the questions were level 3 physical science knowledge and level 1 (indicating conceptual distance). Relating the results of various questions characteristics allowed for a more comprehensive analysis. The that most of the questions involve conceptual distance the concept and data analysis maps are very useful in the analysis of the photosynthesis and cellular respiration concepts that are hierarchically arranged.
A concept and data analysis map of photosynthesis and cellular respiration, Figure 5, helps to display the data to show the interconnected conceptual nature of most photosynthesis and cellular respiration multiple-choice questions. The concept and data analysis maps help to give a bird’s eye view similar to looking at a traffic pattern form a helicopter above the traffic. The concept and data analysis map is similar to the streets which symbolize concepts and the data from the AP Biology Examinations are the measure of the traffic or understanding and necessary distances between streets (concepts) can be determined to show the levels of understanding necessary to correctly answer AP Biology Examination multiple choice questions. The view from the helicopter, concept map, provides an objective and concise overview of the relationships of concepts, integration of chemistry and student difficulties.

Figure 5 and Table 2 make it obvious that photosynthesis was that most difficult because there is an abundance of red and orange item codes indicating difficulty and no green item codes upon visual analysis. Calculations showed that 52.3% of the difficult questions being photosynthesis questions, and 0% being within the highly correct category. Knowing that students have more difficulty with photosynthesis instructors might be more careful to monitor student progress to modify instruction if necessary. The following analysis of the most difficult aspects of photosynthesis and a cellular respiration pinpoints where students have the most difficulty and where there needs to be more attention to teaching. Related bioeducational research is included in the analysis.

Table 3 and Figure 5 indicate that understanding the role do carbon dioxide in photosynthesis the most difficult among the Calvin Cycle questions. The fixation of carbon reappears over and over in the most difficult concepts. Wandersee (1986) indicated the difficulty that student had with the importance of carbon dioxide as raw material of
photosynthesis with a group of 1,450 students and this study expanded the data base to 263,267. Two of the questions involve the fixation of carbon in C3 and C4 plants and that was recently discovered by Hatch and Slack in 1966. The recent discovery might be part of the reason for the low understanding. The research of Griffard and Wandersee (2001) indicated that the students had gaps in distinguishing the meaning of two concepts and fixation was one of the gaps identified in their research. The more recently discovered concepts are not as well communicate and there is less familiarity of the concept among the instructor. Songer and Mintzes’ (1994) research indicated the problems with everyday language in their studies of cellular respiration and the use of the word "fixation" might be an example of the problems that arise from everyday language.

The production of carbohydrates in the Calvin cycle might have been difficult because the student was required to determine a more general answer than the specific answer of glucose that is usually included in most photosynthesis equations. The research of Griffard and Wandersee (2001) indicated that membership gaps, identifying categories, exist.

The difficulty of identifying glucose as an organic molecule could result from a gap according to Griffard and Wandersee (2001). Also, the research of Eisen and Stavy (1988) indicated that as questions become more general less were answered correctly. This study was with 188 high school and university students and this study of 263,267 students supports the Eisen and Stavy research of difficulty with more general questions. Also, the production of oxygen was uncertain. This study confirms the study of Hazel and Prosse (1994) that involved 36 first year university students.

The need of the products from the light reaction to the Calvin Cycle was also among the most difficult among the light reaction questions. Griffard and Wandersee (2001) identified
conceptually distant gaps and the difficulty of understanding the products of the light reaction being the reactants of the Calvin cycle are distant and the concept and data analysis maps indicated the distance. The use of light and chlorophyll were difficult and this was also indicated with the research of Wandersee (1986). Most of the difficult photosynthesis concepts were conceptually distant and required a high level of physical science.

Most of the problems with learning cellular respiration were related to electron transport. The most difficult concept was the movement of protons against the gradient to produce ATP. This is the concept of chemiosmosis which was discovered by Mitchell in 1961 and the Nobel prize awarded to him in 1978 (Mitchell, 1978) and the recent discovery is a factor that contributes to its difficulty. Also, chemiosmosis requires high level of physical science knowledge. Another concept with difficulty was \( \text{NAD}^+ \) being an intermediate electron carrier required knowledge of redox, which is a high level physical science concept. Most educational research of photosynthesis and cellular respiration learning did not consider chemiosmosis and electron transport. This research suggests that more educational research needs to be conducted with respect to chemiosmosis and electron transport. Difficulty understanding that more oxygen could increase ATP production supports the research of Songer and Mintzes (1994) which indicated only 8% of the student in a study of 200 college freshman could predict less energy with anaerobic conditions.

Most of the difficult concepts required knowledge of thermodynamics and Griffard and Wandersee (2001) identified thermodynamics as a gap in the understanding of photosynthesis. The lack of understanding of the basics of thermodynamics and the gaps that results cause the students to fill the gaps with information and most often the information is incorrect according to

The major problems with the integration of photosynthesis and cellular respiration concepts according to the data were with understanding that ATP synthase is a protein in the chloroplasts and the mitochondria. The difficulty of categorizing the enzyme, ATP synthase, as a protein could result for the inability to distinguish categories (Griffard and Wandersee, 2001) and the inability to answer questions with more general answers (Eisen and Stavy, 1988). Also the function of ATP synthase was discovered recently (Boyer, Walker, and Skou, 1997). The lack of understanding that ATP hydrolysis is coupled with positive free energy reactions requires a high level of physical science knowledge and require knowledge of thermodynamics which indicates the need to consider conceptually distant concepts.

NAD$^+$ as an electron carrier in aerobic respiration and photosynthesis was difficult and it required conceptually distant concepts. Student have to track the NAD$^+$ in the carbon cycle and that requires conceptually distance. The concept and data analysis maps indicate the distance. Also there is the need to the categorization of The Krebs cycle as part of aerobic respiration. Usually books show NAD$^+$ as and electron carrier in the Krebs cycle and the student has to make the generalization that the Krebs cycle is part of aerobic respiration. Also, most students did not understand the entrance of electrons from FADH$_2$ into the electron transport chain. Between 1955 and 1959 Crane discovered how electron enters electron transport at ubiquinone, and the relative time frame of the study may have prevented much consideration of it in most textbooks.

Similarly, the difficulty with the question that deals with heterotrophs utilizing organic molecules for energy could be explained with a similar explanation. The student must track what the heterotroph must do in the carbon cycle and then a generalization must be made about what
is utilized. Usually food is what textbooks will describe as what heterotrophs utilize in respiration. Usually textbooks do not make the generalization of the carbon cycle and the generalization of the utilization of organic molecules. Categorization is difficult and causes gaps (Griffard and Wandersee, 2001) and making generalizations usually reduces scores (Eisen, Stavy, 1988). Categorization, conceptual distance, and the need to understand thermodynamic is necessary for the questions that concerns electron transport related to electrochemical gradient in both the mitochondria and the chloroplast.

ATP production both the mitochondria and the chloroplast requires student to understand that ATP is produced in photosynthesis and that photosynthesis is done in the chloroplast. They also have to understand that ATP is produced in cellular respiration and that cellular respiration occurs in the mitochondria. There is both conceptual distance and generalization that has to be done to answer this question. The need to characterize the products of the Krebs Cycle and photosynthesis required conceptual distance.

Extending the analysis of the questions beyond Bloom's cognitive categories helped to allow for a full analysis from different points of view. The concept and data analysis maps helped to analyze conceptual distance in relationship the specific concepts in involved and the physical science knowledge helped to establish the prior knowledge necessary to successfully understand the photosynthesis and cellular respiration questions. The historical analysis relating history of discovery to difficulty indicates that newly discovered concepts are usually more difficult to understand than previously discovered concepts. The new concepts require much physical science to understand and there is usually conceptual distance involved in the understanding. Correlating the findings of this research to previous qualitative studies of smaller scale helps to add more information and to confirm the previous studies.
This research has not only identified the major problems in the teaching of photosynthesis and cellular respiration based on data from 263,267 students, it has introduced the concept and data analysis method of analysis of assessments and curriculum for cognitive components that are required for understanding. This research shows the areas that were most problematic to photosynthesis and cellular respiration learning and assessment. Knowledge of the root of the cognitive environment of the conceptual relationships should help improve instruction and also provide means of assessment for future research on the impact of new instructional strategies on the learning of photosynthesis and cellular respiration. This research supports the recommendation of the NRC in *Bio2010* (2003) to emphasize studies in physical sciences to strengthen the study of biology because concepts similar to photosynthesis and cellular respiration require prior knowledge of physical science.

The AP Biology Examination has been a potential instrument for assessing the status of students' knowledge on photosynthesis and cellular respiration and provides "common ground" (Tanner, Chatman, and Allen, 2003) for university and high school communities to gather to communicate about the issues associate with teaching introductory college biology. Hopefully the common ground of the AP Biology Examination in this article will help foster communication about the difficulties teaching photosynthesis and cellular respiration and will encourage future research that is aimed at the difficulties addressed in this article. Instructional strategies should be based in educational research and this research provides the grounds for future instructional strategy research. Integrating technology based laboratories might help fill the gaps and this research study helps to indicate the location of the gaps with the concept and data analysis maps. Watson and Crick (1953) indicated that they had taken notice to future DNA
research and in a similar fashion future bioeducational technology research “has not escaped our notice” (Watson and Crick, 1953, p. 737).

REFERENCES


<table>
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<tr>
<th>Characteristic of photosynthesis &amp; cellular respiration questions</th>
<th>Components of Characteristics</th>
<th>Description of Characteristic</th>
<th>Quantitative value assigned</th>
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<td>High</td>
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<td>Application</td>
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<td>Percent least difficult questions (70% – 85% correct)</td>
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<td>29a and 29b</td>
<td>55%</td>
<td>ATP + NADPH are products and used in Calvin cycle</td>
</tr>
<tr>
<td>Respiration</td>
<td>7a, b, and c</td>
<td>33%</td>
<td>ATP produced as a result of movement of electrons against concentration gradient</td>
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<tr>
<td>Electron transport</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>8a, b, and c</td>
<td>38%</td>
<td>FADH₂ from Krebs to electron transport</td>
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<tr>
<td></td>
<td>14a and 14b</td>
<td>44%</td>
<td>NAD⁺ as intermediate in electron transport</td>
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<td>16a and 16b</td>
<td>46%</td>
<td>ATP hydrolysis coupled to active transport</td>
</tr>
<tr>
<td></td>
<td>19a and 19b</td>
<td>48%</td>
<td>More O₂ can increase ATP production</td>
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<td>23a and 23b</td>
<td>51%</td>
<td>ATP can act as an allosteric inhibitor</td>
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<td>30a and 30b</td>
<td>55%</td>
<td>Pyruvic acid related to negative feedback</td>
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<td></td>
<td>32a and 32b</td>
<td>56%</td>
<td>More energy from aerobic than anaerobic conditions</td>
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<td></td>
<td>33</td>
<td>56%</td>
<td>Electron transport occurs in double membraned organelle</td>
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<td>Photosynthesis + respiration</td>
<td>4a and 4b</td>
<td>29%</td>
<td>ATP synthase is a protein in mitochondria and chloroplasts</td>
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<td>interrelated</td>
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<td>5a and 5b</td>
<td>30%</td>
<td>ATP hydrolysis coupled to free energy reaction</td>
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<td>6a and 6b</td>
<td>31%</td>
<td>Cytochromes are electron carrier in aerobic respiration and photosynthesis</td>
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<td>11a, b, c, and d</td>
<td>42%</td>
<td>ATP produced in both mitochondria and chloroplast</td>
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<tr>
<td></td>
<td>25a and 25b</td>
<td>53%</td>
<td>Electron transport related to electrochemical gradient in both mitochondria and chloroplast</td>
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<td>26a, b, and c</td>
<td>53%</td>
<td>CO₂ produced in Krebs cycle and not photosynthesis</td>
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<td>27a and 27b</td>
<td>54%</td>
<td>Heterotrophs utilize organic molecules for energy</td>
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<td>AP Question Information</td>
<td>% correct answers</td>
<td>Type of Question</td>
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<td>3a</td>
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<td>8a, 8b, 8c</td>
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<td>48a, 48b</td>
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<td>2002 #42</td>
<td>82</td>
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<td>50a, 50b</td>
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<td>85</td>
<td>respiration</td>
<td>51a, 51b</td>
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**Table 4 Analysis of Relationship of History of Discovery and Difficulty**
<table>
<thead>
<tr>
<th>Author</th>
<th># of learners and grade level</th>
<th>Research Description</th>
<th>Question Description (and topic) %correct</th>
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<tr>
<td>Eisen and Stavy, 1988</td>
<td>188 high school and university</td>
<td>&quot;As questions became more general the percentage of students who answered correctly deceased for both majors and nonmajors&quot; (p. 208). Organic molecules</td>
<td>31 (glucose) - 55% 9 (starch) - 40% 12 (organic) - 44% 13 (organic) - 44% 17 (organic) - 46%</td>
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<tr>
<td>Hazel and Prosse, 1994</td>
<td>36 first year university students</td>
<td>There is uncertainty as to how oxygen is produced. Students are unable to link photosynthesis and other physical and chemical processes such as water uptake and respiration.</td>
<td>1 – 49% 22 – 51% 13 – 44%</td>
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<td>Wandersee, 1986</td>
<td>1,405 5th grade 8th grade 11th grade college sophomores</td>
<td>The least improvement over time was noted for the following concepts: the role of water in photosynthesis, the role of chlorophyll, and the importance of carbon dioxide as a raw material for photosynthesis.</td>
<td>9 – 40% 12 – 44% 13 – 44% 17 – 46% 43 – 66% Avg. 48%</td>
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<tr>
<td>Songer and Mintzes, 1994</td>
<td>200 college freshmen</td>
<td>Only 8% of students predict less energy with anaerobic conditions</td>
<td>19 – 48%</td>
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<tr>
<td>Griffard and Wandersee, 1999</td>
<td>12 introductory college</td>
<td>Concept- distinguish concept (not able to distinguish meaning of 2 concepts (e.g. fixation of carbon)</td>
<td>3 – 27% 36 – 59% Avg. 50.7%</td>
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<td></td>
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<td>Membership gaps (identify category molecules (e.g. organic molecules)</td>
<td>12 – 44% 13 – 44% 17 – 46% Avg. 44.7%</td>
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<td>Conceptually close (simple missing link between 2 concepts) (e.g. constituent of chlorophyll)</td>
<td>10 – 41%</td>
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<td>conceptually distant construct (e.g. CO₂ incorporated into distant organic)</td>
<td>12 – 44% 13 – 44% 17 – 46% 20 – 49% 43 – 66% Avg. 49.8%</td>
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<td>Gaps in biochemistry construct include thermodynamics</td>
<td>2, 3, 5, 6, 7, 8, 14, 16, 18, 21, 24, 25, 26, 28, 32, 34, 36, 41, 44, 45, 49, 50, Avg. = 51.6%</td>
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<td></td>
<td>Gaps in biochemistry construct include community of matter</td>
<td>9 – 40% 12 – 44% 17 – 46% Avg. 43.3%</td>
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</tbody>
</table>
Figure Legends

Figure 1 Characterization of AP Biology photosynthesis and cellular respiration questions using Bloom’s categories in the cognitive domain.

Figure 2 Characteristic of AP Biology photosynthesis and cellular respiration questions using conceptual distance model for all Bloom’s categories in the cognitive domain.

Figure 3 Characterization of AP Biology photosynthesis and cellular respiration questions using physical science level model for Bloom’s categories in the cognitive domain.

Figure 4 Characterization of AP Biology photosynthesis and cellular respiration questions using conceptual distance model for each physical science level.

Figure 5 - Photosynthesis and cellular respiration concept and data analysis map that relates student knowledge on 1990, 1994, 1999 and 2002 (ETS) Biology AP Examinations to the concept.
Legend: The Percentage of Students That Correctly Answered Questions Concerning Concept: Red = 20 – 39; Orange = 40–49; Blue = 50 – 59; Purple = 60 – 69; Green 70 - 85

Figure 6 The Calvin Cycle Concept And Data Analysis Map

Figure 7 The Light Reaction Concept And Data Analysis Map

Figure 8 The Krebs Cycle, Chemiosmosis and Electron Transport Concept And Data Analysis Map
Figure 1 Characterization of AP Biology photosynthesis and cellular respiration questions using Bloom’s categories in the cognitive domain.

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Figure 7
The Light Reaction
Concept And Data
Analysis Map
Figure 8 The Krebs Cycle, Chemiosmosis and Electron Transport Concept And Data Analysis Map
APPENDIX P:

CONCEPT MAPS OF SELECTED PARTICIPANTS
Baxter Concept Maps
Wished he knew a description of cellular respiration. That would help him to get started.
Cellular Respiration

1st process
- Glycolysis
  - Takes place in cytoplasm
  - Leads to intermediate processes
- Fermentation
  - Occurs in cytoplasm

2nd process
- Krebs cycle
  - Occurs in mitochondria
  - Generates NADH

3rd process
- Electron transport
  - Generates ATP
  - Occurs in mitochondria

Redox reactions
- ATP synthase
- NADH

Associated with both exergonic and endergonic

Oxidative phosphorylation

Photosynthesis

Glycolysis

Mitochondria

NADH

ATP Synthase

Intermediates

Acetyl CoA

Carbon Dioxide

Glucose

ATP
Baxter
Delayed
Cellular Respiration
Score: 117

both endergonic and exergonic

is both

cellular respiration
uses

redox reaction

starts with

glucose

which does

oxidative phosphorylation

and enters

glycolysis

produces

pyruvic acid

no oxygen

which is

anaerobic

enter

fermentation

ATP

to produce

carbon dioxide

ATP

to alcohol

not sure how H+ ions get over there

not sure of water

Thinks cytochomes are protease along memerane where there is electron transport

oxygen

enter

mitochondria

emit

produce

carbon dioxide

acetyl Co A

enters

Krebs cycle

produces

ATP

CO2

intermediate e-acceptor

electron transport

which enters (electrons)

hydrogen ions

collect outside the

membrane

inside the

mitochondrion

H+ come back across the membrane through ??

ATP synthase

to make

ATP

not sure how H+ ions get over there
Photosynthesis is a Light Dependent Reaction that uses Chlorophyll to create glucose. The following are also involved:

- oxygen
- energy
- light
- energy

Score 10
Easter future visual field
Photosynthesis
Score: 177

Calvin Cycle and the Photosystems

Photosynthesis:
- Light-dependent reactions
  - Light is absorbed by chlorophyll in the thylakoid membranes.
  - Electrons are excited and pass through the electron transport chain, generating ATP.
  - Oxygen is released as a byproduct.

Light-independent reactions (Calvin cycle):
- CO₂ is fixed by Rubisco into a 3-carbon compound.
- ATP and NADPH are used to regenerate CO₂ for the next cycle.
- Glucose is synthesized from these reactions.

C3 Pathway:
- Occurs in C3 plants, which have a mesophyll layer.
- Utilizes CO₂ in the Calvin cycle.

C4 Pathway:
- Found in C4 plants, which have a bundle sheath layer and mesophyll layer.
- CO₂ is fixed in a separate pathway before being transported to the Calvin cycle.

Photosystem I (PSI) and Photosystem II (PSII):
- PSI captures light energy and generates electrons.
- PSII splits water to produce oxygen and protons.

Electron Transport Chain (ETC):
- Electrons are passed through the ETC, generating ATP.
- Oxygen is the final electron acceptor.

ATP Synthesis:
- ATP is synthesized from the proton gradient created by the ETC.

Carbon Fixation:
- CO₂ is fixed into a 3-carbon compound.

Redox Reaction:
- Reduction of CO₂ to glucose.

Energy Production:
- ATP is the energy currency.

Carbon Fixation:
- Occurs in the Calvin cycle.

Glucose Synthesis:
- Glucose is synthesized from CO₂.

Need ATP before Calvin cycle because Calvin cycle uses energy.

Note: The diagram includes various biological processes and chemical reactions involved in photosynthesis and the Calvin cycle.
Delayed Photosynthesis

Baxter

Photosynthesis is done by autotrophy has both endergonic and exergonic redox reaction

light dependent reaction has

occurs in chloroplast

which has thylakoid composed of chlorophyll

which have photosystems

which are hit by electrons to excite photons

splitting of water to

producing hydrogen ions going to oxygen

intermediate e-acceptor NADPH enter either or electron transport has electrons enter chemiosmosis with H+ to pass through ATP synthase
to create ATP which is photophosphorylation

Calvin cycle allows for carbon fixation which adds carbon dioxide to produce glucose which is cytochromes

472
Bunny Concept Maps
Cellular Respiration

Is fueled by

Sugars

Bunny
Baseline
Cellular Respiration

Score 2
Bunny
Past Visual Field
Cellular Respiration
Score: 129

**cellular respiration**
- performed by heterotrophic autotrophic
- involves both endergonic and exergonic
  - glucose is broken down using aerobic
    - glycolysis occurs in all organisms
      - mitochondrion
        - with oxygen (aerobic)
        - oxidized with carbon dioxide to form pyruvic acid
          - Co Enzyme A
            - to form Acetyl CoA
              - used in Krebs cycle
                - to yield FAD+NAD+ electrons
                  - FADH2
                    - NADH
                      - some ATP

  - without O2
    - enters fermentation
      - produces lactic acid in plants
        - alcohol produced in phyllosphere microbes in kimchee with a little alcohol

  - soil microbes
    - anaerobic
    - cytochromes
      - oxidative phosphorylation

- intermediate e-acceptor enters to electron transport
  - mito. inner membrane
    - mito. matrix

  - hydrogen ions are forced through
    - chemiosmosis
      - has the byproduct of water

  - ATP synthase
    - active transport
      - most ATP is formed

- Substrate Level Phosphorylation
  - NOT SURE HOW

- electron transport
  - for
    - is when
      - are moved by
        - to produce
          - ATP
  - is how
    - most ATP is formed
Bunny
Delayed Cellular Respiration
Score: 126

Both endergonic and exergonic involves cellular respiration occurs in heterotrophic autotrophs
uses glucose
in the cytoplasm which is broken down in glycolysis
which is a 10 step process that yields some pyruvate
if O2 undergoes redox reaction with carbon dioxide produces oxygen
oxidative phosphorylation

mitochondria in the produces
Acetyl Co A
NADH
enters which is used in Krebs cycle
yields some
main thing is the electron transport
yields hydrogen ions
the electrons NAD+
undergo intermediate e-acceptor
cytochromes which needs
inner membrane chemiosmosis to form a
proton gradient with H+

for e- to be forced through ATP synthase to make ATP
at the end the H+ joins with oxygen to make water

fermentation makes lactose acid ethanol
if if plants examples

NAD+ if no O2 enter

lectase acid

ethanol

if animals

which are

to regenerate

examples
Photosynthesis is a light dependent reaction in which plants utilize sun's energy, which is in photons, using chlorophyll, to form splitting of water and hydrogen ions, and create chloroplasts, energy, and starch.
**Future Visual Field**

**Photosynthesis**

- **Autoctrophy** is photosynthesis as reactions that are both endergonic and exergonic.
- **Examples are**
  - Green algae
  - Cabbage plant
  - Light-dependent reaction occurs in mesophyll of chloroplast especially in photosystems
  - Photosystem I
    - Causes activation of e- to cause splitting of water
    - Water to make oxygen and hydrogen ions
  - Photosystem II
    - Intermediate e-acceptor to travel across thylakoid in chemiosmosis
    - Electrons H+ are forced across ATP synthase to make ATP
    - ATP

- **Carbon dioxide**
  - Carbon fixation fixes C with rubisco.
  - Used in RUBP
  - Rubisco
  - Calvin cycle has three turns
  - Fumes
  - ATP
  - C3 and C4 pathway
  - NADPH
  - NADP+ reductase
  - ATP
  - NADP+ reductase
  - Redox reaction
  - Photophosphorylation
  - Carbon dioxide
  - Stroma
  - Photosynthesis
  - Guard cells

- **Glucose**
  - Which is converted to various organic compounds
  - Power
  - Which have cytochromes
  - Stroma
Photosynthesis is a photosynthetic process that occurs in chloroplasts, which are in the thylakoid in the photosystems that have chlorophyll. Light energy from the sun is split and excites water to the reaction centers where H+ are passed to the intermediate e- acceptor for electron transport to the cytochromes, where chemiosmosis happens and ATP synthase generates ATP with the electrons.

Calvin cycle uses carbon dioxide in a process called carbon fixation which produces oxygen. The reductase reaction forms which is used to make other organic molecules. Redox reaction forms NADPH for photosynthesis.

Not sure what goes in.
Bertha Concept Maps
Cellular Respiration

Utilizes

- glucose
- oxygen

To make

- ATP energy
- CO₂
- water

Score 11
Photosynthesis utilizes Plants and CO₂. Bertha Baseline Photosynthesis and Chlorophyll are also involved.
Photosynthesis

- occurs in autotrophs
- begins with the absorption of sunlight by chlorophyll
- uses water as a reactant
- produces oxygen as a byproduct
- involves the conversion of light energy into chemical energy

Photosynthesis occurs in autotrophs, which include
- Cabbage plants
- Green algae
- Photosynthesis
- Splitting of water
- Light-dependent reactions
- Electrons transported by hydrogen ions
- Carbohydrates synthesized in the stroma
- ATP synthesized
- Carbon fixation
- Calvin cycle
- C3 and C4 pathways
**Bertha Post Strategy**

**Interrelationships of Photosynthesis and Cellular Respiration**

Score: 190

- **Autotrophs and Heterotrophs**
  - Cycles between
  - Mitochondrion
  - Cellular Respiration
  - Photosynthesis

- **Stages of Photosynthesis**
  - Light
  - Chloroplast
  - From splitting of oxygen to produce water
  - NADPH also uses which enters Calvin Cycle which joins with RUBP
  - Carbon dioxide
  - 63P which is converted to glucose
  - Glucose through fermentation with organic molecule

- **Stages of Cellular Respiration**
  - Krebs cycle
  - NADH FADH2
  - Which produces ATP and NAD
  - From NAD + FAD
  - ATP synthase
  - NADH + CoQ
  - Mitochondria

- **Energy From Respiration**
  - ATP
  - Ethanol + CO2
  - Kinchons and Yeast

**Glycolysis**

- **Net ATP**
- Acetyl CoA
- Which joins with oxaloacetate to enter Krebs cycle
- Which produces NADH FADH2
- From NAD + FAD
- ATP
- Energy

**Chlorophyll**

- Light reaction
- Electrons that enter electron transport
- Through cytochromes
- Which join with oxygen to produce water
- NAD+ to NADH
- NADH FADH2

---

503
Bertha Delaney
Interrelationship of Photosynthesis and Cellular Respiration
Score: 207

carbon cycle

includes

photosynthesis occurs in chloroplast
begins with light dependent reaction
when absorbs light made of?
chlorophyll light photons

ADP + P enters
which joins with CoA to make ATP

pyruvate enters to produce ATP

NAD+
Acetyl CoA
which enters

mitochondrion

NADPH front enters
electrons which are concentrated in thylakoid

which are concentrated and then they pass through channels in ATP synthase

to power the active transport of?

electron transport to produce energy

which enter into the inner membrane of the mitochondrion

carbon dioxide occurs in mitochondria

which enters oxygen Krebs cycle

FADH2 which enters

Calvin Cycle by joining with RUBP to produce G3P

NAD+ which is converted to glucose

fermentation produces lactic acid ethanol

fermentation produces lactic acid ethanol

glucose enters glycolysis which enters cytoplasm

to produce pyruvate ADP + P enters to produce ATP

oxidation occurs in mitochondrion

ATP synthase to produce ATP

chemiosmosis in a process known as
Brandon Concept Maps
Cellular Respiration

Organisms

Use

oxygen

While using

Biological energy

Occurring in

mitochondria

Brandon Baseline Cellular Respiration

Score 8
cellular respiration

occurs in

heterotrophic

breaks

glucose

in

glycolysis

if

no oxygen

types of fermentation

has examples like Kimchee

intermediate e-acceptor

chemiosmosis

ATP synthase

to make ATP

ATP

is

both endergonic and exergonic

mitochondria

if oxygen enters Krebs cycle has redox reaction

redox reaction

electron transport

which is allow for oxidative phosphorylation

e-passer across cytochromes

???

can be blocked by pesticides

hydrogen ions

go across

???

water

carbon dioxide products

511
Photosynthesis

Occurs in

Plants

Produces

Energy

from

Plants

Fires out

Sun

Photons

Interact with

Chlorophyll

Brandon
Baseline
Photosynthesis
Score 15
Brandon
Delay
Photosynthesis
Score: 65

- **photosynthesis**
  - occurs in autotrophy
  - is both endergonic and exergonic
  - has 2 sets of reactions
    - light dependent reaction
      - occurs in photosystems
        - are hit by photons
          - in chlorophyll
            - allow for splitting of water
              - to produce hydrogen ions
                - go across redox reaction
                  - concentrated in chemiosmosis
                    - ATP synthase
                      - to make ATP
                        - electron transport
                          - has electrons
                            - go across cytochromes
  - Calvin cycle
    - uses thylakoid
      - carbon dioxide
        - in glucose
          - to make carbon fixation
            - intermediate e-acceptor
              - photophosphorylation
                - NADPH
      - oxygen
        - ATP
          - ATP synthase
Brandon
Delay
Interrelationship of Photosynthesis and Cellular Respiration

Score: 171

carbon cycle

includes

cellular respiration

has

glycolysis

that breaks

glucose

in

cytoplasm

to

pyruvate

depends on

oxygen

if no O₂ if O₂, pyruvate is converted

fermentation

Acetyl CoA

enters

Krebs cycle

in

mitochondrion

uses

NAD⁺ to make NADH

FAD to make FADH₂

photosynthesis

has

light dependent reaction

in

chloroplast

light

hits in chlorophyll

splits water

to

hydrogen ions

have electron transport

go across

chemiosmosis

that makes proton pump

have ATP synthase

to put together

ADP + P to ATP

used in Calvin Cycle

uses

RUBP

to make G3P

to make carbon dioxide

carbon fixation

have citochromes

can block with pesticides

have electrons

APPENDIX Q:

CONCEPT MAP SCORE ANALYSIS
Legend for Map Score Analysis Tables

A – Baseline Respiration
B – Baseline Photosynthesis
C – Post Lecture Respiration
D – Past Respiration
E – Present Respiration
F – Future Respiration
G – Delayed Respiration
H – Post Lecture Photosynthesis
I – Past Photosynthesis
J – Present Photosynthesis
K – Future Photosynthesis
L – Delayed Photosynthesis
M – Combined Photosynthesis and Respiration Map Score Post Strategy
N – Combined Photosynthesis and Respiration Map Score Delayed
BDM Extended Analysis Subgroup Concept Map Scores
### Baxter: Conceptual Organization Map Results

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<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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Resp - Respiration
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Comparison Group Concept Map Scores
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- Resp - Respiration
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**Legend**

- Photo - Photosynthesis
- Resp - Respiration
<table>
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<tr>
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<th>Baseline Resp</th>
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<th>Post Strategy Resp</th>
<th>Delayed Resp</th>
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<th>Delay Photo</th>
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*Legend*

Photo - Photosynthesis
Resp - Respiration
Statistical Analysis of Concept Map Scores
Overall Concept Map Score Group Comparisons

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AP and Non AP Group Concept Map Comparison

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<th>Non AP Comparison</th>
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Legend
R = Cellular Respiration
P = Photosynthesis
### AP and Non AP BDM Extended Analysis Subgroup Concept Map Score Analysis

#### AP Students

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<tr>
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<th>Baxter</th>
<th>Bella</th>
<th>Bertha</th>
<th>Beth</th>
<th>Sum</th>
<th>Avg.</th>
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#### Non AP Students

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<tr>
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<th>Bridget</th>
<th>Brook</th>
<th>Bunny</th>
<th>Sum</th>
<th>Avg.</th>
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#### Respiration: Post BDM to Delayed BDM Extended Map Scores (Greatest Score Earned: 108)

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#### Photosynthesis: Post BDM to Delayed BDM Extended Map Scores (Greatest Score Earned: 222)

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<td>Present P</td>
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#### Carbon Cycle of Post BDM to Delayed BDM Extended Map Scores (Greatest Score Earned: 251)

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#### Respiration Visual Field Map Score Comparisons

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<th>FR - PRES R</th>
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<td>59</td>
<td>198</td>
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#### FR - PRES R

|       | 18           | 26           | 33            | 106          | 26.5    |
| FR    | 35           | 18           | 33            | 106          | 22.3    |
| PRES R | 56           | 34           | 59            | 198          | 83.5    |

#### %PRES R - FR

|       | 18           | 26           | 33            | 106          | 26.5    |
| FR    | 35           | 18           | 33            | 106          | 22.3    |
| PRES R | 56           | 34           | 59            | 198          | 83.5    |

#### %FR - PRES R

|       | 18           | 26           | 33            | 106          | 26.5    |
| FR    | 35           | 18           | 33            | 106          | 22.3    |
| PRES R | 56           | 34           | 59            | 198          | 83.5    |

#### %FR - FR

<p>|       | 18           | 26           | 33            | 106          | 26.5    |
| FR    | 35           | 18           | 33            | 106          | 22.3    |
| PRES R | 56           | 34           | 59            | 198          | 83.5    |</p>
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<th>Bella</th>
<th>Bertha</th>
<th>Beth</th>
<th>Sum</th>
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<th>Brandon</th>
<th>Bridget</th>
<th>Brook</th>
<th>Betsy</th>
<th>Sum</th>
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<th>Carbon Cycle of Post BDM to Delayed BDM Score Comparison</th>
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<td>%CC PostBDM - CC DelayedBDM</td>
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Key:
- R (Respiration)
- P (Photosynthesis)
- PRES R = PR (Present R; Past R)
- FP = PRES R (Future R; Present R)
- FR = PR (Future R; Past R)
- R PostBDM - R DelayedBDM (Respiration Post BDM - Respiration Delayed BDM)
- P PostBDM - P DelayedBDM (Photosynthesis Post BDM - Photosynthesis Delayed BDM)
- CC PostBDM - CC DelayedBDM (Carbon Cycle Post BDM - Carbon Cycle Delayed BDM)
### AP and Hon AP Concept Map Score Analysis of BDM Merged Group

#### AP Students

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<th>[ \text{Brandon} \quad \text{Bridget} \quad \text{Brook} \quad \text{Denny} \quad \text{Shelly} \quad \text{Sherlock} \quad \text{Stephanie} \quad \text{Sue} \quad \text{Q} \quad \text{Sylvia} \quad \text{Sum} \quad \text{Avg} ]</th>
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<td>87 88 88 87 52 52</td>
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<td><strong>Raw Map Score Changes</strong></td>
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<tr>
<td>DR - PLR</td>
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<tr>
<td>DP - PLP</td>
<td>33 155 44 19 33 102 42 76 76 68</td>
</tr>
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<tr>
<td>%DP - PLP</td>
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#### Photosynthesis Map (Greatest Score Earned: 119)

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**Key:**
- R is respiration
- P is photosynthesis
- DR - PLR is delayed R - post lecture R
- DP - PLP is delayed P - post lecture P
### BDM Extended Analysis Subgroup Past, Present, and Future Respiration and Photosynthesis Value Added Concept Map

#### Average Scores

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75%  75%
### Biology AP Multiple Choice Exam Question Responses Compared to Concept Mapping Scores

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**total percentage** 33% 58% 100% 100%
APPENDIX R:

RESEARCHER’S POWERPOINT® PRESENTATIONS
Merged BDM Group
Cellular Respiration

By Jewel Reuter
Louisiana State University
October, 2004

© 2004

Cellular Respiration
Past Visual Field
- Visualizing the Past Visual Field
- The visualization agent V. Fields will assist in establishing the visual fields.

V. Fields, Visualization Agent for the Visual Fields
Visualizing the Past Visual Field

Remembering about Cellular Respiration

- It was not easy for me to remember things that had happened in my life that were related to cellular respiration.
- A friend of mine helped me to remember. The text book did not seem to help me think about how cellular respiration has been a part of my life.
- As my friend told me the stories, I began to visualize the stories in my mind and I began to remember things that happened to me.
Sharing Stories

- I wanted to have good examples in my mind before I began to study the complex details.

My uncle had a farm and he read to me "Once Upon a Sandy Loam" when I was young.

Once Upon A Sandy Loam
By Roger B. Swain

- “Yet as one who has spent much of his life shepherding food from the garden into the house, I must point out that even the finest banquet has its roots in the muck.”
- We gardeners are inherently passionate about soil. We like its smell, the damp, moist exhalations of microorganisms working their infinite alchemy.”

http://www.gse-nasa.gov/old/skills/module.htm

The soil microbes got my attention. I did not know there were microbes in the soil. He said that was one reason we plowed the soil.
Plowing and Hoeing

I visualized my friend watching the plowing at a distance. He said the soil was hard and packed tightly. I could imagine how the plowing opened the soil to the air.

Oxygen in the Soil

Soil microbes need Oxygen.
But Some Microbes Do Not Need Oxygen

- I remembered a Korean friend, Lee Kun Hee, and his mother made a special Korean dish called Kimchee.
- She said that she had to add salt so that there would not be oxygen because oxygen would allow the bacteria that would cause it to spoil to live.
- She said the salt "pushed out" the oxygen.

Making Kimchee

She worked hard to make the Kimchee, and I remember the basic recipe. The salt helped to prevent oxygen she said.
Bubbles from Fermentation

I remember seeing the salty water at the top and the cabbage tightly packed below.

I loved to see the bubbles come to the surface. She said that was carbon dioxide from the fermentation.

Going to the Korean Grocery

I remember going to the Korean grocery and learning the words of the ingredients for the Kimchee.

- Korean Grocery Video
Commercial About Kimchee Caught My attention

- Kimchee spicy leaf commercial

While I was at the store I remember seeing the spicy Kimchee cabbage leaf commercial on a Korean videotape.

http://www.kimchi.or.kr/
http://www.kimch.or.kr/german.jpg
http://www.kimchee.or.kr/kimchee.html

Kimchee Running

- I remember his mother talking about getting the Kimchee up and running and I visualized bottle of Kimchee running with tennis shoes.
Anaerobic Vs Aerobic Cellular Respiration Concepts

- Tilling soil helps *aerobic* soil microbes
- Adding salt and pressing cabbage tight helps *anaerobic* Kimchee microbes
- The organisms’ different metabolisms allow for diversity.

Visualizing my experiences of cellular respiration and learning about others with my friend has made me curious to learn more about it. I am ready to learn the details.

Basic Concepts and Focal Points about Cellular Respiration

I remember some information about cellular respiration from my previous biology course.
Atom Color-Coding Legend for Molecule Diagrams

- Carbon: gray
- Oxygen: red
- Hydrogen: white
- Nitrogen: light blue
- Sulfur: yellow
- Phosphorus: orange

http://www.bio.cmu.edu/Courses/Biochem/Webs/diffblocks/Molecules/html#

Hydrolysis of ATP coupled to Free Energy

**Concept:**
Endergonic reactions are coupled with exergonic reactions.

**Focal Point:**
*ATP + H₂O → ADP + Pᵢ* is an exergonic reaction that is used to power endergonic reactions.
*Many reactions need energy because they are endergonic ATP is the source*
Examples of Coupling Energy from ATP Hydrolysis

- Active Transport
- Endergonic Reaction of glycolysis
  - Energy from the hydrolysis of ATP is used to power the reactions.

Energy Sources

- **Concept:**
  Identification of organic molecules as energy sources of heterotrophs.

- **Focal Point:**
  Molecules other than glucose can be used in cellular respiration.
Anaerobic Vs. Aerobic

- **Concept:** Distinguish between anaerobic and aerobic cellular respiration processes.

- **Focal Points:**
  - Location in the cell of anaerobic and aerobic processes.
  - Only 2 ATP/Glucose are produced under anaerobic conditions.

Diagram:

**Anaerobic Conditions**

\[ \text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2 \text{CO}_2 + 2 \text{CH}_3\text{CH}_2\text{OH} + \text{Net 2 ATP} \]

**Environment**

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} + \text{net 36 ATP} \]
**Anaerobic Bacterium**

- CO$_2$ (gas) is one product of heterofermentation.
- C$_6$H$_{12}$O$_6$ produces CO$_2$, lactic acid, ethanol and net 2 ATP.

---

**Aerobic Conditions**

- Reaction:
  
  $$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{net } 36\text{ATP}$$

- Environment

- Aerobic Cell
**Aerobic Yeast Cell**

**Details about Aerobic Conditions which allows for Oxidative Phosphorylation**

- **Mitochondrion** (Enlarged)
- **Environment**
- **Cytoplasm**
- **Nucleus**
- **O₂**

**Chemical Reaction:**

\[ C_6H_{12}O_6 + O_2 \rightarrow CO_2, \text{water and net 36 ATP} \]
Cellular Respiration Review

Gradual Steps To Release Energy

Aerobic Conditions
- glycolysis
- the Krebs cycle
- the electron transport chain and chemiosmosis
- oxidative phosphorylation
- net approximately 36 ATP/glucose

Aerobic Conditions
- glycolysis
- fermentation
- substrate level phosphorylation
- net 2 ATP/glucose
Glycolysis Occurs the Cytosol

- This process is used by all organisms on planet Earth (except viruses).
- Occurs in anaerobic cytosol.
- Glucose + 2NAD$^+$ + 2ADP + 2P$_i$ → 2pyruvic acid + 2 ATP + 2NADH + 2H$^+$
- Allows for substrate level phosphorylation.

Conversion of Pyruvic Acid to Acetyl CoA

2 pyruvic acid → 2 Acetyl CoA
Krebs Cycle Allows for Reduction

- Krebs Cycle allows for oxidation of acetyl CoA and the reduction of NAD⁺ and FAD

\[
\text{Acetyl CoA} + \text{NAD}^+ + \text{FAD} \\
\text{Krebs Cycle} \rightarrow \text{CO}_2 \\
\text{NADH} + \text{FADH}_2 \\
\text{oxygen} \rightarrow \text{Electron Transport chain} \rightarrow \text{NAD}^+ + \text{FAD} + \text{H}_2\text{O} \\
\text{Electromotive Force for Chemiosmosis} \rightarrow 3\text{ATP}/\text{NADH} \\
2\text{ATP}/\text{FADH}_2 \\
\text{ADP} + \text{P}_i \rightarrow \text{ATP synthase} \rightarrow \text{ATP}
\]
Mitochondrion Morphology

Diagram
Electron micrograph

http://int.lard.gov/docs/wanobio.pdf

Model of Mitochondrion Activity
© 2003
by: Jewel Reuter

- Materials:
  1) Golden Yukon or Red Potato
  2) Cup Cake Holders of Proper Dimension for the Potato
  1) Melon Ball Scooper
  1) Knife
  10) Sewing Pins with Large Plastic Heads
  10) Sewing Pins with Medium Plastic Heads
  10) Sewing Pins with Small Metal Head
  1) Each of the Following Labels: Inner Matrix, Outer Membrane, H+ Ion Inner Membrane, Oxidative Phosphorylation, Cytochrome, ATP Synthase, Matrix, Intermembrane Space
**Methods**

1. Cut potato lengthwise (along its longest length)
2. Scoop out most of the center of the potato with the melon ball scooper (leaving about 1/4 - 3/8 inch of the potato to form the space between the inner and outer membranes).
3. Line the inside of the cored potato with the cup cake holders. Place the large headed pins through the cup cake holders and with the pin heads facing the hollowed area.
4. With the labels identify: outer membrane, inner membrane, matrix, ATP synthase and cristae using the above labels.
5. Identify the area where the H+ ions accumulate during respiration to allow for chemiosmosis. Place the small metal head pins in that area. Place the H+ ion label near the pins.
6. Optional: Take a picture of your model and color the above labels.

**Questions:**

Use your model and your textbook to answer the following questions.

1. What is the function of ATP synthase?
2. Explain chemiosmosis using your labeled model.
3. Where is the electron transport chain located?
4. What is the final electron receiver in the electron transport chain?
5. Where does the Krebs Cycle occur?
6. What are the functions of the cristae?
7. Make a labeled diagram of your mitochondrion model.
Application of Cellular Respiration to Daily Life

- **Concept:**
  Application of overall fermentation concepts.

- **Focal Point:**
  Yeast are living organisms capable of metabolic process such as fermentation.

Example: Rising of Yeast Bread
Visualizations and the Basics of Cellular Respiration Accomplished

Visualizing my experiences of cellular respiration and learning the basics has prepared me to learn the details.

Present Visual Field

Now I will bridge details with my general visualizations so that I can understand the details of cellular respiration.
Detailed Concepts and Focal Points about Cellular Respiration

Glycolysis

Enzymes at each step

Glyceraldehyde – 3 – phosphate dehydrogenase

Substrate level phosphorylation

2ATP → 2ADP

2NAD⁺ + 2P₁ → 2NADH + 2H⁺

G - 3 - P (glyceraldehyde - 3 - phosphate)

4ADP + 4P → 4ATP

pyruvic acid

glucose
Step by Step Process

- **Concept:**
  There are many steps to cellular respiration and glucose is not the only molecule to trace through the process.

- **Focal Points:**
  * relate glucose consumption to oxygen consumption.
  * relate pyruvic consumption acid and oxygen consumption.
  * link concepts.

Relationship of Concentrations

- Concentration (µg/l)
- Time (µs)
- Pyruvic acid
- ATP
- glucose
- oxygen
- Pyruvic acid

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Glycolysis Vs. Fermentation

- **Concept:**
  Fermentation occurs anaerobically and regenerates NAD⁺ for glycolysis.

- **Focal Points:**
  * If no oxygen is present some organisms (e.g., yeast) perform fermentation after glycolysis.

  * Only 2 ATP/glucose are produced in glycolysis but no NAD⁺ is regenerated.

  * Fermentation regenerates NAD⁺
Krebs Cycle

- Major accomplishment: reduction of NAD$^+$ + FAD $\rightarrow$ NADH + H$^+$ + FADH$_2$

- acetyl CoA

- oxaloacetate

- NAD$^+$

- FAD

- FADH$_2$

- ADP + Pi

- ATP

- NADH + H$^+$

- citric acid

- CO$_2$

- α-ketoglutarate and other 5 C compounds

Krebs Cycle: Produces NADH and FADH$_2$, (Intermediate H$^+$ carriers) which Contribute H$^+$ to the Electron Transport Chain
Path of H⁺

Concept:
NAD⁺ and FAD are intermediates in electron transport

Focal Points:
- H⁺ + e⁻ from food → NAD⁺ + FAD¹⁻ → NADH + FADH₂ →
  Electron Transport Chain and chemiosmosis → O₂ → H₂O + ATP
- Only NADH + FADH₂ can enter the electron transport chain

Electron Transport Allows for Electrochemical Gradient

Concept:
Electron transport allows for proton-motive force

Focal Points:
H⁺ ions are concentrated between 2 membranes allows for chemiosmosis which powers oxidative phosphorylation.
**Chemiosmosis**

- **Concept:**
  - Chemiosmosis:
    - Protons move across a membrane down a proton gradient to couple redox reactions of electron transport to ATP synthesis.
    - Chemiosmosis occurs in both photosynthesis and cellular respiration.

- **Focal Point:**
  - The result of chemiosmosis is oxidative phosphorylation of ADP and production of most of the ATP in aerobic respiration.

Proton gradient coupled with redox reactions of electron transport → Chemiosmosis → ATP

**Chemiosmosis:**

Formation of H⁺ Concentration Gradient

- Matrix
- Electron Transport Chain
- ATP Synthase
Electron Transport in Double Membrane Structure Allows for Chemiosmosis

- **Concept:**
  Electron transport occurs in a double membrane organelle (mitochondrion and chloroplast) which is in association with chemiosmosis.

- **Focal Points:**
  * The double membrane allows for compartmentalization and concentration H⁺ which is required for chemiosmosis.

  * Prokaryotes have convoluted membranes which function similarly.

---

Cytochromes Are e-Carriers in Photosynthesis and Cellular Respiration

- **Concept:**
  Cytochromes are electron carriers in cellular respiration and photosynthesis.

- **Focal Points:**
  * Electrons cascade down energy gradient and cytochrome-a delivers e- to oxygen, the most electronegative component.

  * The H⁺ is transport to the intermembrane space for chemiosmosis.

http://omega.dawsoncollege.qc.ca/ray/krebs/etc.html
Oxygen and Production of ATP

- **Concept:**
  Understanding role of oxygen in cellular respiration and how oxygen is needed for oxidative phosphorylation.

- **Focal Point:**
  Anaerobic respiration produces less energy (ATP) than aerobic respiration. With oxygen more ATP is produced.

![Diagram of electron transport and chemiosmosis](http://energy.drewucollege.or.ca/ry/breba/etc.htm)
Aerobic Respiration: Most ATP Produced/Glucose

- **Concept:** Oxygen increases ATP production and is reduced to form water.
- **Focal Points:**
  - Oxygen: *has a high electronegativity difference which helps the electrons move down the electron transport chain*
  - *oxidative phosphorylation and production of approximately 36 ATP allows for glucose*

<table>
<thead>
<tr>
<th>Without O₂</th>
<th>With O₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>anaerobic conditions</td>
<td>aerobic conditions</td>
</tr>
<tr>
<td>Net number ATP produced per glucose molecule</td>
<td>2</td>
</tr>
</tbody>
</table>

H⁺ Diffuses Across ATP Synthase: ATP is Produced

- **Electron Transport Chain**
- **Space Between Outer and Inner membrane**
- **Matrix**
- **ATP Synthase**
- **Outer Membrane**
A Closer Look at Concentrating H⁺ to Create a Gradient

A Closer Look at ATP Production

Outer Membrane

Krebs Cycle

Matrix

2H⁺ + ½O₂ → ATP

ADP + Pᵢ → ATP

oxi dative phosphorylation

ATP Synthase

Outer Membrane of Mitochondrion

H⁺

H⁺

H⁺

H⁺

H⁺

H₂O

Water

Reduction of Oxygen

O₂
ATP Synthase Animation

http://rsb.info.nih.gov/NeuroChem/biomach/ATPsyn.html#ref2

ATP Synthase

- **Concept:**
  Understanding that ATP synthase is located in the mitochondrial and chloroplast membranes and is an enzyme made of protein.

- **Focal Point:**
  The final production of ATP occurs at ATP synthase, which is an enzyme that catalyzes the reaction of $\text{ADP + P} \rightarrow \text{ATP}$. The $\text{H}^+$ travels through the $\text{H}^+$ channel in the ATP synthase from high concentration of $\text{H}^+$ to low concentration of $\text{H}^+$, and thus powers ATP generation.
Plants Perform Respiration

- **Concept:**
  Plants need oxygen.

- **Focal Point:**
  *Plants must perform cellular respiration to produce ATP for cell activities.*
  *(All organisms must perform cellular respiration to get energy from organic molecules.)*
Carbon Cycle

■ Concept:
Understanding of how cellular respiration produces carbon dioxide and photosynthesis uses it.

■ Focal Point:
*Krebs Cycle produces carbon dioxide and the Calvin Cycle of photosynthesis uses it.
Medical Applications

- Chemiosmosis
- Electron transport

Cyanide Poisoning

- Since the days of ancient Rome, cyanide and the derivatives of this highly toxic substance have been used as weapons.
- Napoleon III proposed the use of cyanides to enhance the effectiveness of his soldiers' bayonets during the Franco-Prussian War.

Medical Applications

- Chemiosmosis
- Electron transport

Cyanide Poisoning

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Poisons Related to Electron Transport

- **NADH + H+**
- **FADH2**
- **½ O2 + 2H+**
- **ADP + P**

Intermediate membrane space

- **rotenone**
- **antimycin A**
- **cyanide**

Uncouplers Related to Chemiosmosis

- **NADH + H+**
- **FADH2**
- **½ O2 + 2H+**
- **ADP + P**

Intermediate membrane space

- **Uncouplers, dinitrophenol, dissolve in the membrane, and function as carriers for H+.**
- **Uncouplers block oxidative phosphorylation by dissipating the H+ electrochemical gradient.**

Uncouplers pump H+ back into the matrix and prevent the development of an electrical gradient.

http://www.ri.edu/iopb/iopb/ref/radiothermodynamics/part2/uncoupl.html
Medical Research

Mitochondria Research

Photosynthesis

Photosynthesis
The Past Visual Field

By Jewel Reuter
Louisiana State University
October, 2004

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Visualizing the Past Visual Field
Remembering about Photosynthesis

- It was not easy for me to remember things that had happened in my life that were related to photosynthesis. The text book did not seem to help me think about how photosynthesis has been a part of my life.
- A friend of mine helped me to remember.
- As my friend told me the stories, I began to visualize the stories in my mind and I began to remember things that happened to me.

Remembering Victory Garden Stories

- I loved to hear stories as a child and I still do.
- My friend’s aunt told him about how she planted big gardens during World War II so they would have enough food. There were rations, limits to food and supplies, to be sure there would be enough food and supplies for the soldiers.
- He shared his aunt’s story with me.
December 7, 1941 Began WW II

Rations were necessary to be sure there was enough supplies to fight the war.

Victory Gardens and Selecting Seeds

- Housewives planted tomatoes, lettuce, beets, peas and carrots in their backyards.
- They used what they needed and learned to preserve the excess for future use.
- The Department of Agriculture and seed companies gave advice.
- More than 40 percent of the country’s produce were grown in the nation’s back yards.
The War Ended

and So Did the Victory Gardens

Nagasaki
1940's – Smoke billows up over Nagasaki, Japan after bombing by atomic bomb on 9 August 1945. (U.S. Air Force photo)

Victory Garden

He remembered wearing an army cap as he worked with his family in the garden while they talked about World War II Victory Gardens.
Then I remembered a special tomato garden.

A Special Tomato Garden

My grandmother loved tomatoes. She always planted the tomatoes so they would get enough sunlight. I would help her water the garden. The plants needed water and light she would say. She looked to see that the plants would get enough light. She watered the newly planted plants with water from a watering can.
Eating in the Garden

I liked to use the watering can to water the garden. The best part about the garden was picking the tomatoes and eating them while I was in the garden.

The Garden
Now I eat from a salad bar and only I barely remember those days of eating in the garden.

The Salad Bar and Grocery Produce Section

- It is not easy to realize that the food I eat comes from plants in farms and gardens.

http://www.ars.usda.gov/is/PDFInfo/loc83/MM06C1.htm

http://www.ars.usda.gov/is/PDFInfo/loc83/MM06C2.htm
Wheat Fields and Breads

When I eat bread I do not think about the large fields of wheat plants.

https://www.ag.nd.edu/extension/banner/3498-339m
https://www.ag.nd.edu/extension/banner/6211-27.htm

Photosynthesis provides food. It is not always so obvious. The plants are cut or processed.
Grapes of Wrath

I remember reading the book the *Grapes of Wrath*. It was about farming problems and the resulting lack of food.

A Clip from The Grapes of Wrath
The U.S. Dust Bowl

- May 1934, a cloud of topsoil from the Great Plains blanketed the eastern U.S.
- In 1975, the Council of Agricultural Science and Technology warned that severe drought in the Great Plains could trigger another Dust Bowl.
- Dust Bowl: Part of the Great Plains region of the U.S. which is subject to severe drought.

[Link to Earth Observatory: http://earthobservatory.nasa.gov/Study/DustBowl/]

Abandoned farm in the Dust Bowl

- Coldwater District, near Dalhart, Texas

[Link to news article: http://www.nws.noaa.gov/om/earth_dust_bowl.html]
Home of a Dust Bowl Refugee

- Imperial County, California.

Photosynthesis provides food. It worries me to see our farms not able to produce food. I assume there will be plenty of food that is easy to get.
Basic Concepts and Focal Points about Photosynthesis

I remember some information about photosynthesis from my previous biology course. Looking at the book helped me to remember the basics.

Autotrophs Do Photosynthesis

- photosynthetic bacteria (e.g. cyanobacteria)
- Algae (e.g. *Spirogyra*)
- Plants (e.g. *Vitis labrusca*)

[Links to images and information: photosynthetic bacteria, Algae *Spirogyra*, Plants *Vitis labrusca*]
The First Autotrophs: Banded Iron Formations

- Banded iron formations are very large bodies of sedimentary rock laid down some 2.5 billion years ago.
- At that time, the Earth still had its original atmosphere of nitrogen and carbon dioxide.
- That would be deadly for us but it was hospitable to many different microorganisms in the sea, including the first photosynthesizers.
- These organisms gave off oxygen as a waste product, which immediately bonded with the abundant dissolved iron to yield minerals like magnetite and hematite.

Autotrophs Require

- **Concept:** Carbon dioxide, water, light and chlorophyll are required for photosynthesis.
- **Focal Point:** Photosynthesis converts light energy into the chemical energy of other organic molecules and sugars.
Photosynthesis

- Converts light energy into the chemical energy of sugars and other organic molecules.
- Transfers electrons from water to energy-poor CO₂.
- Water is oxidized (loses electrons).
- Carbon dioxide is reduced (gains electrons).

Photosynthesis Uses Light Energy

Reactants

6 H₂O + 6 CO₂

Products

Organic compounds (e.g. C₆H₁₂O₆) + 6 O₂

- To drive the electrons from water to their more energetic states in the sugar products.
- To convert solar energy into chemical energy.
- Oxygen (O₂) is a byproduct and is released into the atmosphere.
Chlorophyll

- \( X = \text{CH}_3 \) (chlorophyll a)
- \( X = \text{CHO} \) (chlorophyll b)

Absorption Spectra of Chlorophyll a and b

- Concept:
  - Light and chlorophyll are required for photosynthesis.
- Focal Point:
  - Various wavelengths of light are absorbed by various chlorophyll molecules.

Different Chlorophylls

- Vary in their absorption spectra and allow for diversity.
- The following is an example.

https://www.enotes.com/human-physiology/chlorophyll-527321
https://www.enotes.com/human-physiology/chlorophyll-527322
https://www.enotes.com/human-physiology/chlorophyll-527323
Engelmann’s *Spirogyra* Experiment

- Engelmann’s experiment revealed that bacteria requiring oxygen move to regions where oxygen is being liberated by photosynthesis.
- The most oxygen was produced with blue and red light.

The Stoma: CO₂ and O₂ Exchange

**Concept:**
- Carbon dioxide is a gas that is required for photosynthesis. Water, light and chlorophyll are also required for photosynthesis.
- Oxygen is a byproduct of photosynthesis which is exchanged to the atmosphere at the stoma openings of plants.

**Focal Point:**
The plants have cuticle and other epidermal cells to protect and to proven water loss. The stoma openings allow for gas exchange to the mesophyll cells that perform photosynthesis. Carbon dioxide is absorbed by diffusion and oxygen is release by diffusion.
**Leaf: Structure and Function**

- Leaf structure is closely associated with its photosynthetic function. Leaves must permit carbon dioxide access to the photosynthetic cells but impede water from diffusing out. This oxygen that is a reactant product of photosynthesis must be allowed to escape from the leaf.

**Plant Cell Structure**

- Chloroplast
- Cytoplasm
- Mitochondrion
- Nucleus
- Cell wall and cell membrane
- Stroma
- Thylakoid
- Granum
- Outer and inner membranes
Prokaryotic VS Eukaryotic

- **Concept:**
  Thylakoid membranes are the site of the light reaction.

- **Focal Point:**
  Prokaryotic cells have thylakoid membranes for the light reaction, but they are not arranged into a granum structure.
Cyanobacteria Have Thylakoid Membranes

Diagram is based on an electron micrograph of typical cyanobacteria.

Oxygen Produced in Light Reaction

- **Concept:**
  Water is split in the light reaction and this is the source of energy for production of ATP and NADPH.

- **Focal Point:**
  2 waters are required to make one $O_2$ molecule
Oxygen is Produced from Water Molecules

- **Concept:** Oxygen isotope $^{18}O$ can be used to follow the oxygen in water.
- **Focal Point:**
  - Two oxygen atoms in the water molecules become the oxygen molecule byproduct. Two water molecules are required to make one $O_2$ molecule.

---

**Photolysis of Water**

- Granum
- Photosystem II
  - $H_2O$ to $2e^- + 2H^+ + \frac{1}{2}O_2$
- Photosystem I
  - NADP$^+$ Reductase
  - ATP Synthase
- Electron Transport Chain
Chloroplast model

- Chloroplast Electron Micrograph

http://neptune.gsfc.nasa.gov/~brian/chloro.html

Making a Chloroplast Model

This procedure allows one to build either a large or small chloroplast model.

- **Large Chloroplast Model:**
  - **Materials:**
    - 2 large aluminum disposable turkey baking pans
    - 16 paper plates
    - 1 can of black spray paint
    - 1 can of green spray paint
    - 2 rolls of 3/4" cellophane tape
    - 2 rolls of clear masking tape
    - 1 pair scissors
  - **Procedure:**
    1. Lay the paper plates down so that the bottom side is up.
    2. Mark the outside (bottom) of each paper plate. Paint 8 paper plates black and 8 paper plates green.
    3. Allow the paper plates sufficient time to dry.
    4. Cut out one of the paper plates on half.
    5. Place the two halves together and pressed side edge to edge to make a semicircle.
    6. Place all the black plates together and pressed side edge to edge to make three circles.
    7. Place 3 black plates together in a stack and tape the semicircular plate to the top of the stack.
    8. Tape the green plates together in a stack to form a square.
    9. Position the 2 stacks of 3 plates inside a turkey pan to simulate the chloroplast.
    10. Tape the plates to the turkey plate with masking tape in two directions to firmly support the paper plates.
    11. Cover the plate by placing the other turkey pan upside-down on top of the other turkey pan.
Making a Chloroplast Model (Cont.)

- **Small Chloroplast Model:**
  
  **Material:**
  - 2 disposable aluminum potato baking dishes
  - 8 junior mints
  - 1 roll clear tape
  - 1 plastic knife

  **Procedure:**
  - Stack the junior mints 4 mints high.
  - *Tape the mints together with clear tape. Be careful not to hold the mints too tight or they will crush.
  - Repeat the above steps with the remaining 4 mints.
  - Position the two 4 mint stacks in the potato dish.
  - *Tape the 4 mint high stack carefully in the proper position in the potato dish.
  - *Tape the other 4 mint stack in its proper position.
  - Cut one of the two top mints in half along its cross section with the plastic knife.
  - *Place do not tape the other potato dish over the bottom potato dish.

Moss balls

- *Cladophora aegagropilla* is not really a plant, but a ball of algae, so it is a decorative exception from the rule about avoiding algae at all costs. It is normally found in shallow lakes, where the movement of the waves forms it into a sphere. In an aquarium it must be turned regularly to keep it in shape. *C. aegagropilla* can be divided into smaller pieces, which become spherical with time, or which form a carpet, if attached to roots and stones. Protected in parts of Japan.

**Family**: Cladophoraceae

- **Country/Region**: Asia, Europe
- **Height**: 10 cm Width: 10 cm
- **Light requirement**: very low-high
- **Temperature**: 5–28 °C
- **Hardiness**
  - Hardyness: medium-very hard
  - pH tolerance: 6.5
  - Growth: very slow
Present Visual Field

Now I will learn more details about photosynthesis and understand the concepts.

Light Reaction Related to Calvin Cycle

- **Concept:**
  Products of light reaction are ATP and NADPH (O₂ is a byproduct) molecules in the Calvin Cycle

- **Focal Points:**
  * ATP and NADPH are used in the Calvin Cycle.
  * The light reaction is needed for the production of organic molecules for the Calvin Cycle.
  * Light Reaction occurs in the thylakoid of the granum in the chloroplast
Producing ATP and NADPH in Light Reaction

- **Concept:**
  Electron transport and chemiosmosis occur in chloroplast and produce ATP and NADPH. Products of light reaction are ATP and NADPH (O$_2$ is a byproduct) molecules in the Calvin Cycle.

- **Focal Points:**
  - **ATP**
    - Electron transport occurs on the carrier molecules within the thylakoid membrane.
    - H$^+$ ions are concentrated in the lumen and then diffuse across the ATP synthase to create ATP by photophosphorylation of ADP + P$\gamma$ → ATP
  - **NADPH**
    - H$_2$O through noncyclic to NADP$^+$
    - Energy from electron transport is used to reduce NADP$^+$ to NADPH
  - **Light Reaction** occurs in the thylakoid of the grana in the chloroplast.

---

**Light Reaction**

Diagram showing the process of light reaction with details of electron transport, ATP synthesis, and the movement of electrons and protons through the thylakoid membrane.
**Photophosphorylation**

Occurs in Light Reaction of Photosynthesis

\[ 2e^- + 2H^+ + \frac{1}{2}O_2 \rightarrow H^+ \]

**Energy Is Released from Photolysis**

- Energy is used to make ATP and NADPH
Photosynthesis Reactions Related

Calvin Cycle Fixes Carbon

- **Concept:**
  - CO$_2$ enters the plant’s stomata and is used in Calvin Cycle. Chlorophyll are required for photosynthesis.

- **Focal Point:**
  - The Calvin Cycle produces organic G-3-P molecules with the CO$_2$ in the stroma of the chloroplast. G-3-P is used to produce glucose and other organic molecules such as cellulose, fats and proteins. Molecules other than glucose can be produced in photosynthesis.
The words "CO₂ fixation" refer to the attachment of CO₂ to an organic compound: each CO₂ binds to a 5-carbon *ribulose biphosphat* (*RuBP*) molecule in a C₃ plant.

[link](http://family.virginia.org/etc/designs/michal/genealogy/files/2010/01/2010_120100000-necobio/Photosynthesis_photony.htm)
**Carbon Cycle**

- **Concept:**
  Understanding of how cellular respiration produces carbon dioxide and photosynthesis uses it.

- **Focal Point:**
  Krebs Cycle produces carbon dioxide and the Calvin Cycle of photosynthesis uses it.

---

**Melvin Calvin’s Nobel Prize in Chemistry 1961**

- "Using the carbon-14 isotope as a tracer, Calvin and his team mapped the complete route that carbon travels through a plant during photosynthesis, starting from its absorption as atmospheric carbon dioxide to its conversion into carbohydrates and other organic compounds."

- "In doing so, the Calvin group showed that sunlight acts on the chlorophyll in a plant to fuel the manufacturing of organic compounds, rather than on carbon dioxide as was previously believed."

1961 Nobel Prize in Chemistry Presentation Introduction

Nobel Prize Introduction Speech (cont.)

"In order to grow and to perform its various activities, every living organism needs a supply of energy in some suitable form. In this respect the organisms existing on this planet can be divided into two fundamentally different groups."

"All animals, including man, and also some lower organisms, require a supply of energy-rich organic material, food-stuffs that "contain calories", to use a popular expression."

"The energy contained in the food-stuffs is made available by a biological oxidation ("combustion") of carbohydrates, fats etc. Obviously, these types of organisms, the so-called heterotrophic organisms, are absolutely dependent on supplies of organic material, occurring outside themselves.

http://www.library.lib.gov/td/dtl/lib/nobelleurelates/lili4_Calvin.htm#accept

Nobel Prize Introduction Speech (cont.)

"As opposed to the heterotrophic organisms, the organisms belonging to the second group, the so-called autotrophic organisms, i.e. the green plants and certain bacteria, do not require organic material supplied from without."

"They synthesize organic compounds, primarily carbohydrates, from simple substances, carbon dioxide and water, substances that in themselves, do not contain any calories."

"The energy needed for the synthesis is supplied by light which is absorbed by the organisms and subsequently converted by them from light energy into chemical energy."

"The sequence of reactions by which carbon dioxide and water are converted to carbohydrate is called carbon dioxide assimilation or, taking into account the role of light energy, photosynthesis.

http://www.library.lib.gov/tdid/dtl/lib/nobelleurelates/lili4_Calvin.htm#accept
Nobel Prize Introduction Speech (cont.)

- "It becomes obvious that photosynthesis not only provides an explanation for the existence of the autotrophic organisms but also furnishes food for man and animals."
- "In other words, photosynthesis is the absolute prerequisite for all life on earth and the most fundamental of all biochemical reactions."
- "It has been estimated that plants and microorganisms on earth transform about 5,000 tons of carbon from carbon dioxide to carbohydrate per second, with at least four-fifths of this amount contributed by organisms in the oceans."

http://www.library.icsu.org/oids/2/nlib/nobellaureates/Lib4_Calvin.htm#accept

Following the Path of CO₂ in Photosynthesis

- **Concept:**
  CO₂ is used to make organic molecules such as G-3-P.

- **Focal Point:**
  Isotopes of carbon and oxygen can be used to track the C and O in CO₂.
Organic Molecules are produced in the chloroplast

- **Concept:**
  
  CO$_2$ is used to make organic molecules such as G-3-P.

- **Focal Point:**
  
  Isotopes of carbon and oxygen can be used to track the C and O in CO$_2$. Carbon and oxygen are used to make the organic compound.
Calvin’s Obituary Notice:  
January 8, 1997

- On the day of the Japanese surrender, Lawrence told Calvin that, "Now is the time to do something useful with radioactive carbon."
- Calvin organized a team of Rad Lab researchers to study photosynthesis.

Calvin’s Obituary Notice:  
January 8, 1997

- Used the carbon-14 isotope as a tracer
- mapped the complete route that carbon travels through a plant during photosynthesis
- starting from its absorption as atmospheric carbon dioxide
- to its conversion into carbohydrates and other organic compounds.
- showed that sunlight acts on the chlorophyll in a plant to fuel the manufacturing of organic compounds rather than on carbon dioxide as was previously believed.
Calvin Cycle

Carbon Fixation Phase 1

CO₂
rubisco

Reducing Phase 2

1, 3-Biphosphoglycerate
5 ATP → 6 ADP
6 NADPH
6 NADP⁺ + 6 H⁺

Regeneration Phase 3

RUDP
6-3-P

Transported from chloroplast to make glucose + other organic compounds

C₃ and C₄ Plants

C₃
* Photosynthesis occurs within the mesophyll—which form a dense layer on the upper surface of the leaf and a spongy layer on the lower surface.
* Bundle-sheath cells surrounding the veins are not photosynthetic.

C₄
* The leaves of C₄ plants are structured differently than those of C₃ plants.
* Photosynthesis occurs within the bundle sheath cells plants, which surround the vein.

Efficiency of C₄ Photosynthesis
* This mechanism requires extra ATP
* But under hot, dry conditions C₄ plants are two to three times more efficient than C₃ plants.
* In moderate weather, C₄ plants are at an advantage.
**CAM**

CAM (crassulacean-acid metabolism) photosynthesis is found in most desert plants, particularly the succulents (plants that store water in thick, fleshy leaves).

- The Calvin cycle occurs in mesophyll cells of these plants but the stomata open only at night when it is cool and more humid.
- CO₂ fixation occurs when the stomata are open at night. CO₂ is stored as a 4 carbon compound and is released to the cells during the day.
- CAM plants are 5 to 7 times more efficient than C₄ plants.

---

**C₃ versus C₄**

[C₃ Plant Diagram]

- CO₂ enters the leaf through the stomata and is used in the Calvin cycle to produce glucose.
- Glucose is then transported to the bundle sheath cells where it is converted to sucrose.

[C₄ Plant Diagram]

- CO₂ is first fixed into a 4-carbon compound (PEP) by PEPCO (PEP carboxylase) in the bundle sheath cells.
- The 4-carbon compound is then transported to the mesophyll cells where it is decarboxylated and the CO₂ released is used in the Calvin cycle.

PEP = phosphoenolpyruvate
PEPCO = PEP carboxylase (enzyme that fixes CO₂)
C₄ vs. CAM Plants

Future Visual Field
Eliminating Algae in My Aquarium

I can cover my aquarium with black plastic and waited to see the algae die from the lack of light.

Eliminating Weeds

We could covered the found with black plastic to kill the weeds. The weeds are green and after they are covered they will turned brown and died. We will eliminated the weeds by eliminating the light.
Videos of Plants Treated with Herbicides

- Video
- Atrazine action on the donor side of photosystem II
  [http://www.bioorganicchemistry.net/atrazine-synthesis-inhibitors.html](http://www.bioorganicchemistry.net/atrazine-synthesis-inhibitors.html)
- Bromoxynil by binding to the Qb-binding niche on the D1 protein of the photosystem II complex
  [http://www.tarax.com/edu/chemical/bromoxynil.html](http://www.tarax.com/edu/chemical/bromoxynil.html)
NASA Experiments with Soybeans

- Soybeans are the largest single source of protein meal and vegetable oil in the human diet. After a 70-day growth period, plants were harvested; grain was returned to Earth for analysis.

Winter Vs. Summer

[Map showing differences in climate, vegetation, and temperature between winter and summer across the world.]

- [Link to more information on the NASA website: http://www.nasa.gov/mission_pages/Monthly/]
- [Additional resources: http://www.nasa.gov/links/]

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**Photosynthesis in December**

Photosynthetic Activity (Dec. 18–25, 2000)

- Low
- High

---

**Elevated CO₂ and Growth Measurement**

- Near Phoenix, Arizona, scientists measure the growth of wheat surrounded by elevated levels of atmospheric carbon dioxide. The study, called Free Air Carbon Dioxide Enrichment (FACE), is to measure carbon dioxide's effect on plants. It is the largest experiment of this type ever undertaken.

http://www.jrs.ueda.gov/tse/graphics/photos/65652-18.htm
Data Collection Apparatus in the Field

- http://www.ars.usda.gov/is/timeline/light.htm

Red Mulch

- The plant recognizes far-red light as the signal. If the plant detects an abundance of far-red reflection, it draws that there must be other plants growing nearby. The phytochrome will then signal the plant to put more energy (photosynthesis) in the top of the plant (shoot) instead of in the bottom of the plant (roots). The shoot, in effect, is trying to outgrow its competition.

- Far-red is just outside the visible light spectrum. It is not visible to the human eye, but can be sensed by the plant. Far-red wavelengths are important to the plant because of the competition factor in nature. A plant can "see" when there are other plants close by because of the increase of far-red wavelengths the other plants reflect. This will then signal the plant to make the necessary adjustments when their本科生 to try to outgrow the others around them since they are competing for sunlight and other resources.

http://www.ars.usda.gov/is/hs-field-grim.htm
Using the Right Color of Light in Space

http://science.nasa.gov/headlines/y2004/reels/0reel_1.htm

Soybean Research

After a 70-day growth period, plants and harvested grain will be returned to Earth for analysis.

Green, leafy spinach may soon power more than Popeye’s biceps

Comparison Group
Cellular Respiration

By
Jewel Reuter
October, 2004

Cellular Respiration Test Questions

- What questions do you think were easiest?
- What questions were the most difficult?
- Which questions would you like to discuss?
- What concepts would you like to discuss?
What Do You Think You Need to Study More About Cellular Respiration?

- Think about this?
- Respond
- Discuss
- Take a few minutes to study.

Slides from Cellular Respiration Lecture PowerPoints

- What slides from the lecture PowerPoints would you like to review about cellular respiration?
- Think about these?
- Respond
- Discuss
- Take a few minutes to study.
Selected Cellular Respiration Questions

- We need to look at the following questions that many of you missed.
- What is your response to these questions?

Encounters with Cellular Respiration

- Yogurt vs. Bread
- Running and getting leg cramps
- Compare and contrast the above.
Yogurt

- Develop a list of experiments that could be done with yogurt related to cellular respiration.
- Develop with them procedures that could be done to test or track the changes in fermentation.

Track Changes in Lactic Acid Production

- How does pH change with time of incubation?
  > Introduction
  > Procedure
  > Results
  > Conclusion
Bread

- Develop a list of experiments that could be done with bread related to cellular respiration.
- Develop procedures that could be done to test or track the changes in fermentation.
- Lab Procedures for yeast and a balloon.

Basic Fermentation BioKit® Investigation

- Yeast is essential to baking and fermentation
- What rate can yeast ferment with sucrose and glucose solutions?
Group Assignment

- Group 1: 10% sucrose
- Group 2: 5% sucrose
- Group 3: 5% glucose

Procedure

- Obtain one large and one small vial.
- Add 10 ml yeast suspension to small vial.
- Finish filling the vial with the designated sugar solution.
- Hold the small vial upright, and lower the large vial on top of it.
- Hold two vials firmly and turn upside down.
- Carbon dioxide gas from fermentation will collect in the small vial.
- Measure the zero point.
- Measure every 5 minutes for up to 45 minutes. Remember to subtract the zero point.
Data

- Complete Table 1 and graph the average gas column length.
- Answer questions.

Aerobic Cellular Respiration Laboratory

- $12\text{H}_2\text{O} + 6\text{CO}_2 \rightarrow \text{C}_6\text{H}_12\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O}$
- $PV = nRT$ where: $P$ stands for pressure of the gas, $V$ stands for the volume of the gas, $n$ stands for the number of molecules of gas there are, $R$ stands for the gas constant, and $T$ stands for the temperature of the gas in degrees Kelvin.
The Carbon Dioxide Experimental Design Difficulty

- Carbon dioxide is formed as oxygen is used. The pressure due to CO₂ might cancel out any changes due to the consumption of oxygen. To get rid of this problem, a chemical will be added that will selectively take out the carbon dioxide put off. Potassium hydroxide will chemically react with the carbon dioxide by this equation: CO₂ + K₂CO₃ + H₂O.

Materials

- water bath
- graduated cylinder
- Thermometer
- Tape
- metal washers
- Beads
- germinating peas
- non-germinating peas
- beads
- beakers ice
Procedure

- For assembly of the respirometers
- Obtain 6 vials, each with a stopper and a pipette.
- Place a small wad of absorbent cotton in the bottom of each vial and using a dropper, saturate the cotton with 13% KOH solution. Make sure the vials are dry on the inside. Do not get KOH on the sides of the respirometer.
- Place a small wad of non-absorbent cotton on top of the KOH saturated cotton, making sure the same amount is used for each respirometer.
- Place the first set of peas in their respective vials. Do the same for the second set of peas. Insert the stopper with the calibrated pipette. Place a weighted collar on the end of each vial.
- Make a sling of masking tape attached to each side of the water baths to hold the pipettes out of the water during the equilibration period of seven minutes. Vials 1, 2, and 3, should rest in the room temperature water while 4, 5, and 6, should rest in the 10-degree Celsius water bath. After seven minutes of equilibration, immerse all 6 respirometers entirely in their designated water baths.

Respirometer Contents

<table>
<thead>
<tr>
<th>Respirometer</th>
<th>Temperature</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Room</td>
<td>Germinating seeds</td>
</tr>
<tr>
<td>2</td>
<td>Room</td>
<td>Dry Seeds and Beads</td>
</tr>
<tr>
<td>3</td>
<td>Room</td>
<td>Beads</td>
</tr>
<tr>
<td>4</td>
<td>10°C</td>
<td>Germinating Seeds</td>
</tr>
<tr>
<td>5</td>
<td>10°C</td>
<td>Dry Seeds and Beads</td>
</tr>
<tr>
<td>6</td>
<td>10°C</td>
<td>Beads</td>
</tr>
</tbody>
</table>

http://cns.k12.ar.us/messengale/Cell%20%20Respiration.htm
Data
- Fill in tables and graphs.
- Answer questions.

Write Lab Report
- Review the template to write from.
Photosynthesis

By
Jewel Reuter
October, 2004

Photosynthesis Test Questions

- What questions do you think were easiest?
- What questions were the most difficult?
- Which Questions would you like to discuss?
- What concepts would you like to discuss?
What Do You Think You Need to Study More About Photosynthesis

- Think about this?
- Respond
- Discuss
- Take a few minutes to study.

Slides from Photosynthesis Lecture PowerPoints

- What slides from the lecture PowerPoints would you like to review about cellular respiration?
- Think about these?
- Respond
- Discuss
- Take a few minutes to study.
Selected Photosynthesis Questions

- We need to look at the following questions that many of you missed.
- What is your response to these questions?

Exercise 4A: Plant Pigment Chromatography:

- Paper chromatography is a useful technique for separating and identifying pigment and other molecules from cell extracts that contain a complex mixture of molecules.
- The solvent moves up the paper by capillary action, which occurs as a result of the attraction of solvent molecules to the paper and the attraction of the solvent molecules to one another.
- As the solvent moves up the paper, it carries along any substances dissolved in it. The pigments are carried along at different rates because they are not equally soluble in the solvent and because they are attracted, to different degrees, to the fibers of the paper through the formation of intermolecular bonds, such as hydrogen bonds.
Procedure

1. Obtain a 250 mL beaker which has about 2 cm of solvent at the bottom. Cover the beaker with aluminum foil to prevent the vapors from spreading. It is also suggested this work be done under a fume hood.
2. Cut a piece of filter paper which will be long enough to reach the solvent. Draw a line about 1.0 cm from the bottom of the paper.
3. Use a quarter to extract the pigments from spinach leaf cells. Place a small section of leaf on the top of the pencil line. Use the ribbed edge of the coin to crush the leaf cells. Be sure the pigment line is on top of the pencil line. Use a back and forth movement exerting firm pressure through out.
4. Place the chromatography paper in the cylinder. See Figure 4.2 below. Do not allow the pigment to touch the solvent.
5. Cover the beaker. When the solvent is about 1 cm from the top of the paper, remove the paper and immediately mark the location of the solvent front before it evaporates.
6. Mark the bottom of each pigment band. Measure the distance each pigment migrated from the bottom of the pigment origin to the bottom of the separated pigment band. Record the distance that each front, including the solvent front, moved in Table 4.1. Depending on the species of plant used, you may be able to observe 4 or 5 pigment bands.

Analysis of Results

- The relationship of the distance moved by a pigment to the distance moved by the solvent is a constant called $R_f$. It can be calculated for each of the four pigments using the formula:

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

- Record your $R_f$ values in Table 4.2
Exercise 4B: Photosynthesis / The Light Reaction

- Light is a part of a continuum of radiation or energy waves. Shorter wavelengths of energy have a greater amounts of energy. For example, high-energy ultraviolet rays can harm living things.
- Wavelengths of light within the visible spectrum of light power photosynthesis, when light is absorbed by leaf pigments, electrons within each photosystem are boosted to a higher energy level and this energy level is used to produce ATP and to reduce NADP to NADPH. ATP and NADPH are then used to incorporate CO$_2$ into organic molecules, a process called carbon fixation.

Design of the Exercise

- Photosynthesis may be studied in a number of ways. For this experiment, a dye-reduction technique will be used. The dye-reduction experiment tests the hypothesis that light and chloroplasts are required for the light reactions to occur. In place of the electron acceptor, NADP, the compound DPIP (2,6-dichlorophenol-indophenol), will be substituted. When light strikes the chloroplasts, electrons boosted to high energy levels will reduce DPIP. It will change from blue to colorless.
- In this experiment, chloroplasts are extracted from spinach leaves and incubated with DPIP in the presence of light. As the DPIP is reduced and becomes colorless, the resultant increase in light transmittance is measured over a period of time using a spectrophotometer. The experimental design matrix is presented in Table 4.3.
Cuvette Set-up

<table>
<thead>
<tr>
<th>Block</th>
<th>Cuvettes</th>
<th>2 Unboiled Dark</th>
<th>3 Unboiled Light</th>
<th>4 Alkaline Chloroplast Light</th>
<th>5 No Chloroplasts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphate Buffer</td>
<td>1 ad.</td>
<td>1 ad.</td>
<td>1 ad.</td>
<td>1 ad.</td>
<td>1 ad.</td>
</tr>
<tr>
<td>Bleached Water</td>
<td>1 ad.</td>
<td>1 ad.</td>
<td>1 ad.</td>
<td>1 ad.</td>
<td>1 ad.</td>
</tr>
<tr>
<td>Unboiled Chloroplast</td>
<td>2 drops</td>
<td>2 drops</td>
<td>2 drops</td>
<td>2 drops</td>
<td>2 drops</td>
</tr>
<tr>
<td>Boiled Chloroplast</td>
<td>3 drops</td>
<td>3 drops</td>
<td>3 drops</td>
<td>3 drops</td>
<td>3 drops</td>
</tr>
</tbody>
</table>

Summary of Cuvettes

<table>
<thead>
<tr>
<th>Cuvette</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Unboiled/Dark</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Unboiled/Light</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Boiled/Light</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 No Chloroplasts</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

http://apsc.k12.ar.us/massengal/AF%20Laboratories.htm
Encounters with Photosynthesis

- Do plant produce oxygen?

Spinach Experiment

- **Purpose:**
  
  To explain how the experiment measures the occurrence of photosynthesis in spinach.
Hypothesis

Only discs under bright light will rise.

Materials

- Fresh spinach
- 0.2% sodium bicarbonate (NaHCO₃)
- 250-mL flask with 2 hole rubber stoppers
- Vacuum source
- #3 Cork borer
- Glass sfbr rod
- 6 Petri dishes
- 2 Reflector lamps
- 2 Support stands for lamps
- 2 1L or 2L beakers
- Culture dish
- Forceps
- Cutting board
Procedure

1. Attach the lamp to the support stand so that the lamp is approximately 25 cm from the base.
2. Fill large beaker with cold water to act as a heat filter for the dish you will place under the lamp.
3. Pour 0.25 NaHCO₃ solution into 3 petri dishes, making them 2/3 full. Pour 100 ml of 0.25 NaHCO₃ solution into a 250-ml flask.
4. Get spinach leaves and cut 50 to 50 discs with a cork borer, not including the large veins.
5. Attach vacuum tubing to the side of the flask and put the rubber cork firmly on top.
6. Make a vacuum to aspirate the discs until they sink and pour into a large dish.
7. Discard floating discs and place 10 to 15 discs in each petri dish.
8. Place one dish under the 100-ml beaker under the lamp, one under room light, and one under no light.
9. Count the number of floating discs in each dish and calculate the percent of the floating discs.

Procedure

- Photosynthesis in Leaf Discs, Procedure: Prepare 20 ml syringes by filling them with the buffer provided (50 mM potassium phosphate buffer with 10 mM sodium bicarbonate (NaHCO₃; bicarbonate of soda); the control buffer does not contain bicarbonate. Punch out disks from a green leaf using a paper punch. Place 10 disks into each syringe.
- Apply a vacuum by pulling back on the plunger while swirling until all of the disks are no longer floating. Stand the syringe on its plunger about 15 cm from the fluorescent light bulb. At 2-minute intervals for 20 minutes, invert the chambers to agitate the leaf disks, and then immediately return them to the light in their previous position. Count the total number of disks that are floating every two minutes. The time required for a leaf disk to float is an index of the net rate of photosynthesis.
- (oxygen produced by photosynthesis minus oxygen consumed by cellular respiration).
To calculate the % of floating disks:
number of floating disks • 100% = % floating
- total number of disks
### Table of Results

<table>
<thead>
<tr>
<th>Elapsed time (minutes)</th>
<th>Bicarbonate-containing buffer</th>
<th>Bicarbonate-containing buffer</th>
<th>Control Buffer</th>
<th>Control Buffer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Floating disks</td>
<td>% floating</td>
<td>Floating disks</td>
<td>% floating</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
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<td>18</td>
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<tr>
<td>20</td>
<td></td>
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</tr>
</tbody>
</table>

To calculate the % of floating disks: `number of floating disks ÷ total number of disks × 100%`

Post your data with other groups. (Why would this be a good idea?) Plot the data on a graph.

### Another Photosynthesis Lab?
Interrelationship of Photosynthesis and Cellular Respiration

Dissolved Oxygen and Primary Aquatic Productivity: Laboratory 12

- Dissolved oxygen levels are an extremely important factor in determining the quality of an aquatic environment. Dissolved oxygen is necessary for the metabolic processes of almost every organism.
- Primary production is the energy accumulated by plants since it is the first and basic form of energy storage. The flow of energy through a community begins with photosynthesis. All of the sun’s energy that is used is termed gross primary production. The energy remaining after respiration and stored as organic matter is the net primary production, or growth. The equation for photosynthesis is as follows:

\[ 12\text{H}_2\text{O} + 6\text{CO}_2 \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O} \]
Materials

- **Measurement of Dissolved Oxygen**
  This part of the lab required a sample bottle of water from a natural source, a BOD bottle, thermometer, manganous sulfate, alkaline iodide, thiosulfate, a 2-ml pipette, sulfuric acid, a 20-ml sample cup, a white piece of paper, starch solution, and a nomograph.

- **Measurement of Primary Productivity**
  Part B required a sample bottle of water from a natural source, 7 BOD bottles, aluminum foil, 17 cloth screens, rubber bands, a light, thermometer, concavity slides, light microscope, manganous sulfate, alkaline iodide, thiosulfate, a 2-ml pipette, sulfuric acid, a 20-ml sample cup, a white piece of paper, starch solution, and a nomograph.

Measurement of Primary Productivity

- A second sample bottle was filled from a natural source making sure there were no air bubbles. Seven BOD bottles were filled completely with the sample with no air bubbles. The first bottle was labeled #1 blank. The second bottle served as the dark bottle and was labeled #2 dark. The other five bottles were labeled according to the light intensity: #3 100%, #4 10%, #5 25%, #6 50%, and #7 75%.
- Bottle #2 was wrapped completely in aluminum foil so that it received no light. The other five bottles were wrapped in screens to produce the desired light intensity. Bottle #1 had no screens, bottle #2 had 3 screens, bottle #3 had 5 screens, bottle #4 had 7 screens, and bottle #5 had 8 screens. The screens were held in place with rubber bands. Bottles #6-7 were placed under a light source and left overnight.
- Bottle #1 was fixed by following the Weiskel method. Eight drops of manganous sulfate were added to the bottle. Next, eight drops of alkaline iodide was added and the precipitate manganous hydroxide was formed. The bottle was mixed several times and then allowed to settle until the precipitate was below the shoulders of the bottle. A scoop of sulfuric acid was added, and the bottle was inversed until all of the precipitate dissolved. The sample turned a clear yellow. It was left at room temperature until the other samples were processed.
- A color match was observed under a light source, so that the different organisms present could be identified.
- The next day, bottles #6-7 were fixed by following the same method used on bottle #1. The dissolved oxygen levels were determined in each of the seven bottles. A 3-ml of the sample were pipeted into the sample cup. The cup was placed on a white sheet of paper so that the color changes could be observed. A range of starch solution was added to the sample, making it turn purple. The sample was then blended with the starch. One drop of the starch was added at a time until the color changed to a pale yellow color.
- **Productivity Simulation**
  The regeneration data from Part B was converted to carbon productivity. The data was graphed with comparison to water depths.
Write Lab Report

- Review the template to write from.

END
Aerobic cellular respiration refers to the process of converting the chemical energy of organic molecules into a form immediately usable by organisms. Glucose may be oxidized completely if sufficient oxygen is available and is summarized by the following reaction:

\[
\text{With Aerobic Cells} \\
\text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2(\text{g}) \rightarrow 6 \text{H}_2\text{O} + 6 \text{CO}_2(\text{g}) + \text{energy} \\
\text{(glucose + oxygen)} \rightarrow \text{water + carbon dioxide + energy)
\]

Often, this energy is used to convert ADP and phosphate into ATP, useable cellular energy. All organisms, including plants and animals, oxidize glucose for energy, but not all organisms use oxygen. If oxygen is not present, the organisms undergo fermentation, anaerobic respiration. Fermentation reactions are anaerobic, proceeding without oxygen. Anaerobic reactions involve cellular food products and/or glucose sugar as their reactants. *Saccharomyces cerevisiae* is commonly known as "bakers’ yeast" or "brewers’ yeast". The yeast **ferments** sugars present in the flour or added to the dough, giving off **carbon dioxide** and ethanol. The CO2 is trapped as tiny bubbles in the dough, which rises. The yeasts gain energy from the breakdown (fermentation) of carbohydrates, and people enjoy the soft texture of the bread.

\[
\text{With Anaerobic Yeast in Bread Dough} \\
\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow \text{C}_2\text{H}_5\text{OH} + \text{CO}_2(\text{g}) + \text{energy} \\
\text{(glucose)} \rightarrow \text{ethanol + carbon dioxide + energy)
\]

**THE FALLING BREAD (A CASE STUDY FOR THIS LAB)**

The following is a possible scenario that could be occurring in a bakery near your school campus. There is a new bread dough that is not rising and is causing the bakers problems. The bakers want to inform the dough ingredient distribution company that they think there is a problem with the recipe temperature. They need to report scientific information to the dough ingredient distribution company. This laboratory is designed to help you solve this hypothetical problem.

Bakers in the area have been experiencing problems with new bread dough ingredients that are
suppose to make the bread rise faster at cold temperatures instead of warm temperatures. The bakers think that the new and improved yeast that they use in the new bread dough products needs to be risen at a different temperature than the cold temperature recipe. The size of the loaves of their bread is important. If the bread does not rise enough, it is hard and if they have to wait for a long time for the bread to rise it slows down their production. In this lab you will see what temperature is the best to for the new bread dough to rise. Using the CO₂ Gas Sensor, you will monitor the carbon dioxide produced by yeasts during fermentation at various temperatures, and you will test to see if bread dough without yeast added performs fermentation. The following is a scenario about the details of the bakery’s problems.

THE RISE AND FALL OF THE BREAD

The Cajun Bakery has a reputation for wonderful bread. Their business was booming and they could barely keep up with the demand. The owner, Mr. Boudreaux, was sold a new type of bread dough that would rise faster at cooler temperatures instead of warmer temperatures, and would not tie up the ovens for so long. A problem arose as soon as the bakery switched to the new bread dough.

“Mr. Boudreaux, this new dough is taking longer than the old dough to rise, I thought it would be faster,” said the baker, Henri. “Other bakers in the area have been having problems with the new bread dough, too. It is supposed to rise faster in cooler temperatures, but if the bread dough does not rise enough, the bread is hard.

“Henri, we got to do something or we will lose most of our customers,” said Mr. Boudreaux. “I don’t believe what the distributor promised about the dough and I want to test it.”

“Me, too, Mr. B. What about your sister, Mr. B., isn’t she a biologist at LSU? I bet she could help you.” said Henri. I know the yeast and the dough have something to do with biology.”

“I called her this morning, Henri. She’s coming over later to pick up some of the bread dough. She said she will do an experiment to find the problem.” said Mr. Boudreaux. “I wonder what kind of experiment she will do.”

OBJECTIVES

In this experiment, you will

• use a CO₂ Gas Sensor to measure concentrations of carbon dioxide during fermentation.
• study the effect of temperature on fermentation rate.
• determine whether yeast in bread dough respires.
• compare the rates of cellular respiration in dough with and without yeast.
Figure 1

Carbon dioxide sensor

18 oz. Peter Pan Peanut Butter Sensosphere or 8 oz Folgers plastic instant coffee bottle

Figure 2

Bread dough

31.04 Balance
### MATERIALS

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Macintosh or Windows PC</td>
<td>(1) Thermometer or Temperature Sensor</td>
</tr>
<tr>
<td>Vernier computer interface</td>
<td>(1) Ice Water Bath</td>
</tr>
<tr>
<td>Logger Pro</td>
<td>(1) Warm Water Bath</td>
</tr>
<tr>
<td>Vernier CO₂ Gas Sensor</td>
<td>(1) Room Temperature Water Bath</td>
</tr>
<tr>
<td>30 g Bread Dough with Yeast Pillsbury Hot Roll Mix (16 oz.) with Yeast</td>
<td>(1) 18 oz. Peter Pan Peanut Butter Sensosphere or 8 oz. Folgers plastic coffee bottle</td>
</tr>
<tr>
<td>(30) Bread Dough without Yeast Pillsbury Hot Roll Mix (16 oz.) without Yeast</td>
<td>(3) Quart Size Freezer Ziplock Bag</td>
</tr>
<tr>
<td>(1) 3/8 Inch Drill with 1-1/8 inch Drill Bit</td>
<td>(2) small 2 inch diameter Petri dishes</td>
</tr>
</tbody>
</table>

![Figure 3](image-url)
PROCEDURE

1. Empty the peanut butter from the 18 oz. Peter Pan Peanut Butter bottle, wash and dry it.

2. Drill a 1-1/8 inch hole in the center of the plastic lid using the drill to create a Peter Pan Peanut Butter Bottle Sensosphere. See Figures 1. (Your instructor will have this prepared for you.)

3. Plug the CO2 Gas Sensor into Port 1 of the Vernier computer interface.

4. Prepare the computer for data collection by opening the file in the Experiment 11B folder of *Biology with Computers*. If the sensor is not an autoID sensor, select OK from the Sensor Confirmation screen. The vertical axis has carbon dioxide concentration scaled from 0 to 5000 ppm. The horizontal axis has time scaled from 0 to 5 minutes. The data rate is set to 6 samples/minute.

Part I Bread with Yeast, Warm Temperature

5. Measure the warm water bath temperature using a thermometer and record the temperature in Table 1.

6. Take the mass of the bottom of a Petri dish or tare the mass. Place about 30 g bread sample with yeast sample in the bottom of the Petri that is at rising at the warm temperature of about 40°C. See Figure 2. Record the mass in Table 1.

7. Place the 30 g mass on the Petri plate bottom into the Peter Pan Peanut Butter Sensosphere.

8. Place the shaft of the CO2 Gas Sensor in the opening of the Sensosphere. Gently twist the stopper on the shaft of the CO2 Gas Sensor into the Sensosphere opening. Do not twist the shaft of the CO2 Gas Sensor or you may damage it.

9. Wait one minute, then begin measuring carbon dioxide concentration by clicking Collect ( ). Data will be collected for 5 minutes.

10. Remove the CO2 Gas Sensor from the Sensosphere. Place the bread in the Petri plate bottom into a Ziplock bag and into the cold water bath with ice cubes. The cold water will prepare the bread dough for part II of the experiment.

11. Use a notebook or notepad to fan air across the openings in the probe shaft of the CO2 Gas Sensor for 1 minute.

12. Fill the Sensosphere with water and then empty it. Thoroughly dry the inside of the Sensosphere with a paper towel.

13. Determine the rate of cellular respiration:
   a. Move the mouse pointer to the point where the data values begin to increase. Hold down the left mouse button. Drag the mouse pointer to the end of the data and release the mouse button.
   b. Click the Regression button, to perform a linear regression. A floating box will appear with the formula for a best fit line.
   c. Record the slope of the line, m, as the rate of cellular respiration for dough at warm temperature in Table 2.
   d. Close the linear regression floating box.
14. Move your data to a stored run. To do this, choose Store Latest Run from the Experiment menu.

**Part II  Bread without Yeast, Warm Temperatures**

15. Repeat Steps 8-14 substituting the warm yeast bread dough with warm non-yeast bread dough. In Step 5 place the non-yeast bread dough in the Petri plate on a paper towel and not in the ice bath.

**Part III  Bread with Yeast, Cool Temperatures**

16. Place the Sensosphere in ice bath. Cover the outside of the chamber with ice. See Figure 3.

17. Use the thermometer to measure the water temperature of the ice water bath containing the cold bread dough with yeast. Record the temperature in Table 1.

18. Remove the bread dough in the Ziplock bag from the cold water and blot the bag dry. Remove the bread dough on the Petri plate from the bag. Keep the dough dry between two paper towels.

19. Repeat Steps 8 – 13 using the cold bread dough with yeast.

**DATA**

<table>
<thead>
<tr>
<th>Bread Doughs</th>
<th>Temperature (°C)</th>
<th>Mass (g)</th>
<th>Rate of cellular respiration (ppm/s)</th>
<th>Rate of cellular respiration/mass (ppm/s/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Yeast, warm temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With yeast, cool temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without Yeast, warm temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**QUESTIONS**

1. Do you have evidence that fermentation occurred in bread dough? Explain.

2. What is the effect of temperature on the rate of yeast fermentation?

3. Why do yeast undergo fermentation?

4. Why is yeast important to making bread?

5. Make a diagram of the relative heights of the dough without yeast, with yeast at cool temperature and with yeast at warm temperature. This series of diagrams of the dough will
represent a living graph. (Optional: Use a digital camera to take pictures of the various bread doughs. Use these images to make the living graph.)

6. Using the data from this laboratory, make a recommendation on what you think the owner of the Cajun Bakery could do to modify their procedure to make bread faster. Explain your recommendation.

EXTENSIONS

1. Make a PowerPoint Presentation that explains your experiment, results and your recommendations to the bakers about how they could make larger bread faster.

2. Compare the cellular respiration rate among various types of flours and bread (white, wheat, rye, sour dough, etc.).

2. Compare the cellular respiration rate among dough risen for different time periods, such as 1, 3, and 5 hours.

3. Compare the cellular respiration rate among various amounts of sugar added to the dough.

4. Compare the cellular respiration rate among various amounts of water added to the dough.

REFERENCES:

Saccharomyces cerevisiae, University of Leicester, Department of Microbiology and Immunology, 28, Oct. 2002 < www-micro.msb.le.ac.uk/video/Scerevisiae.html>


Details of yeast fermentation.

http://www-micro.msb.le.ac.uk/video/Scerevisiae.html
Plants make sugar, storing the energy of the sun into chemical energy, by the process of photosynthesis. When they require energy, they can tap the stored energy in sugar by a process called cellular respiration.

The process of photosynthesis involves the use of light energy to convert carbon dioxide and water into sugar, oxygen, and other organic compounds. This process can be summarized by the following reaction:

$$6 \text{H}_2\text{O} + 6 \text{CO}_2 + \text{light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2$$

Cellular respiration refers to the process of converting the chemical energy of organic molecules into a form immediately usable by organisms. Glucose may be oxidized completely if sufficient oxygen is available in the following reaction:

$$\text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{H}_2\text{O} + 6 \text{CO}_2 + \text{energy}$$

All organisms, including plants and animals, oxidize glucose for energy. Often, this energy is used to convert ADP and phosphate into ATP. Using the CO₂ Gas Sensor, you will attempt to monitor the carbon dioxide consumed or produced by plants.

**THE INCREASE OF PEOPLE WITHOUT AN INCREASE IN PLANTS**

**A MODLE STUDY FOR THIS STITUATION**

The following is a possible scenario that is occurring in many areas of the world.

There is now an abundance of people in many areas of the world. They need a place to live, and many areas have been deforested to provide living areas for the people. Many people are concerned about the increased number of people and a decreased number of plants. They are concerned that there is a greater production of carbon dioxide by the people and that there are less plants to use the carbon dioxide. They would like scientific information about the situation, and it is difficult to do studies on large areas. The following is a model system to simulate the human population explosion. An increase number of mealworms in a chamber with a limited amount of plants is a small situation that is a good model to show the impact of having more animals with the same number of plants or a lesser number of plants. This model would provide information to the worried people who want to better understand the impact of more animals and less plants on the ecosystem. This laboratory is designed to help you create a model system to help you to predict the impact of an increased number of animals without an increased number of plants.

Using the CO₂ Gas Sensor, you will monitor the carbon dioxide produced by the plants and mealworms during respiration and the amount of carbon dioxide use by the plants with photosynthesis so see the relationship between the amount of plants and animals in a model ecosystem.
OBJECTIVES

In this experiment you will,

• use an CO2 Gas Sensor to measure the amount of carbon dioxide consumed or produced by plants and animals in a model ecosystem.
• determine the rate of respiration and photosynthesis of a plant.
• determine the change in rate of respiration with the increase number of animals in the system.

MATERIALS

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>LabPro or CBL 2 Interface</td>
<td>(1)</td>
</tr>
<tr>
<td>TI Graphing Calculator</td>
<td></td>
</tr>
<tr>
<td>DataMate Program</td>
<td></td>
</tr>
<tr>
<td>Vernier CO2 Gas Sensor</td>
<td></td>
</tr>
<tr>
<td>Aluminum Foil</td>
<td></td>
</tr>
<tr>
<td>3/8 Inch Drill with 1-1/8 inch Drill Bit</td>
<td></td>
</tr>
<tr>
<td>Rubber Band or Twist Tie</td>
<td></td>
</tr>
<tr>
<td>(1) 32 oz Benzel’s Bretzel pretzel jar</td>
<td></td>
</tr>
<tr>
<td>Cabbage or Okra Seedling (With Roots and Soil Wrapped in Plastic Wrap)</td>
<td></td>
</tr>
<tr>
<td>500-mL Tissue Culture Flask (Heat Sink)</td>
<td></td>
</tr>
<tr>
<td>2 Fluorescent Lamps</td>
<td></td>
</tr>
<tr>
<td>Forceps</td>
<td></td>
</tr>
<tr>
<td>Plastic Wrap</td>
<td></td>
</tr>
<tr>
<td>10 - 30 g Mealworms</td>
<td></td>
</tr>
</tbody>
</table>
PROCEDURE

1. Drill a 1-1/8 inch hole in the center of the plastic lid using the drill to create a 32 oz Benzel’s Bretzel pretzel jar Sensosphere. See Figures 1 and 2. (Your instructor will have this prepared for you.)

2. Plug the CO₂ Gas Sensor into Channel 1 of the LabPro or CBL 2 interface. Use the link cable to connect the TI Graphing Calculator to the interface. Firmly press in the cable ends. (If using the computer, use Experiment 31b. Prepare the computer for data collection by opening the file in the Experiment 31B folder of Biology with Computers. (If the sensor is not an autoID sensor, select OK from the Sensor Confirmation screen.) The vertical axis has carbon dioxide concentration scaled from 0 to 2 PPT (parts per thousand). The horizontal axis has time scaled from 0 to 10 minutes. The data rate is set to 6 samples/minute.)

3. Turn on the calculator and start the DATAMATE program. Press CLEAR to reset the program.

4. Set up the calculator and interface for a CO₂ Gas Sensor.
   a. Select SETUP from the main screen.
   b. If the calculator displays CO₂ GAS (PPT) in CH 1, proceed directly to Step 5. If it does not, continue with this step to set up your sensor manually.
   c. Press ENTER to select CH 1.
   d. Select CO₂ GAS from the SELECT SENSOR menu.
   e. Select parts per thousand (PPT) as the unit.

5. Set up the data-collection mode.
   a. To select MODE, press ▲ (the up arrow key) once and press ENTER.
   b. Select TIME GRAPH from the SELECT MODE menu.
   c. Select CHANGE TIME SETTINGS from the TIME GRAPH SETTINGS menu.
   d. Enter “15” as the time between samples in seconds.
   e. Enter “40” as the number of samples (data will be collected for 10 minutes).
   f. Select ADVANCED from the TIME GRAPH SETTINGS menu.
   g. Select CHANGE GRAPH SETTINGS from the ADV. TIME GRAPH SETTINGS menu.
   h. Select CH 1-CO₂ GAS (PPT) from the SELECT GRAPH menu.
   i. Enter “0” for Ymin, “2” as Ymax, and “0.1” as Yscl.
   j. Select OK to return to the TIME GRAPH SETTINGS menu.
   k. Select OK to return to the setup screen.
   l. Select OK to return to the main screen.

6. Obtain plant from the resource table and blot the leaves dry, if damp, between two pieces of paper towel. Remove the plant form the cell pack (small pot). Wrap the soil and roots gently in plastic wrap with a rubber band or twist tie.

7. Place the plant into the respiration chamber, using forceps if necessary. Wrap the respiration chamber in aluminum foil so that no light reaches the seedling.

8. Place the CO₂ Gas Sensor into the bottle as shown in Figure 2. Gently twist the stopper on the shaft of the CO₂ Gas Sensor into the chamber opening. Do not twist the shaft of the CO₂ Gas Sensor or you may damage it. Wait 3 minutes before proceeding to Step 9.
9. Select START to begin data collection. Data will be collected for 10 minutes.

10. When data collection has finished, a graph of CO2 GAS vs. TIME will be displayed. Press ENTER to return to the main screen.

11. Perform a linear regression to calculate the rate of respiration/photosynthesis.
   a. Select ANALYZE from the main screen.
   b. Select CURVE FIT from the ANALYZE OPTIONS menu.
   c. Select LINEAR (CH 1 VS TIME) from the CURVE FIT menu.
   d. The linear-regression statistics for these two lists are displayed for the equation in the form:
      \[ Y = A \times X + B \]
   e. Enter the value of the slope, \( A \), as the rate in the proper table.
   f. Press ENTER to view a graph of the data and the regression line.
   g. Press ENTER to return to the ANALYZE menu.
   h. Select RETURN TO MAIN SCREEN from the ANALYZE menu.

12. Remove the aluminum foil from around the respiration chamber.

13. Fill the tissue culture flask with water and place it between the lamp and the respiration chamber. The flask will act as a heat shield to protect the plant leaves.

14. Turn the lamp on. Place the lamp as close to the leaves as reasonable. Do not let the lamp touch the tissue culture flask. Note the time. The lamp should be on for 3 minutes prior to beginning data collection.

15. Store the data from the first run so that it can be used later.
   a. Select TOOLS from the main screen.
   b. Select STORE LATEST RUN from the TOOLS MENU.

16. After the three-minute time period is up, repeat Steps 9 – 11.

17. Store the data from the first run so that it can be used later.
   a. Select TOOLS from the main screen.
   b. Select STORE LATEST RUN from the TOOLS MENU.

18. Add 10 g of mealworms, wait 3 min and repeat Steps 9 - 11.

19. After the three-minute time period is up, repeat Steps 9 – 11.

20. Add 10 g of mealworms and repeat Steps 9 - 11.

21. Graph both runs of data on a single graph. To do this:
   a. Select GRAPH from the main screen, then press ENTER.
   b. Select MORE, then select L2, L3 AND L4 VS L1 from the MORE GRAPHS menu. All three runs should now be displayed on the same graph. Each point of the plant in the dark is plotted with a cross, each point of the plant with light is plotted with a box, and each point of plant with mealworms is plotted with a dot.
c. Examine the data points along the displayed curves of L2 (mealworms with plant in light) vs. L1. As you move the cursor right or left, the time (X) and carbon dioxide concentration (Y) values of each data point are displayed below the graph.

d. Press $\downarrow$ to switch the cursor to the curve of L3 (plant in light) vs. L1. Examine the data points along the curve.

e. Press $\downarrow$ to switch the cursor to the curve of L4 (plant in dark) vs. L1. Examine the data points along the curve.

f. Use the displayed graph and Table 1 to answer the questions below.

g. (Optional) Print a copy of your graph per your teacher’s instructions.

h. When finished with the graph, press [ENTER] to exit.

i. Select RETURN TO GRAPHS SCREEN from the MORE GRAPHS menu.

j. Select MAIN SCREEN from the graph screen.

k. Select QUIT from the main screen to exit the program.

22. Remove the seedling from the respiration chamber, using forceps if necessary. Take the mass of the seedling and the seedling and mealworms for the total biomass, without the plastic wrap. Record the mass in proper table. Clean and dry the respiration chamber.

**DATA**

<table>
<thead>
<tr>
<th>Seedling</th>
<th>Total Biomass (g)</th>
<th>Rate of respiration/photosynthesis (PPT/s)</th>
<th>Rate of respiration/photosynthesis/mass (PPT/s/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seedling in Dark</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seedling in Light</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seedling and Mealworms in the Light</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**QUESTIONS**

1. Were either of the rate values a positive number? If so, what is the biological significance of this?

2. Were either of the rate values a negative number? If so, what is the biological significance of this?

3. Do you have evidence that cellular respiration occurred in the plant? Explain your answer.

4. Do you have evidence that photosynthesis occurred in the plant? Explain your answer.
5. List five factors that might influence the rate of carbon dioxide production or consumption in plants. Explain how you think each will affect the rate?

6. What is the impact of adding animals to the ecosystem? Explain.

7. What do you think would be the impact on the ecosystem if the plant was cut in half and the mealworms remained constant in number? Explain.

8. How does this model system compare to the present human population explosion?

9. Assuming that the animal population is going to continue to increase, what could we do to minimized the problems to the ecosystem if all we had was plants to manipulate?

EXTENSIONS

1. Make a PowerPoint Presentation that explains your experiment, results and your recommendations to the farmers about how the mealworms influence the level of carbon dioxide and how your model represents the earth and the human population.

2. Design and perform an experiment to test one of the factors that might influence the rate of carbon dioxide production or consumption in Question 5.

3. Compare the rates of photosynthesis and respiration among various amount plants and mealworms.

4. Compare the rates of photosynthesis and respiration among various types of plants and animals and determine the best combination to allow to the use of carbon dioxide.

REFERENCES:
Masterman, David and Holman, S.(2000) Biology with Computers. Beaverton, OR: Vernier Software and Technology. (CBL and calculator protocols and handout Format were derived from this book.)
Heat Wave
The Effects of Water Temperature on Particular Algae and Photosynthesis

© 2004
by: Jewel Reuter

Algae, like other photoautotrophs, make sugar, storing the energy of the sun into chemical energy, by the process of photosynthesis. When they require energy, they can tap the stored energy in sugar by a process called cellular respiration.

The process of photosynthesis involves the use of light energy to convert carbon dioxide and water into sugar, oxygen, and other organic compounds. This process can be summarized by the following reaction:

\[ 6 \text{H}_2\text{O} + 6 \text{CO}_2 + \text{light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \]

Cellular respiration refers to the process of converting the chemical energy of organic molecules into a form immediately usable by organisms. Glucose may be oxidized completely if sufficient oxygen is available in the following reaction:

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{H}_2\text{O} + 6 \text{CO}_2 + \text{energy} \]

All organisms, including both autotrophs and heterotrophs, oxidize glucose for energy. Often, this energy is used to convert ADP and phosphate into ATP. Using the CO₂ Gas Sensor, you will attempt to monitor the carbon dioxide consumed or produced by algae.

Moss Balls, *Chladophora aegagropila*, a slow growing filamentous algae which improves filtration in your tank. It will not interfere with medications/treatments in the tank and may even inhibit growth of other types of algae. They are found in shallow lakes where the waves help to form the shape. They make much oxygen during the day with photosynthesis and they fall back to the bottom at night, and they group best in tropical environments.

HEAT WAVE: EFFECTS OF WATER TEMPERATURE ON PARTICULAR ALGAE AND PHOTOSYNTHESIS (A CASE STUDY FOR THIS LAB)

The following is a possible scenario that could be occurring near your campus.
Heat Wave!

Cotille and Boudreaux have a house with a sunroom and a patio. The sunroom is air conditioned and the patio is outdoors and each has its own aquarium. Both aquariums get the same amount of sunlight.

Boudreaux loves the aquariums and takes care of them regularly. Last summer he bought lots of moss balls from a friend to put in the aquariums. His friend told him that they were not plants but were algae and would help oxygenate the water.

A couple of months past and Boudreaux was off on his summer vacation when he noticed that the moss balls in the sunroom aquarium were doing fine and were growing, but the ones in the patio aquarium were shrinking in size and did not look healthy.

“Cotille,” says Boudreaux. “Come outside. These moss balls on the patio are dying. You haven’t been dumping anything poisonous into the aquarium…have you?”

Cotille goes to the aquarium and looks at the moss balls and says, “No, Boudreaux, I have not dumped anything in the aquariums. It must be 100º out here. I bet you I know what’s happening? The patio aquarium is too hot for the moss balls and if it get too hot the enzymes shut down and the it can’t make its food.”

“What difference does the heat make?” Boudreaux asked.

“Well, moss balls are native to the tropics and they are accustomed to a moderate temperature range. The patio is so hot the moss balls can’t function,” said Cotille

Cotille, can’t we do something to check the effect the temperature has on the moss balls? Didn’t you do something similar with algae in college?” Boudreaux said.

“You are right, Boudreaux,” said Cotille. “Let’s start testing the moss balls right now!”

OBJECTIVES

In this experiment you will,

- use an CO₂ Gas Sensor to measure the amount of carbon dioxide consumed or produced by plants during photosynthesis and cellular respiration.
- determine the rate of cellular respiration and photosynthesis of algae at various temperatures.
- This laboratory is designed to help you solve this hypothetical problem, and is designed for groups. Various groups use moss balls at various temperatures and compare results.
Figure 1
### MATERIALS/GROUP SET-UP

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Vernier computer interface</td>
<td>(1) 18 oz. Peter Pan Peanut Butter Sensosphere</td>
</tr>
<tr>
<td>Power Macintosh or Windows PC</td>
<td>(1) moss ball (<em>Chladophora aegagropila</em>)</td>
</tr>
<tr>
<td>Logger Pro</td>
<td>(1) circular ballasted fluorescent Lamp</td>
</tr>
<tr>
<td></td>
<td>(light: Sylvania CF30/830 FC8T9 (30 W, ring light ballasted lamp adaptors)</td>
</tr>
<tr>
<td></td>
<td>(CF30EL/CIRC/830/MED 120 V 60 Hz. These are Sylvania to match the lights.)</td>
</tr>
<tr>
<td>(1) Vernier CO₂ Gas Sensor</td>
<td>(1) portable lamp screw mount sockets with on/off switch, electric cord and clamp</td>
</tr>
<tr>
<td>(1) 3/8 Inch Drill with 1-1/8 inch Drill Bit</td>
<td>Optional (2) Regular Fluorescent Lamps To be used in place of the circular lamp.</td>
</tr>
<tr>
<td>Room temperature water bath</td>
<td>Optional (2) 500-mL Tissue Culture Flasks for heat sinks. Only to be used if regular fluorescent lamps are used instead of circular lamps.</td>
</tr>
<tr>
<td>Ice bath (approximately 5°C)</td>
<td>(1) Roll Aluminum Foil</td>
</tr>
<tr>
<td>Warm water bath (approximately 5°C)</td>
<td>(1) Balance</td>
</tr>
</tbody>
</table>

### PROCEDURE

1. Drill a 1-1/8 inch hole in the center of the plastic lid using the drill to create a 18 oz Peter Pan Peanut Butter Sensosphere. See Figure 1. (Your instructor will have this prepared for you.)

2. Plug the CO₂ Gas Sensor into Channel 1 of the LabPro interface.

3. Prepare the computer for data collection by opening the file in the Experiment 31B folder of *Biology with Computers*. (If the sensor is not an autoID sensor, select OK from the Sensor Confirmation screen.) The vertical axis has carbon dioxide concentration scaled from 0 to 2 PPT (parts per thousand). The horizontal axis has time scaled from 0 to 10 minutes. The data rate is set to 6 samples/minute.

**Part I Room Temperature Conditions in the Dark**

4. Obtain moss ball and the water bath for the desired incubation conditions.

5. Place the moss ball into the Sensosphere. Wrap the Sensosphere in aluminum foil so that no light reaches the moss ball.

6. Place the CO₂ Gas Sensor into the Sensosphere as shown in Figures 1. Gently twist the stopper on the shaft of the CO₂ Gas Sensor into the chamber opening. Do not twist the shaft of the CO₂ Gas Sensor or you may damage it. Wait 3 minutes before proceeding to Step 7.
7. Click [Collect] to begin data collection. Data will be collected for 10 minutes.

8. When data collection has finished, determine the rate of cellular respiration:
   a. Move the mouse pointer to the point where the data values begin to increase. Hold down the left mouse button. Drag the pointer to the point where the data ceases to rise and release the mouse button.
   b. Click on the Regression button, [ ], to perform a linear regression. A floating box will appear with the formula for a best fit line.
   c. Record the slope of the line, $m$, as the rate of cellular respiration in Table 1.
   d. Close the linear regression floating box.

9. Move your data to a stored run. To do this, choose Store Latest Run from the Experiment menu.

**Part II  Various Temperature Conditions in the Light**

10. Remove the aluminum foil from around the Sensosphere.

11. Place circular fluorescent lamp around the Sensosphere. See Figure 1. (Option: Fill a flask with water and place it between the incandescent lamp and the Sensosphere. The flask will act as a heat sink to protect the plant leaves. The circular lamp is the preference for best results and does not require a heat sink.)

12. Turn the circular lamp on. Place the lamp as close to the Sensosphere as reasonable. Do not let the lamp touch the tissue culture flask. Note the time. The lamp should be on for 3 minutes prior to beginning data collection.

13. After the three-minute time period is up, repeat Steps 7 – 8.

14. After the three-minute time period is up, click [Collect] to begin data collection. Data will be collected for 10 minutes.

15. When data collection has finished, determine the rate of photosynthesis:
   a. Move the mouse pointer to the point where the data values begin to decrease. Hold down the left mouse button. Drag the pointer to the point where the data ceases to decline and release the mouse button.
   b. Click on the Regression button, [ ], to perform a linear regression. (Select latest run if a dialogue box appears.) A floating box will appear with the formula for a best fit line.
   c. Record the slope of the line, $m$, as the rate of photosynthesis in Table 1.
   d. Close the linear regression floating box.

16. Label a graph showing your photosynthesis and cellular respiration data.
   a. Label each curve by choosing Text Annotation from the Insert menu. Enter “Photosynthesis at ____ºC” in the edit box. Repeat to create an annotation for the “Cellular Respiration at ____ºC” data. Drag each box to a position near its respective curve.
   b. Print a copy of the Graph window, with both data sets displayed. File, Print Graph and select Print Footer. Enter your name(s) and the number of copies of the graph you want.

17. **Repeat** steps 4-17 with a different temperature. (Hot at 30º - 35ºC and Cold at 5º - 10ºC)
Complete Table 1.

18. Remove the moss ball from the Sensosphere. Take the mass of the moss ball. Record the mass in proper table. Return the moss ball to its original container. Clean and dry the Sensosphere.

19. With data from Tables 1 – 5, complete Tables 6 and 7 and make graphs of the data from Tables 6 and 7 using Logger Pro, Graphical Analysis, Excel or graph paper.

**DATA**

<table>
<thead>
<tr>
<th>Moss Ball</th>
<th>Moss Ball Mass (g)</th>
<th>Temp. (°C)</th>
<th>Rate of cellular respiration/photosynthesis (PPT/s)</th>
<th>Rate of cellular respiration/photosynthesis/mass (PPT/s/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light with room temp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light with cold temp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light with hot temp</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dark with room temp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**QUESTIONS**

1. Under what conditions were the rates positive? If so, what is the biological significance of this?

2. Were any of the rate values negative numbers? If so, what is the biological significance of this?

3. Do you have evidence that cellular respiration occurred in some conditions? Explain your answer.

4. Do you have evidence that photosynthesis occurred in moss balls of some conditions? Explain your answer.

5. What conditions were best for the moss balls?

6. List five factors that might influence the rate of carbon dioxide production or consumption in mossballs. Explain how you think each will affect the rate?

7. Why do moss balls need to perform photosynthesis and under what conditions do they
perform photosynthesis?

8. Why do moss balls need to perform cellular respiration and under what conditions do they perform cellular respiration?

9. How could you use a light sensor to gather more complete data about this problem?

10. Using the data from this laboratory, make a recommendation on what you think the Cotille and Boudreaux should do with the aquarium. Explain.

EXTENSIONS

1. Make a PowerPoint Presentation that explains your experiment, results and your recommendations to Boudreaux about how the temperature is influencing their moss balls.

2. Design and perform an experiment to test one of the factors that might influence the rate of carbon dioxide production or consumption in Question 5.

3. Compare the rates of photosynthesis and cellular respiration at various temperatures and light.

4. Compare the rates of photosynthesis and cellular respiration among various types of algae and plants.

5. Use gaseous oxygen sensor and carbon dioxide sensor to collect data.

REFERENCES:


Cell Respiration
Solving the Mystery of the Mexican Jumping Beans

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by: Jewel Reuter

Cellular respiration refers to the process of converting the chemical energy of organic molecules into a form immediately usable by organisms. Glucose may be oxidized completely if sufficient oxygen is available by the following equation:

\[
\text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{ O}_2(g) \rightarrow 6 \text{ H}_2\text{O} + 6 \text{ CO}_2(g) + \text{energy} \\
\text{(glucose + oxygen)} \rightarrow \text{(water + carbon dioxide + energy)}
\]

All organisms, including plants and animals, oxidize glucose for energy. Often, this energy is used to convert ADP and phosphate into ATP. It is known that peas undergo cellular respiration during germination. Do jumping beans undergo cellular respiration when not jumping? The results of this experiment will verify that jumping beans do respire when not jumping. Using your collected data, you will be able to answer the question concerning respiration and movement and being alive.

Using the CO₂ Gas Sensor, you will monitor the carbon dioxide produced by Mexican jumping beans during cellular respiration. Both jumping and stationary jumping beans will be tested. Additionally, cellular respiration of jumping beans at two different temperatures will be tested.

Mexican jumping beans are actually seeds in which a moth larva occupy and mature. The “jumping” motion is really movement of the larva within the seed. By late summer, capsules of the Mexican jumping bean shrub (Sebastiana pavoniana) separate into three sections, each section splits open and ejects a seed. Hollowed out sections called carpels, containing moth larvae fall to the ground and start a new phase of jumping and hopping, the jumping activity increases with temperature.

**CELL RESPIRATION AND SOLVING THE MYSTERY OF THE MEXICAN JUMPING BEANS (A CASE STUDY FOR THIS LAB)**

The following is a possible scenario that could be occurring near your school campus.

The Mystery of the Jumping Beans

Claire was in the biology lab and asked her instructor if she could get a beaker from the stockroom. The teacher nodded and Claire went into the stockroom looking for a 250 ml beaker. The stockroom was packed with supplies and she looked at each shelf.

She suddenly saw a box marked Jumping Beans. Jumping Beans? She thought. Can these be real? She got the beaker and went back to the teacher.
“Are those really jumping beans in the stockroom?” she asked.

The instructor said, “Yes, there are jumping beans in the stockroom, but they may be old.”

“What difference does it make if they are old?” said Claire.

“Well,” said the instructor, “jumping beans are actually seeds in which a moth larva occupy and mature. If you cut open the seed, you can see the larva. The “jumping” motion is really movement of the larva within the seed. By late summer, capsules of the Mexican jumping bean shrub separate into three sections, each section splits open and ejects a seed. Hollowed out sections called carpels, containing moth larvae fall to the ground and start a new phase of jumping and hopping, the jumping activity increases with temperature.”

“How do we know that the larva are still alive? If they have been in the stockroom a long time, they might be dead,” said Claire.

“Claire, if you are interested, we can test the beans to see if they are still living.”

“I really would like to test the beans, but what would we do,” Claire replied.

“Let’s get out a few sensors and see what is happening with these creatures. We can see if they are still alive without cutting open the seeds and killing them if they are still alive.” said the instructor.

**OBJECTIVES**

In this experiment, you will

- use a CO² gas sensor to measure concentrations of carbon dioxide.
- study the effect of temperature on cellular respiration.
- determine whether jumping beans are alive using principles of cell respiration.
- compare the rates of cellular respiration in jumping and stationary jumping beans.
MATERIALS

- Power Macintosh or Windows PC
- Vernier computer interface
- Logger Pro
- Vernier CO₂ Gas Sensor
- 25 warm jumping beans
- Small Plastic bag
- 250-mL respiration chamber
- Ice cubes
- 1-L beaker
- Thermometer
- Two 100-mL beakers
- Graphical Analysis (optional)

PROCEDURE

1. Prepare the computer for data collection by opening the file in the Experiment 11B folder of *Biology with Computers*. The vertical axis has carbon dioxide concentration scaled from 0 to 5000 ppm. The horizontal axis has time scaled from 0 to 5 minutes. The data rate is set to 6 samples/minute.

2. Plug the CO₂ Gas Sensor into Port 1 of the Vernier computer interface.

**Part I Jumping Beans, Warm Temperatures and Marbles**

3. Obtain 25 warm jumping beans. Use the thermometer to measure the room temperature. Record the temperature in Table 1.

4. Place the warm jumping beans into the respiration chamber.

5. Place the shaft of the CO₂ gas sensor in the opening of the respiration chamber. Gently twist...
the stopper on the shaft of the CO₂ gas sensor into the chamber opening. Do not twist the shaft of the CO₂ gas sensor or you may damage it.

6. Wait one minute, then begin measuring carbon dioxide concentration by clicking [Collect]. Data will be collected for 5 minutes. While the data is being collected count the total number of jumps for all the jumping beans and record it in Table 2.

7. Remove the CO₂ gas sensor from the respiration chamber. Place the jumping beans into a small plastic bang and then in a 100-mL beaker filled with cold water and an ice cube.

8. Use a notebook or notepad to fan air across the openings in the probe shaft of the CO₂ gas sensor for 1 minute.

9. Fill the respiration chamber with water and then empty it. Thoroughly dry the inside of the respiration chamber with a paper towel.

10. Determine the rate of respiration:
   a. Move the mouse pointer to the point where the data values begin to increase. Hold down the left mouse button. Drag the mouse pointer to the end of the data and release the mouse button.
   b. Click the Regression button, [Regression], to perform a linear regression. A floating box will appear with the formula for a best fit line.
   c. Record the slope of the line, \( m \), as the rate of respiration for jumping beans at room temperature in Table 2.
   d. Close the linear regression floating box.

11. Move your data to a stored run. To do this, choose Store Latest Run from the Experiment menu.

12. Obtain 25 marbles and place them in the respiration chamber.

13. Repeat Steps 5 – 11 for the marbles.

**Part II Jumping Beans, Cool Temperatures**

14. Place the respiration chamber in an ice bath. Cover the outside of the chamber with ice.

15. Use the thermometer to measure the water temperature of the 100-mL beaker containing the moving jumping beans. Record the water temperature in Table 1.

16. Remove the jumping beans from the cold water.

17. Repeat Steps 5 – 11 to collect data with the jumping beans at a cold temperature. While the data is being collected count the total number of jumps for all the jumping beans and record it in Table 2.
**DATA**

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
</tr>
<tr>
<td>Room to warm</td>
</tr>
<tr>
<td>cold water</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>jumping beans</td>
</tr>
<tr>
<td>jumping beans, room to warm temperature</td>
</tr>
<tr>
<td>jumping beans, cool temperature</td>
</tr>
<tr>
<td>Glass beads or marbles, room temperature</td>
</tr>
</tbody>
</table>

**QUESTIONS**

1. Do you have evidence that cellular respiration occurred in the jumping beans? Explain.
2. What is the effect of jumping on the rate of cellular respiration in jumping beans?
3. What is the effect of temperature on the rate of cellular respiration in jumping beans?
4. Why do living jumping beans undergo cellular respiration?
5. Are your beans alive and explain your answer.
6. Why do plants need to perform cellular respiration and under what conditions do they perform cellular respiration?
7. Using the data from this laboratory, make a recommendation on what you think Claire should report to her instructor? Explain.

**EXTENSIONS**

1. Compare the respiration rate among various types of jumping beans and seeds.
2. Compare the respiration rate among jumping beans that have at various temperatures for various time periods, such as 1, 3, and 5 days, 1 month, 6 months, 1 year, 2 years.
3. Compare the respiration rate among various types of small animals, such as insects or earthworms.
4. Make a PowerPoint Presentation that explains your experiment, results and your recommendations to Claire on whether the beans are alive or dead.
5. Design and perform an experiment to test one of the factors that might influence the rate of carbon dioxide production.
REFERENCES:

A) Start Program.
Start → Programs → Vernier → Logger Pro

B) Basic Interface

C) Open Experiment.
File → Open → Biology With Computers → then the specific experiment

D) Start Data Collection. Click
E) Slope of Line (m).
   Click $R=\ldots$

   The slope will appear in a floating box.

F) Store Latest Run.
   Experiment $\rightarrow$ Store Latest Run

G) Add Text Annotation.
   Insert $\rightarrow$ Text Annotation
H) Save File.  
File→Save As→My Documents or other location  
*DO NOT OVERWRITE THE EXPERIMENT FILE, DO NOT SAVE CHANGES

I) Be sure to save the file in My Documents and not Program files.

J) Print Graph.  
File→Print→Print Graph

K) Include Footer  
Check Footer→Add Name and Comment
USING LOGGER PRO TO DETERMINE THE RATE OF A REACTION

1. Plug the desired sensor(s) into the designated Channel(s) 1, 2 and 3 of the LabPro interface.

2. Open Logger Pro (Start ➞ Programs—Vernier Software ➞ Logger Pro).

3. Select Biology with Computers folder.

4. Prepare the computer for data collection by opening the desired experiment file in the Biology with Computers folder. (If the sensor is not an autoID sensor, select OK from the Sensor Confirmation screen.). For example, if Experiment 31B is selected, the vertical axis has carbon dioxide concentration scaled from 0 to 2 PPT (parts per thousand). The horizontal axis has time scaled from 0 to 10 minutes. The data rate is set to 6 samples/minute.

5. Set up the experimental conditions and sensors.

6. Click [Collect] to begin data collection. The data will collect for the designated time that is included in the particular experiment file. While the data is collecting the STOP button will replace the Collect button. When the data collection is complete, the Collect button will reappear and the data collection will end.

7. When data collection has finished, determine the rate of the reaction:
   a. Move the mouse pointer to the point where the data values begin to increase. Hold down the left mouse button. Drag the pointer to the point where the data ceases to rise and release the mouse button.
   b. Click on the Regression button, [ ], to perform a linear regression. A floating box will appear with the formula for a best fit line.
   c. Record the slope of the line, \( m \), as the rate of the specific reaction into a specific table.
   d. Close the linear regression floating box.

9. Move your data to a stored run. To do this, choose Store Latest Run from the Experiment menu.

10. Modify the experimental conditions and repeat steps 6 – 9.
Plants make sugar, storing the energy of the sun into chemical energy, by the process of photosynthesis. When they require energy, they can tap the stored energy in sugar by a process called cellular respiration.

The process of photosynthesis involves the use of light energy to convert carbon dioxide and water into sugar, oxygen, and other organic compounds. This process can be summarized by the following reaction:

\[
6 \text{H}_2\text{O} + 6 \text{CO}_2 + \text{light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2
\]

Cellular respiration refers to the process of converting the chemical energy of organic molecules into a form immediately usable by organisms. Glucose may be oxidized completely if sufficient oxygen is available in the following reaction:

\[
\text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{H}_2\text{O} + 6 \text{CO}_2 + \text{energy}
\]

All organisms, including plants and animals, oxidize glucose for energy. Often, this energy is used to convert ADP and phosphate into ATP. Using the CO\textsubscript{2} Gas Sensor, you will attempt to monitor the carbon dioxide consumed or produced by plants.

**THE PICKLE “DILL”EMMA: EFFECTS OF POLLUTION ON THE LEAVES OF PLANTS AND PHOTOSYNTHESIS (A CASE STUDY FOR THIS LAB)**

The following is a possible scenario that could be occurring near your school campus.

There is a large pickle factory that is near an irrigation stream. It seems that there is pickle juice in the irrigation water and the crops downstream are not growing well. The farmers think the pickle juice is causing the crops problems, but they need help to scientifically show that the pickle juice causes plants problems. The following is a scenario that gives background information about the problem.

"Adelle," shouts Pierre, "The tomato plants are growing very slowly and half the season is over. We're having the same problem that we did for the past two years. I don't know what the problem is. I am ready to quit farming and go fishing for a living."

"I've talked to the other farmers and everybody along the bayou is having the same problem. They are ready to give up too." said Pierre.
"Pierre, before you hitch the boat to the truck why don't you go to the high school and let the science department see what's wrong. It might be something contaminating the crop that is causing the problem." said Adelle.

"If it is pollution what can we do?" asked Pierre.

"We will decide what to do when we know what the is causing the problem. You should go see Mrs. Coty Ledon and ask her to analyze the plants and tell her what is happening."

Pierre goes to the high school and sees Mrs. Ledon. She asks Pierre to bring a sample of the soil and irrigation water from the area. Mrs. Ledon takes out a strip of pH paper and finds that the soil and the water are below pH 6. This means that the soil and the water are acidic. Pierre sees this and thinks for a moment.

"The pickle factory! The came here three years ago and that's when the trouble started. We use the water from the bayou to irrigate or water the crops. I wonder if the pickle factory is dumping excess pickle juice into the bayou." said Pierre.

So Pierre told the other farmers and they stormed into the plant manager's office at the pickle factory. They all told him about the problems. The plant manager told them that the pickle factory is not dumping any pickle juice into the bayou or anywhere else and even if it were, pickle juice is harmless.

Pierre demands, "It is a pickle juice problem. You are killing our crops!"

"Well you will have to prove that accusation, sir." said the plant manager.

So Pierre went back to Mrs. Coty Ledon at the high school and told her about the meeting at the pickle factory.

Mrs. Ledon said, "Well we will just have to do a little experiment to prove it to the pickle factory, Pierre."

"What kind of experiment will you do?" asked Pierre.

**OBJECTIVES**

In this experiment you will,

- use an CO₂ Gas Sensor to measure the amount of carbon dioxide consumed or produced by plants during photosynthesis and cellular respiration.
- determine the rate of cellular respiration and photosynthesis of a plant without pickle juice and with pickle juice on its leaves.
- This laboratory is designed to help you solve this hypothetical problem, and is designed for groups. Various groups use plants with various concentrations of pickle juice and one group uses plants without pickle juice.
MATERIALS/GROUP SET-UP

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vernier computer interface</td>
<td>(1) 3 oz. Tall Nestea Instant Unsweetened Tea Jar Sensosphere or (1) 32 oz Benzel’s Bretzel pretzel jar</td>
</tr>
<tr>
<td>Power Macintosh or Windows PC</td>
<td>(1) Cabbage, tomato, cucumber or okra Seedling (With Roots and soil Wrapped in Plastic Wrap)</td>
</tr>
<tr>
<td>Logger Pro</td>
<td>(1) circular ballasted fluorescent Lamp (light: Sylvania CF30/830 FC8T9 (30 W, ring light ballasted lamp adaptors (CF30EL/CIRC/830/MED 120 V 60 Hz. These are Sylvania to match the lights.))</td>
</tr>
<tr>
<td>(1) Vernier CO₂ Gas Sensor</td>
<td>(1) portable lamp screw mount sockets with on/off switch, electric cord and clamp</td>
</tr>
<tr>
<td>(1) 3/8 Inch Drill with 1-1/8 inch Drill Bit</td>
<td>Optional (2) Regular Fluorescent Lamps To be used in place of the circular lamp.</td>
</tr>
<tr>
<td>(1) Roll Aluminum Foil</td>
<td>Optional (2) 500-mL Tissue Culture Flasks for heat sinks. Only to be used if regular fluorescent lamps are used instead of circular lamps.</td>
</tr>
<tr>
<td>(1) Sandwich Ziplock or Plastic Wrap</td>
<td>100 ml Dill pickle juice (100%, 50%, 25%, 0%)</td>
</tr>
<tr>
<td>(1) Rubber Band or Twist Tie</td>
<td>(1)Balance</td>
</tr>
</tbody>
</table>

PROCEDURE

Note: One group should use plants without pickle juice and the other groups should use plants with pickle juice. Tables 1 and 6 are for plants without pickle juice and Tables 2-5 and 7 are for plants with pickle juice.

1. Drill a 1-1/8 inch hole in the center of the plastic lid using the drill to create a 3 oz. tall Nestea Instant Unsweetened Tea Jar Sensosphere or the 32 oz pretzel jar. See Figure 1. (Your instructor will have this prepared for you.)

2. Plug the CO₂ Gas Sensor into Channel 1 of the LabPro interface.

3. Prepare the computer for data collection by opening the file in the Experiment 31B folder of Biology with Computers. (If the sensor is not an auto ID sensor, select OK form the Sensor Confirmation screen.) The vertical axis has carbon dioxide concentration scaled from 0 to 2 PPT (parts per thousand). The horizontal axis has time scaled from 0 to 10 minutes. The data rate is set to 6 samples/minute.

Part I Dark Conditions

4. Obtain plant with pickle juice of a specific concentration (or without pickle juice) from the resource table and blot the leaves dry, if damp, between two pieces of paper towel. Remove the plant form the cell pack (small pot). Wrap the soil and roots gently in plastic wrap with a rubber band or twist tie. See Figure 1. Select table from Data section that corresponds to the concentration of pickle juice you are using.
5. Place the plant with pickle juice (or without pickle juice) into the Sensosphere. Wrap the Sensosphere in aluminum foil so that no light reaches the seedling.

6. Place the CO₂ Gas Sensor into the Sensosphere as shown in Figures 1. Gently twist the stopper on the shaft of the CO₂ Gas Sensor into the chamber opening. Do not twist the shaft of the CO₂ Gas Sensor or you may damage it. Wait 3 minutes before proceeding to Step 7.

7. Click to begin data collection. Data will be collected for 10 minutes.

8. When data collection has finished, determine the rate of cellular respiration:
   a. Move the mouse pointer to the point where the data values begin to increase. Hold down the left mouse button. Drag the pointer to the point where the data ceases to rise and release the mouse button.
   b. Click on the Regression button, , to perform a linear regression. A floating box will appear with the formula for a best fit line.
   c. Record the slope of the line, \( m \), as the rate of cellular respiration in Table 1.
   d. Close the linear regression floating box.

9. Move your data to a stored run. To do this, choose Store Latest Run from the Experiment menu.

**Part II Light Conditions**

10. Remove the aluminum foil from around the Sensosphere.

11. Place circular fluorescent lamp around the Sensosphere. See Figure 1. (Option: Fill a flask with water and place it between the lamp and the Sensosphere. The flask will act as a heat sink to protect the plant leaves. The circular lamp is the preference for best results and does not require a heat sink.)

12. Turn the circular lamp on. Place the lamp as close to the Sensosphere as reasonable. Do not let the lamp touch the tissue culture flask. Note the time. The lamp should be on for 3 minutes prior to beginning data collection.

13. After the three-minute time period is up, repeat Steps 7 – 8.

14. After the three-minute time period is up, click to begin data collection. Data will be collected for 10 minutes.

15. When data collection has finished, determine the rate of photosynthesis:
   a. Move the mouse pointer to the point where the data values begin to decrease. Hold down the left mouse button. Drag the pointer to the point where the data ceases to decline and release the mouse button.
   b. Click on the Regression button, , to perform a linear regression. (Select latest run if a dialogue box appears.) A floating box will appear with the formula for a best fit line.
   c. Record the slope of the line, \( m \), as the rate of photosynthesis in Table 1.
   d. Close the linear regression floating box.

16. Label a graph showing your photosynthesis and cellular respiration data.
a. Label each curve by choosing Text Annotation from the Insert menu. Enter “Photosynthesis” in the edit box. Repeat to create an annotation for the “Cellular Respiration” data. Drag each box to a position near its respective curve.

b. Print a copy of the Graph window, with both data sets displayed. File, Print Graph and select Print Footer. Enter your name(s) and the number of copies of the graph you want.

17. Remove the seedling from the Sensosphere. Take the mass of the seedling without the plastic wrap. Record the mass in proper table. Return the plant to its original container without plastic wrap on its roots. Clean and dry the Sensosphere.

18. Repeat steps 4-17 with a different seedling and a different concentration of pickle juice. Complete proper tables.

19. With data from Tables 1 – 5, complete Tables 6 and 7 and make graphs of the data from Tables 6 and 7 using Logger Pro, Graphical Analysis, Excel or graph paper.

**DATA**

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Seedling Without Pickle Juice (0% Pickle Juice, 100% Water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seedling Without pickle juice</td>
<td>Seedling Mass (g)</td>
</tr>
<tr>
<td>Dark</td>
<td>Rate of cellular respiration/photosynthesis (PPT/s)</td>
</tr>
<tr>
<td>Light</td>
<td>Rate of cellular respiration/photosynthesis/mass (PPT/s/g)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Seedling With 25% Pickle Juice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seedling With 25% Pickle Juice</td>
<td>Seedling Mass (g)</td>
</tr>
<tr>
<td>Dark</td>
<td>Rate of cellular respiration/photosynthesis (PPT/s)</td>
</tr>
<tr>
<td>Light</td>
<td>Rate of cellular respiration/photosynthesis/mass (PPT/s/g)</td>
</tr>
</tbody>
</table>
Table 3
Seedling With 50% Pickle Juice

<table>
<thead>
<tr>
<th>Seedling With 50% Pickle Juice</th>
<th>Seedling Mass (g)</th>
<th>Rate of cellular respiration/photosynthesis (PPT/s)</th>
<th>Rate of cellular respiration/photosynthesis/mass (PPT/s/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4
Seedling With 75% Pickle Juice

<table>
<thead>
<tr>
<th>Seedling With 75% Pickle Juice</th>
<th>Seedling Mass (g)</th>
<th>Rate of cellular respiration/photosynthesis (PPT/s)</th>
<th>Rate of cellular respiration/photosynthesis/mass (PPT/s/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5
Seedling With 100% Pickle Juice

<table>
<thead>
<tr>
<th>Seedling With 100% Pickle Juice</th>
<th>Seedling Mass (g)</th>
<th>Rate of cellular respiration/photosynthesis (PPT/s)</th>
<th>Rate of cellular respiration/photosynthesis/mass (PPT/s/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 6
Seedlings in the Light

<table>
<thead>
<tr>
<th>% Pickle Juice</th>
<th>Rate of cellular respiration/photosynthesis/mass (PPT/s/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Table 7
Seedlings in Dark

<table>
<thead>
<tr>
<th>% Pickle Juice</th>
<th>Rate of cellular respiration/photosynthesis/mass (PPT/s/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

QUESTIONS

1. Were either of the rate values a positive number with the pickle juice and non-pickle juice seedlings? If so, what is the biological significance of this?

2. Were either of the rate values a negative number with the pickle juice and non-pickle juice seedling? If so, what is the biological significance of this?

3. Do you have evidence that cellular respiration occurred in pickle juice and non-pickle juice seedling? Explain your answer.

4. Do you have evidence that photosynthesis occurred in pickle juice and non-pickle juice seedling leaves? Explain your answer.

5. List five factors that might influence the rate of carbon dioxide production or consumption in leaves. Explain how you think each will affect the rate?

6. Why do plants need to perform photosynthesis and under what conditions do they perform photosynthesis?
7. Why do plants need to perform cellular respiration and under what conditions do they perform cellular respiration?

8. How could you use a pH sensor to gather more complete data about this farming problem?

9. Compare the rates of photosynthesis and cellular respiration among plants with and without pickle juice over time in the light and the dark using Tables 6 and 7. (You should plot the data from Tables 6 and 7 to help with your analysis.)

10. Using the data from this laboratory, make a recommendation on what you think the farmers should report and request from the Pickle Company. Explain.

EXTENSIONS

1. Make a PowerPoint Presentation that explains your experiment, results and your recommendations to the farmers about how the pickle juice is influencing their crops.

2. Design and perform an experiment to test one of the factors that might influence the rate of carbon dioxide production or consumption in Question 5.

3. Compare the rates of photosynthesis and cellular respiration among various amounts of pickle juice.

4. Compare the rates of photosynthesis and cellular respiration among various types of plants.

5. Use gaseous oxygen sensor and carbon dioxide sensor to collect data.

REFERENCES:

INTRODUCTION
Throughout time Korean winters have been long and severe. The frigid conditions forced people to preserve vegetables for this season. The word Kimchee in Korean means "sunken vegetable." Chinese cabbages and radishes were "sunk" into salted water and seasonings were added, such as chili peppers, and later on the flavor of salted fish. Some think that Kimchee is the most colorful of all pickled vegetables. Kimchee is "Korean sauerkraut" and is now becoming popular across the world due to its appealing effervescent and spicy flavor. Kimchee can be classified as fermented vegetables, since many kinds of bacterial reactions contribute to its characteristic flavor. It contains lactic acid, which aids digestion. Organic acids control stomach secretions and the vegetable fibers are favorable to the digestive track. Fermentation also produces vitamins B1, B2, B12, and niacin.

Just before winter, Koreans take a "Kimchee Holiday" in November. Neighbors gather together in each other's yards to prepare Kimchee. Kimchee is always on the Korean dining table. It goes well with rice, is a good appetizer and gives special flavor to stews and vegetables.

Napa, *Brassica rapa*, also known as Chinese cabbage and Pe-tsai, has special microbes that live on its leaves, and are called phyllosphere microbes. If the proper amount of salt is added to the napa, some microbes become active and they metabolize the sugars in the cabbage. The high salt concentration and tight packing of the cabbage creates an anaerobic, without oxygen, environment and the extreme halophilic bacteria begin to grow. As they perform heterofermentation to get energy to survive, they produce lactic acid, ethanol, carbon dioxide and other compounds. Heterofermentation allows the production of a variety of products, and can be thought of as a hybrid of both lactic acid and alcoholic fermentations.

THE KIMCHEE SHORTAGE (A CASE STUDY FOR THIS LAB):

The following is a possible scenario that could be occurring in a restaurant near your school campus. There is a large Kimchee shortage in many areas of the country. This laboratory is designed to help you solve this hypothetical problem.

There is a big demand for Kimchee, and it must be fresh, not canned or frozen. During the fermentation process, the Kimchee is ready to eat when the pH of the salt solution, brine, is 3.5. It takes days to ferment the napa, and refrigeration does not stop the fermentation. Many restaurants and groceries need more Kimchee. The restaurant owners at the Kimchee Palace near the campus think that temperature would be a factor to change. They think that higher temperatures will help the napa ferment faster, but are worried about the quality of the Kimchee. Your goal is to see what influence temperature has on fermentation of napa. Overall there is a shortage of Kimchee and the Korean Food Research Institute is attempting to find new ways of producing and storing Kimchee. This lab will give you an opportunity to participate in the Kimchee research.
Using the CO2 and O2 Gas Sensors, you will monitor the carbon dioxide and oxygen concentrations during fermentation of the microbes of the phyllosphere. You will also be able to monitor microbe grow with the Turbidity or Colorimeter Sensors, and various environmental conditions with the pH, Conductivity and Thermometer Sensors. Using your collected data, you will determine the difference in the rates of fermentation at various temperatures to answer this question concerning temperature and the fermentation of napa in the production of Kimchee. During the lab you will also determine factors other than temperature that could be changed to make the Kimchee faster. Napa will be fermented at different temperatures and tested over 21 days.

There are 3 parts to the lab set-up:

**Part 1: Making Kimchee and Setting Up Incubation Conditions**

**Part 2: Tracking Cellular Respiration of Microbes with Carbon Dioxide and Oxygen Sensors**

**Part 3: Tracking Microbe Growth and Environmental Changes with pH, Conductivity, Temperature and Turbidity or Colorimeter Sensors**

### ALL MATERIALS CHECKLIST FOR THE LAB

| (2) LabPros or CBL 2 Interfaces | (1) 40 oz. Utz Pretzel Stick Bottle or (1) 20-26 oz Benzel’s Bretzel Bakery Inc. Jar with 4½” Diameter x 2/3” High Plastic Lid |
| (2) TI Graphing Calculators with DataMate Program | (3) 20 oz. Sam’s Choice Purified Drinking Water Bottles |
| 27 g Pickling Salt (9 g/Bottle) | (1) Exacto Knife and or Scissors |
| (1) Vernier CO2 Gas Sensor | 1362 g Napa, Chinese Cabbage, or Bok Choy (454 g/Bottle) |
| (1) Vernier pH Sensor | (3) Returnable Barqs Root Beer or Orange Crush Bottles |
| (1) Vernier Conductivity Sensor | (1) Graphical Analysis (Optional) |
| (1) Vernier Turbidity Sensor | (1) Turbidity Cuvette |
| (1) Vernier Stainless Steel Thermometer (or Traditional Thermometer) | (1) Turbidity Standard (StableCal® Formazin Standard 100 NTU) |
| (1) Vernier O2 Gas Sensor | (2) 3.5 ml Cuvettes with Lids |
| (1) Empty Film Canister or empty D.O. Bottle for Sampling Brine | (1) Sam’s Choice Water Bottle Box or Paper File Box |
| (1) Roll Aluminum Foil | (1) Ice Bath |
| (3) Sandwich Size Ziploc Bags | (3) Black Garbage Bags |
| (3) Solo Cups (16 oz.) | (1) Refrigerator at Approximately 10° C |
| (1) 1 ml Dropper Pipet with 0.5 ml Scaling | (3) Pairs Disposable Gloves (Optional) |
| (3) Quart Size Frozen Sherbet Containers | 100 ml Distilled Water |
| (1) Roll Masking Tape to Make Sensor Fit Snug in jar insertion hole | (1) 3/8 Inch Drill with 1-1/8 inch Drill Bit |
| (3) Rubber Bands | (1) Roll of Paper Towels |

### PART 1: MAKING KIMCHEE AND SETTING UP INCUBATION CONDITIONS:

The cabbage has special microbes that live on its leaves and the community of microbes is called the phyllosphere. Some microbes are capable of anaerobic fermentation if there is the proper salt concentration. Microbes that can survive under extreme salt conditions are termed extreme halophiles.
The bottle is the fermentation vat. Anaerobic conditions need to be created. The cabbage is packed tightly with a Barq’s 12 oz. returnable soft drink bottle (or other returnable soft drink bottle) and salt is added. Closely packing the cabbage pushes out much of the air. Also, the salt causes osmosis of water from the cabbage to allow for the creation of a brine, salt water solution. The brine layer reduces the amount of oxygen significantly and the crowning with the Solo cup bottom decreases the surface exposed to air for anaerobic conditions to be established. The cabbage or other leafy vegetable is the source of sugar and microbes for the fermentation.

**OBJECTIVES**

In this section of the experiment, you will

- create an anaerobic environment suitable for heterofermentative microbes of the phyllosphere.
- create a high salt environment suitable for the heterofermentative microbes, which are extreme halophiles.
- establish incubation temperatures.

**PART 1 MATERIALS CHECKLIST PER 3 BOTTLE COMPARISON SET-UP**

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1362 g Napa, Chinese Cabbage (454 g/Bottle)</td>
<td></td>
</tr>
<tr>
<td>27 g Pickling Salt Total (9 g Salt/Bottle)</td>
<td></td>
</tr>
<tr>
<td>(3) 20 oz. Sam's Choice Purified Drinking Water Bottles</td>
<td></td>
</tr>
<tr>
<td>(1) Exacto Knife and or Scissors</td>
<td></td>
</tr>
<tr>
<td>(3) Barq's Returnable Root Beer Bottles</td>
<td></td>
</tr>
<tr>
<td>(3) Sandwich Size Ziploc Bags</td>
<td></td>
</tr>
<tr>
<td>(3) Rubber Bands</td>
<td></td>
</tr>
<tr>
<td>(3) Solo Cups (16 oz.)</td>
<td></td>
</tr>
<tr>
<td>(3) Quart Size Frozen Sherbet Containers</td>
<td></td>
</tr>
<tr>
<td>(1) Warm Water Bath (Heating Pad or Electric Skillet with Water)</td>
<td></td>
</tr>
<tr>
<td>Approximately 35°C</td>
<td></td>
</tr>
<tr>
<td>(1) Ice Bath</td>
<td></td>
</tr>
<tr>
<td>(1) Sam’s Choice Water Bottle Box or Paper File Box</td>
<td></td>
</tr>
<tr>
<td>(2) Black Garbage Bags</td>
<td></td>
</tr>
<tr>
<td>(1) Refrigerator or Storage Area of Approximately 10°C</td>
<td></td>
</tr>
<tr>
<td>(1) Roll Aluminum Foil</td>
<td></td>
</tr>
<tr>
<td>(1) Roll of Duct Tap or Masking Tape</td>
<td></td>
</tr>
<tr>
<td>(3) Pairs Disposable Gloves(Optional)</td>
<td></td>
</tr>
</tbody>
</table>

**PROCEDURE**

A. Preparing Sam’s Choice Water Bottles and Napa
>Cut top of bottle immediately below the shoulder of the bottle, close to the label. (Fig. 1)
>Remove label after cutting off top.
>Remove the outer leaves of the cabbage. (Fig. 2)

**B. Cutting and Massing Cabbage**

>Cut cabbage into smaller pieces. (Fig. 3)
>It is optional to wear disposable gloves.
>Measure 454 g of cabbage. Most classroom digital balances will require you to measure total amount in parts. (Fig. 4)

**C. Massing Pickling Salt**
>Measure 9.0 grams of pickling salt. (Fig. 5)

**D. Preparing Cabbage Layers**

>Place bottle in a quart size frozen sherbet container to collect excess fluid that will overflow from the bottle.

>Place about a 2-inch layer of cabbage at the bottom of the bottle.

>Sprinkle with a moderate amount of salt. (Fig. 7) Reserve salt for the other layers.

**E. Compressing a Layer, Adding a Layer and Crowning with the Solo Cup Lid**
Press the cabbage and salt with the Barq's Root Beer returnable glass bottle. Be patient and you will see a watery brine form. (Fig. 8)
Repeat pressing layers and salt until all the cabbage and salt are packed into the bottle. (Fig. 9)
Remember to recover excess liquid, brine, in the sherbet container.
Cut the bottom of a 16 oz. Solo keg cup.
Place it on top of the packed cabbage and salt. (Fig. 10)

**F. Placing the Bottle Top Into the Lower Part of the Bottle**

>Place the top of the bottle inside of the cut bottom. Loosen cap. (Fig. 11) Be careful not to dent or split the bottle top.
>Press the bottle top into the cabbage until it fits securely and there is brine on top of the keg cup cover.
>Be sure there is at least a ½ inch brine layer of fluid at the top. If necessary carefully pour the recovered brine liquid from your sherbet container into the bottle.
>Check that there are no gaps or leaks around the bottle top and bottom.
>Place the sandwich Ziploc bag on top of the bottle like a hat to cover it. Use a rubber band to gently secure the Ziploc bag. Be sure not to place pressure on the bottle. This cover will prevent things from falling in to the well around the bottle top that is inserted into the bottle bottom.

Repeat the Above Procedure and make a total of 3 bottles.

**G. Preparation of 3 Incubation Conditions:**

1) **Cold:** Place first bottle in a black garbage bag and twist it to remove excess air. The bag will keep provide darkness and will catch any fluid that might overflow. Place it in the refrigerator that has a temperature of about 10 °C. Measure the temperature and record it in Table 1.

2) **Room temperature:** Place second bottle in the Sam’s Choice Bottled Water box that is lined with a black 30 gallon garbage bag. Twist the bag tops and push out excess air. Close the box and be sure there are no light leaks. You may need to place Duct Tap or masking tape over the holes of the box. The temperature should approximately 20 °C. Measure the temperature and record it in Table 2.
3) **Warm**: Place third bottle in a black garbage bag and twist it to remove excess air. The bag will keep it dark and will catch any fluid that might overflow. Then place wrapped bottle into a warm water bath consisting of an electric fry pan with water and regulate the temperature to about 35 °C. (Check to be sure the temperature stays constant.) Measure the temperature and record it in Table 3. Then cover the bottle and top of the fry pan with aluminum foil to hold in the heat, to keep it dark and to prevent evaporation. Instead of a fry pan, a heating pad with a blanket over the bottles also provides the needed heat.

**PART 2: TRACKING CELLULAR RESPIRATION OF MICROBES WITH SENSORS**

Aerobic cellular respiration refers to the process of converting the chemical energy of organic molecules into a form immediately usable by organisms. Glucose may be oxidized completely if sufficient oxygen is available and is summarized by the following reaction:

<table>
<thead>
<tr>
<th>With Aerobic Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₆H₁₂O₆ + 6 O₂(g) → 6 H₂O + 6 CO₂(g) + energy</td>
</tr>
<tr>
<td>(glucose + oxygen → water + carbon dioxide + energy)</td>
</tr>
</tbody>
</table>

Often, this energy is used to convert ADP and phosphate into ATP, useable cellular energy. All organisms, including plants and animals, oxidize glucose for energy, but not all organisms use oxygen. If oxygen is not present, the organisms undergo fermentation, anaerobic respiration. Fermentation reactions are anaerobic, proceeding without oxygen being present. Anaerobic reactions involve cellular food products and/or glucose sugar as their reactants. Without oxygen the heterofermentative microbes can combinations of ethyl alcohol (C₂H₅OH), carbon dioxide (CO₂), and lactic acid (C₃H₇O₂COOH) as their products.

<table>
<thead>
<tr>
<th>With Anaerobic, Halophilic, heterofermentative Microbes and Cabbage Leaves</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₆H₁₂O₆ → C₂H₄OCOOH + C₂H₅OH + CO₂(g) + other compounds + energy</td>
</tr>
<tr>
<td>(glucose → lactic acid + ethanol + carbon dioxide + other compounds + energy)</td>
</tr>
</tbody>
</table>

People have developed many ways to prevent food spoilage that use fermentation and Kimchee is one of them. Wine, beer, and sauerkraut are other examples. The microbes in the leaf’s phyllosphere use the sugar in the napa or leafy vegetable to perform anaerobic heterofermentation and produce Kimchee.

There are a variety microbes in the cabbage phyllosphere, and they become active under different environmental conditions because of different metabolisms. During glycolysis the microbes convert glucose to pyruvic acid. Then some of the microbes perform heterofermentation to convert the pyruvic acid into lactic acid, ethanol and carbon dioxide. The lactic acid production causes the pH to drop, and the lower pH activates other microbes, which have a slightly different metabolism and the rate of production of the products changes. Also, as
heterofermentation occurs the carbon dioxide level increases, and some of the carbon dioxide reacts with water to produce carbonic acid which also causes the pH to decrease. Temperature is a factor for microbe activation and metabolism, and influences product production.

Using the CO2 and O2 Gas Sensor, you will monitor the carbon dioxide and oxygen concentrations during cellular respiration of the various microbes of the phyllosphere. The oxygen sensor in Part C will help to establish that these organisms do not use oxygen in fermentation and the carbon dioxide sensor in Parts B and C will help to establish that these organisms produce carbon dioxide in fermentation. If you only have a carbon dioxide sensor you will only monitor the carbon dioxide concentration in Part B.

**OBJECTIVES**

In this experiment, you will

- use a CO2 Gas Sensor to measure concentrations of carbon dioxide during anaerobic cellular respiration.
- compare the rates of fermentation at different temperatures.
- compare the rates of fermentation over 21 days of fermentation

**PART 2 A AND B MATERIALS CHECKLIST**

<table>
<thead>
<tr>
<th>(1) LabPro or CBL 2 Interface</th>
<th>(1) Vernier CO2 Gas Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) TI 83 or 83 Plus Graphing Calculator with DataMate Program</td>
<td>(1) (40 oz.) Utz Pretzel Stick Bottle with Plastic Lid or (1) (20-26 oz.) Benzel’s Bretzel Bakery Pretzel Bottle with Plastic Lid</td>
</tr>
<tr>
<td>(1) Ice Bath with Temperature of Approximately 10° C</td>
<td>(1) Warm Water Bath (Heating Pad or Electric Skillet with Water) with Temperature of Approximately 35° C</td>
</tr>
<tr>
<td>(1) ⅜ Inch Drill with ⅛ inch Drill Bit</td>
<td>(1) Kimchee Fermentation Bottle</td>
</tr>
<tr>
<td>(2) Thermometer Sensors or Traditional Thermometers</td>
<td></td>
</tr>
</tbody>
</table>
PROCEDURE FOR CARBON DIOXIDE DATA COLLECTION
(USE ONE CBL)

PART A: PREPARING SENSOSPHERE (40 OZ. UTZ PRETZEL BOTTLE DATA COLLECTION CHAMBER)

1. Empty the pretzels from the 40 oz. Utz plastic pretzel bottle, wash and dry it.
2. Drill a 1¼ inch hole in the center of the plastic lid using the drill to create an Utz Bottle Sensosphere. You may also use a (20-26 oz.) Benzel’s Bretzel Bakery Pretzel Bottle with Plastic Lid. See Figures 12 and 13. (Your instructor will have this prepared for you.)

PART B WITH CALCULATOR: PROCEDURE FOR CARBON DIOXIDE DATA COLLECTION FOR MEASURING RATES OF RESPIRATION AT VARIOUS TEMPERATURES WITH CALCULATOR AND DATAMATE

1. Plug the CO₂ Gas Sensor into Channel 1 of the LabPro or CBL 2 interface. Use the link cable to connect the TI Graphing Calculator to the interface. Firmly press in the cable ends.

2. Turn on the calculator press APPS and start the DATAMATE program. Press \text{CLEAR} to reset the program.

3. Set up the calculator and interface for a CO₂ Gas Sensor.
   a. If the calculator displays CO₂ GAS (PPM) in CH 1, proceed directly to Step 4. If it does not, continue with this step to set up your sensor manually.
   b. Select SETUP from the main screen.
   c. Press \text{ENTER} to select CH 1.
d. Select CO2 GAS from the SELECT SENSOR menu.
e. Select parts per million (PPM) as the unit.
f. Select OK to return to the main screen.

4. Set up the data-collection mode.
   a. To select MODE, press (the up arrow key) twice and press (ENTER).
   b. Select TIME GRAPH from the SELECT MODE menu.
   c. Select CHANGE TIME SETTINGS from the TIME GRAPH SETTINGS menu.
   d. Enter “15” as the time between samples in seconds.
   e. Enter “40” as the number of samples (data will be collected for 10 minutes).
   f. Select OK twice to return to the main screen.

5. Data Collection Temperatures Should be the Same as Incubation Temperatures:
   Measure the temperature of incubation using a thermometer and record the temperature in the proper table. Attempt to keep the testing temperature constant to the incubation temperature by using an ice bath or water bath.
   >To maintain the 10°C temperature use the ice bath.
   >To maintain room temperature of 20 – 25 °C keep data collection area near incubation area.
   >To maintain warm temperature of 30 – 35°C use warm water bath.

6. Obtain one room temperature (20°C) Kimchee fermentation bottle with napa or bottle at desired temperature.

7. Remove Utz bottle top with the 1½ inch hole, and place the Kimchee fermentation bottle in the large Utz bottle respiration chamber and remove the Kimchee fermentation bottle cap.

8. Replace the Utz bottle top and place the shaft of the CO2 Gas Sensor in the opening of the sensosphere chamber top. Gently twist the stopper on the shaft of the CO2 Gas Sensor into the chamber opening. Do not twist the shaft of the CO2 Gas Sensor or you may damage it.

9. Wait one minute, then select START to begin data collection. Data will be collected for 10 minutes. (It is important to begin data collection within a minute. The carbon dioxide is diffusing out of the bottle and if too much time lapses before you begin data collection you may get lower rates. Be consistent with the procedure.)

10. When data collection has finished, a graph of CO2 GAS VS. TIME will be displayed. Press (ENTER) to return to the main screen.

11. Remove the bottle with the napa from the chamber and replace the cap. Now remove the CO2 Gas Sensor from the respiration chamber.

12. Use a notebook or notepad to fan air across the openings in the probe shaft of the CO2 Gas Sensor for 1 minute.

13. Fill the respiration chamber with water and then empty it. Thoroughly dry the inside of the respiration chamber with a paper towel.

14. Perform a linear regression to calculate the rate of respiration.
   a. Select ANALYZE from the main screen.
   b. Select CURVE FIT from the ANALYZE OPTIONS menu.
c. Select LINEAR (CH 1 VS TIME) from the CURVE FIT menu.
d. The linear-regression statistics for these two lists are displayed for the equation in the form:

\[ Y = A \times X + B \]
e. Enter the value of the slope, \( A \), as the rate of respiration in the appropriate table.
f. Press [ENTER] to view a graph of the data and the regression line.
g. Press [ENTER] to return to the ANALYZE menu.
h. Select RETURN TO MAIN SCREEN from the ANALYZE menu.

15. Store the data from the first run or the latest run so that it can be used later.
   a. Select TOOLS from the main screen.
   b. Select STORE LATEST RUN from the TOOLS MENU.

16. **Cold (10° C) Temperature Kimchee Fermentation Bottle:** Use the thermometer to measure the temperature. Record the temperature in Table 1: Fermentation of Kimchee at Cold Temperature Conditions. Then repeat Steps 5 – 15 substituting the cold Kimchee fermentation bottle for the room temperature bottle (or bottle at another incubation temperature).

17. **Warm (35° C) Temperature Kimchee Bottle:** Use the thermometer to measure the temperature. Record the temperature in Table 3: Fermentation of Kimchee at Warm Temperature Conditions. Then repeat Steps 5 – 15 with the Kimchee fermentation bottle from the warm water bath. When you have completed Step 14 skip directly to Step 18.

18. Graph all three runs of data on a single graph. To do this:
   a. Select GRAPH from the main screen, then press [ENTER].
   b. Select MORE, then select L2, L3 AND L4 VS L1 from the MORE GRAPHS menu.
   c. All three runs should now be displayed on the same graph. Each point of the cold fermentation with a cross, each point of room temperature fermentation is plotted with a box, and the warm temperature fermentation is plotted with a dot.
   d. Use the displayed graph and Tables 1, 2 and 3 to answer the questions at the end of the lab in the Question Section.
   e. When finished with the graph, press [ENTER] to exit.
   f. Select RETURN TO GRAPHS SCREEN from the MORE GRAPHS menu.
   g. Select MAIN SCREEN from the graph screen.

**PART B WITH COMPUTER**: **PROCEDURE FOR CARBON DIOXIDE DATA COLLECTION FOR MEASURING RATES OF RESPIRATION AT VARIOUS TEMPERATURES WITH COMPUTERS AND LOGGER PRO SOFTWARE**

1. Plug the CO₂ Gas Sensor into Channel 1 of the LabPro interface.

2. Open Logger Pro (Start→Programs—Vernier Software→Logger Pro).

3. Select Biology with Computers folder.

4. Prepare the computer for data collection by opening the experiment Cell Respiration (CO₂ Sensor) file in the Biology with Computers folder. (If the sensor is not an autoID sensor,
select OK from the Sensor Confirmation screen.). The vertical axis has carbon dioxide concentration scaled from 0 to 5000 ppm. The horizontal axis has time scaled from 0 to 5 minutes. The data rate is set to 6 samples/minute.

5. **Data Collection Temperatures Should be the Same as Incubation Temperatures:**
   Measure the temperature of incubation using a thermometer and record the temperature in the proper table. Attempt to keep the testing temperature constant to the incubation temperature by using an ice bath or water bath.
   >To maintain the 10° C temperature use the ice bath.
   >To maintain room temperature of 20 – 25 ° C keep data collection area near incubation area.
   >To maintain warm temperature of 30 – 35° C use warm water bath.

6. Obtain one room temperature (20° C) Kimchee fermentation bottle with napa or bottle at desired temperature. Record temperature of the incubation in the appropriate table.

7. Remove Utz bottle top with the 1½ inch hole, and place the Kimchee fermentation bottle in the large Utz bottle respiration chamber and remove the Kimchee fermentation bottle cap.

8. Replace the Utz bottle top and place the shaft of the CO2 Gas Sensor in the opening of the sensosphere chamber top. Gently twist the stopper on the shaft of the CO2 Gas Sensor into the chamber opening. Do not twist the shaft of the CO2 Gas Sensor or you may damage it.

9. Wait one minute, then begin measuring carbon dioxide concentration by clicking **Collect**. Data will be collected for 5 minutes. (It is important to begin data collection within a minute. The carbon dioxide is diffusing out of the bottle and if too much time lapses before you begin data collection you may get lower rates. Be consistent with the procedure.)

10. When data collection has finished, remove the bottle with the napa from the chamber and replace the cap. Now remove the CO2 Gas Sensor from the respiration chamber.

11. Use a notebook or notepad to fan air across the openings in the probe shaft of the CO2 Gas Sensor for 1 minute.

12. Fill the respiration chamber with water and then empty it. Thoroughly dry the inside of the respiration chamber with a paper towel.

13. Determine the rate of respiration:
   a. Move the mouse pointer to the point where the data values begin to increase. Hold down the left mouse button. Drag the mouse pointer to the end of the data and release the mouse button.
   b. Click the Regression button, ![Regression](image), to perform a linear regression. A floating box will appear with the formula for a best fit line.
   c. Record the slope of the line, $m$, as the rate of respiration for the Kimchee at the particular temperature in the appropriate table.
   d. Close the linear regression floating box.

14. Move your data to a stored run. To do this, choose Store Latest Run from the Experiment menu.

15. **Cold (10° C) Temperature Kimchee Fermentation Bottle:** Use the thermometer to measure the temperature. Record the temperature in Table 1: Fermentation of Kimchee at Cold
Temperature Conditions. Then repeat Steps 7 – 14 substituting the cold Kimchee fermentation bottle for the room temperature bottle (or bottle at another incubation temperature).

16. **Warm (35° C) Temperature Kimchee Bottle:** Use the thermometer to measure the temperature. Record the temperature in Table 3: Fermentation of Kimchee at Warm Temperature Conditions. Then repeat Steps 7 – 14 with the Kimchee fermentation bottle from the warm water bath.

**PART C: PROCEDURE FOR CARBON DIOXIDE AND OXYGEN DATA COLLECTION TO HELP TO IDENTIFY ANAEROBIC RESPIRATION**

(USE ONE CBL)

**OBJECTIVES**

In this experiment, you will

- use a CO₂ Gas Sensor to measure concentrations of carbon dioxide during anaerobic cellular respiration.
- use an O₂ Gas Sensor to measure concentrations of oxygen gas during anaerobic cellular respiration.
- compare the rates of fermentation at different temperatures.
- compare the rates of fermentation over 21 days of fermentation.
- compare the rates of oxygen and carbon dioxide consumption during anaerobic respiration.

**MATERIALS**

<table>
<thead>
<tr>
<th>(1) LabPro or CBL 2 Interface</th>
<th>(1) Vernier CO₂ Gas Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) TI 83 or 83 Plus Graphing Calculator With DataMate Program</td>
<td>(1) Vernier O₂ Gas Sensor</td>
</tr>
<tr>
<td>(1) Ice Bath with Temperature of Approximately 10° C</td>
<td>(1) Warm Water Bath (Heating Pad or Electric Skillet with Water) with Temperature of Approximately 35° C</td>
</tr>
<tr>
<td>(1) ⅜ Inch Drill with 1⅛ inch Drill Bit</td>
<td>(1) (20-26 oz.) Benzel’s Bretzel Bakery Pretzel Bottle with Plastic Lid or (40 oz.) Utz Pretzel Stick Bottle with Plastic Lid</td>
</tr>
<tr>
<td>(1) Kimchee Fermentation Bottle</td>
<td>(1) 4½” Diameter x 2/3” High Plastic Lid</td>
</tr>
<tr>
<td>(1) Roll Masking Tape to Make Pipe Fit Snug in jar insertion hole</td>
<td></td>
</tr>
</tbody>
</table>

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Part C: Preparing Sensosphere (20 -26 oz. Benzel’s Bretzel Bakery Pretzel Bottle Or Data Collection Chamber)

1. Empty the pretzels from the (20-26 oz.) Benzel’s Bretzel Bakery Pretzel Bottle with Plastic Lid or (40 oz.) Utz Pretzel Stick Bottle with Plastic Lid, wash and dry it.

2. Drill two (2) 1¼ inch holes in the 4.5 inch diameter plastic lid using the drill to create an Utz or Benzel Bottle Sensosphere. See Figures 14 -16. (Your instructor will have this prepared for you.)
3. Insert the carbon dioxide and oxygen sensors as shown in Figures 14 and 15. It may be necessary to wrap the oxygen sensor with masking tape to achieve a snug fit.

**PROCEDURE**

1. Plug the O₂ Gas Sensor into Channel 1 and the CO₂ Gas Sensor into Channel 2 of the LabPro or CBL 2 interface. Use the link cable to connect the TI Graphing Calculator to the interface. Firmly press in the cable ends.

2. Turn on the calculator and press APPS, then start the DATAMATE program. Press CLEAR to reset the program.

3. Set up the calculator and interface for an O₂ Gas Sensor and CO₂ Gas Sensor.
   a. Select SETUP from the main screen.
   b. Press ENTER to select CH 1.
   c. Select OXYGEN GAS from the SELECT SENSOR menu.
   d. Select parts per thousand (PPT) as the unit.
   e. Press once, then press ENTER to select CH2.
   f. Select CO2 GAS from the SELECT SENSOR menu.
   g. Select parts per thousand (PPT) as the unit.

4. Set up the data-collection mode.
   g. To select MODE, press (the up arrow key) twice and press ENTER.
   h. Select TIME GRAPH from the SELECT MODE menu.
   i. Select CHANGE TIME SETTINGS from the TIME GRAPH SETTINGS menu.
   j. Enter “15” as the time between samples in seconds.
   k. Enter “40” as the number of samples (data will be collected for 10 minutes).
   l. Select OK twice to return to the main screen.

5. Measure the room temperature using a thermometer and record the temperature in Table 2.

6. Obtain the Kimchee bottle of at least 3 days from room temperature.

7. Place Kimchee bottle into the respiration chamber, and open the bottle. **Data collection temperatures should be the same as incubation temperatures:** Measure the temperature of incubation using a thermometer and record the temperature in the proper table. Attempt to keep the testing temperature constant to the incubation temperature by using an ice bath or water bath.
   >To maintain the 10° C temperature use the ice bath.
   >To maintain room temperature of 20 – 25 °C keep data collection area near incubation area.
   >To maintain warm temperature of 30 – 35° C use warm water bath.

8. Twist on the bottle top. Insert the CO₂ and O₂ Sensors into the plastic lid of the respiration chamber as shown in Figures 14 and 15. The O₂ Gas Sensor may require masking tape on the body to achieve a snug fit. Place the CO₂ Gas Sensor into the plastic lid of the chamber as shown in Figures 14 and 15. Gently twist the stopper on the shaft of the CO₂ Gas Sensor into the chamber opening. Do not twist the shaft of the CO₂ Gas Sensor or you may damage it.

9. Wait two minutes, and then select START to begin data collection. Data will be collected for
10 minutes.

10. When data collection has finished, untwist the bottle lid from the respiration chamber.

11. Fill the respiration chamber with water and then empty it. Thoroughly dry the inside of the respiration chamber with a paper towel.

12. Press _ENTER_ to view the graph of O2 GAS VS. TIME. When finished, press _ENTER_ to return to the graph menu. Press _▼_ once, and then press _ENTER_ to view the graph of CO2 GAS VS. TIME. When finished, press _ENTER_ to return to the graph menu. Select MAIN SCREEN from the graph menu.

13. Perform a linear regression to calculate the rate of respiration.
   a. Select ANALYZE from the main screen.
   b. Select CURVE FIT from the ANALYZE OPTIONS menu.
   c. Select LINEAR (CH 1 VS TIME) from the CURVE FIT menu.
   d. The linear-regression statistics for these two lists are displayed for the equation in the form:
      \[ Y = A \times X + B \]
   e. Enter the absolute value of the slope, A, as the rate of respiration related to change in oxygen concentration in Table 1, 2, or 3 for the appropriate temperature Kimchee bottle.
   f. Press _ENTER_ to view a graph of the data and the regression line.
   g. Press _ENTER_ to return to the ANALYZE menu.
   h. Repeat Steps 13b – 13g to calculate the respiration rate using the data from the CO2 Gas Sensor (CH 2 VS TIME).
   i. Select RETURN TO MAIN SCREEN from the ANALYZE menu.

14. Measure the cold temperature of the cold incubation area using a thermometer and record the temperature in Table 1.

15. Obtain the Kimchee bottle of at least 3 days from cold temperature.

16. Place Kimchee bottle into the respiration chamber, and open the bottle.

17. Repeat Steps 6 – 13 using the cold Kimchee. Place all data in Table 1.

18. Measure the warm temperature of the cold incubation area using a thermometer and record the temperature in Table 3.

19. Obtain the Kimchee bottle of at least 3 days from warm temperature.

20. Place Kimchee bottle into the respiration chamber, and open the bottle.

21. Repeat Steps 6 – 13 using the warm Kimchee. Place all data in Table 3.

**PART 3: TRACKING MICROBE GROWTH AND ENVIRONMENTAL CHANGES WITH TURBIDITY, PH, CONDUCTIVITY**

Microbial growth can be measured by turbidity, cloudiness. The cloudiness is produced by light reflecting off the microbes in the water or brine; therefore, the more microbes in the water, the higher the turbidity. If the conditions are anaerobic and there is an adequate salt concentration,
the extreme halophilic microbes of the phyllosphere grow and Kimchee is formed. If there is oxygen or inadequate salt, the aerobic microbes grow and cause the cabbage to rot. The cabbage spoils instead of being preserved. Observations of the cabbage need to be made in relation to the turbidity readings. If the cabbage spoils, it turns a dark brown color. Using the Turbidity Sensor or Colorimeter, you will monitor microbe reproduction while making Kimchee.

As the anaerobic microbes grow and reproduce in the high salt environment, they produce lactic acid and other products including ethanol and carbon dioxide as a result of heterofermentation of plant carbohydrates. Using the pH Sensor, you will monitor the production of lactic acid, which also indicates the growth and heterofermentation of the microbes. Also, the carbon dioxide produced reacts with water to produce carbonic acid and further lowers the pH. Using the Conductivity Sensor, you will monitor the salt concentration to ensure an environment suitable for extreme halophilic microbes to grow while making Kimchee. You will also check the temperature of the environment.

OBJECTIVES
In this experiment, you will
- use a Turbidity Sensor to measure concentration of microbes during heterofermentation.
- use a Colorimeter to measure concentration of microbes during heterofermentation.
- use pH Sensor to determine acidity during heterofermentation.
- use Conductivity Sensor to determine salt concentration of the brine.
- compare the rates of growth of microbes during fermentation at different temperatures.
- compare the changes in pH during heterofermentation.

PART 3 MATERIALS CHECKLIST

<table>
<thead>
<tr>
<th>Colorimeter Method</th>
<th>Turbidity Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) LabPro or CBL 2 Interface</td>
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</tr>
<tr>
<td>(1) TI 83 or 83 Plus Graphing Calculator with DataMate Program</td>
<td>(1) TI 83 or 83 Plus Graphing Calculator with DataMate Program</td>
</tr>
<tr>
<td>(1) Vernier Colorimeter Sensor</td>
<td>(1) Turbidity Cuvette</td>
</tr>
<tr>
<td>(1) Soft, Lint-Free Cloth or Tissue</td>
<td></td>
</tr>
<tr>
<td>(1) Kimchee Brine Sample</td>
<td></td>
</tr>
<tr>
<td>(1) 1 ml Pipet</td>
<td></td>
</tr>
<tr>
<td>(1) Thermometer Sensor or Traditional Thermometer</td>
<td></td>
</tr>
<tr>
<td>(1) Roll of Paper Towels</td>
<td></td>
</tr>
<tr>
<td>(1) TI 83 or 83 Plus Graphing Calculator with DataMate Program</td>
<td>(1) Sampling Bottle Similar to D.O. Calibration Bottle</td>
</tr>
<tr>
<td></td>
<td>(1) Sampling Bottle Similar to D.O. Calibration Bottle</td>
</tr>
<tr>
<td></td>
<td>(1) Cuvette and Lid</td>
</tr>
<tr>
<td></td>
<td>(2) 5-mL Pipettes or 10-mL Graduate Cylinders</td>
</tr>
<tr>
<td></td>
<td>(1) Dropper Pipet or Beral Pipet</td>
</tr>
<tr>
<td></td>
<td>(1) Waste Sample Disposal Container 200 ml</td>
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<td></td>
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<tr>
<td></td>
<td>(1) Vernier pH Sensor</td>
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<tr>
<td></td>
<td>(1) Vernier Conductivity Probe</td>
</tr>
</tbody>
</table>

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**KIMCHEE FERMENTATION BOTTLE BRINE**

**Fig. 17**

**Fig. 18**

**PROCEDURE**

**PART A: COLLECTION OF SAMPLES**

1. Carefully swirl the Sam’s Choice Kimchee fermentation bottle to suspend the microbes above the Solo cup top. Then carefully pour about 7 ml – 10 ml of the contents of the brine layer (see Fig. 17) into a clean D. O. bottle or an empty film canister (see Fig. 18). Later you will remove 1.0 ml to prepare the turbidity cuvette or 1.5 ml to the colorimeter cuvette.

   The remaining 6.0 - 9.0 ml of brine is used for the pH and conductivity readings. Be careful not to spill it.

   You need to decide which method of turbidity you will use. PART B is the procedure for using the Colorimeter and PART C is the procedure for the Turbidity Sensor.

**Part B. Testing Procedure for Turbidity (with Colorimeter), pH and Conductivity**

1. Plug the Colorimeter Sensor into Channel 1 of the LabPro or CBL 2 interface. Use the link cable to connect the TI Graphing Calculator to the interface. Firmly press in the cable ends. Then plug a pH Sensor into Channel 2 of the LabPro or CBL 2 interface. Set the selector switch on the side of the Conductivity Probe to the 0-20,000 range. Plug the Conductivity...
Probe into Channel 3 of the LabPro or CBL 2 interface.

2. Turn on the calculator and press APPS and select the DATAMATE program. Press \[\text{CLEAR}\] to reset the program.

3. Set up the calculator and interface for the Turbidity, pH and Conductivity Sensors.
   a. Select SETUP from the main screen.
   b. If CH 1 displays COLORIMETER, proceed directly to Step 4. If it does not, continue with this step to set up your sensor manually.
   c. Press \[\text{ENTER}\] to select CH 1.
   d. Select COLORIMETER from the SELECT SENSOR menu.
   e. Press \[\uparrow\] once, then press \[\text{ENTER}\] to select CH2.
   f. Select PH from the SELECT SENSOR menu.
   g. Press \[\uparrow\] once, then press \[\text{ENTER}\] to select CH3.
   h. Select CONDUCTIVITY from the SELECT SENSOR menu. Select CONDUCT 20,000 (MICS/L) from the CONDUCTIVITY menu. If an older Conductivity Sensor is not autodetected, the switch has to be set to 20000 µS.

4. Prepare a \textit{blank} for the Colorimeter by filling an empty cuvette ¾ full with distilled water. Seal the cuvette with a lid. To correctly use a Colorimeter cuvette, remember:
   - All cuvettes should be wiped clean and dry on the outside with a tissue.
   - Handle cuvettes only by the top edge of the ribbed sides.
   - All solutions should be free of bubbles.
   - Always position the cuvette with the cuvette clear side facing toward the white reference mark at the cuvette slot on the Colorimeter.

5. Set up the calculator and interface for the colorimeter and calibration:
   \textbf{A. NEW COLORIMETER}

   \textbf{Wavelength Selection to Calibrate New Colorimeter}

   a. Place the blank in the cuvette slot of the Colorimeter and close the lid.
   b. Select green (565 nm) wavelength using the wavelength selection arrows at the top of the colorimeter shown in Figure 19.
c. The new Vernier Colorimeter offers a simplified method for calibration. Before calibrating be sure the Colorimeter has been powered for about 5 minutes. (One of the four green wavelength indicator lights should be turned on.)

d. Insert a cuvette filled with distilled water for your blank cuvette at 100% transmittance or 0 absorbance. (A clear side of the cuvette must face the arrow at the back of the cuvette slot.)

e. Next, press the CAL button until the red LED begins to flash. Then release the CAL button.

f. When the LED stops flashing, the calibration is complete.

g. The calibration procedure tunes the output of the colorimeter to present values that can be used by the software. Important: Unlike older versions of the Colorimeter, with this model you do not need to go to the special calibration menu in the data collection programs. Proceed directly to Step 4. If your Colorimeter does not have a CAL button, continue with the next section (Calibrate the OLD Colorimeter) to calibrate your Colorimeter.

B. Calibrate the OLD Colorimeter.

First Calibration Point
a. Go to SETUP then choose Calibrate → CH1: Colorimeter (%T) from the Experiment menu and then click Calibrate Now.

b. Turn the wavelength knob on the Colorimeter to the “0% T” position.

c. Type “0” in the edit box.

d. When the displayed voltage reading for Reading 1 stabilizes, click Keep.

Second Calibration Point

e. Turn the knob of the Colorimeter to the Green LED position (565 nm).

f. Type “100” in the edit box.

g. When the displayed voltage reading for Reading 2 stabilizes, click Keep, then click Done.

Measure the Kimchee phyllosphere population with the Colorimeter (Various Days)
Each team should perform the following steps.
4. Obtain a 1.5 mL Kimchee sample from the various temperatures. Add 1.5 mL of distilled water to the sample to dilute it 50%.

5. You are now ready to collect absorbance data for the phyllosphere bacteria. Quickly perform these steps:
   a. Mix the contents of the cuvette until all air bubbles are removed from the clear sides of the cuvette.
   b. Wipe the outside of the cuvette with a tissue and place it into the Colorimeter.
   c. Close the lid and wait for the absorbance value displayed on the calculator to stabilize.
   d. Record the absorbance value in the appropriate table.
   e. Remove the cuvette from the Colorimeter.

6. Repeat Steps 4 and 5 for the other incubation temperatures. Record your absorbance values for the various temperatures as instructed by your teacher in the appropriate table (Tables 1-3).

PART C. TESTING PROCEDURE FOR TURBIDITY (WITH THE TURBIDITY SENSOR), PH AND CONDUCTIVITY

Turbidity with Turbidity Sensor
1. Plug the Turbidity Sensor into Channel 1 of the LabPro or CBL 2 interface. Use the link cable to connect the TI Graphing Calculator to the interface. Firmly press in the cable ends. Then plug a pH Sensor into Channel 2 of the LabPro or CBL 2 interface. Set the selector switch on the side of the Conductivity Probe to the 0-20,000 µS range. Plug the Conductivity Probe into Channel 3 of the LabPro or CBL 2 interface.

2. Turn on the calculator and press APPS and select the DATAMATE program. Press CLEAR to reset the program.

3. Set up the calculator and interface for the Turbidity pH and Conductivity Sensors.
   i. Select SETUP from the main screen.
   j. If CH 1 displays TURBIDITY (NTU), proceed directly to Step 4. If it does not, continue with this step to set up your sensor manually.
k. Press [ENTER] to select CH 1.
l. Select TURBIDITY (NTU) from the SELECT SENSOR menu.
m. Press [▼] once, then press [ENTER] to select CH2.
n. Select PH from the SELECT SENSOR menu.
o. Press [▼] once, then press [ENTER] to select CH3.
p. Select CONDUCTIVITY from the SELECT SENSOR menu. Select CONDUCT 20,000 (MICS/L) from the CONDUCTIVITY menu.

   • If your instructor directs you to manually enter the calibration values, select CALIBRATE, then MANUAL ENTRY. Enter the slope and intercept values, select OK, then proceed to Step 5.

   If your instructor directs you to perform a new calibration for the Turbidity Sensor, follow this procedure.

First Calibration Point
   a. Select CALIBRATE, and then select CALIBRATE NOW.
   b. Prepare a blank by rinsing the turbidity cuvette with distilled water, then filling it ¾ full with distilled water. Place the lid on the cuvette. Gently wipe the outside with a soft, lint-free cloth or tissue.
   c. Check the cuvette for air bubbles. If air bubbles are present, gently tap the bottom of the cuvette on a hard surface to dislodge them.
   d. Holding the cuvette by the lid, place it in the Turbidity Sensor. Make sure that the mark on the cuvette is aligned with the mark on the Turbidity Sensor. Close the lid.
   e. When the voltage reading is stable, press [ENTER].
   f. Enter “0” as the turbidity of the water.
   g. Remove the cuvette and set aside for use in Step 8.

Second Calibration Point
   h. Obtain the cuvette containing the Turbidity Standard (100 NTU) and gently invert it four times to mix in any particles that may have settled to the bottom. Important: Do not shake the standard. Shaking will introduce tiny air bubbles that will cause error in the turbidity calculation.
   i. Wipe the outside with a soft, lint-free cloth or tissue.
   j. Holding the standard by the lid, place it in the Turbidity Sensor. Make sure that the mark on the cuvette is aligned with the mark on the Turbidity Sensor. Close the lid.
   k. When the voltage reading is stable, press [ENTER].
   l. Enter “100” as the turbidity of the standard.
   m. Select OK to return to the setup screen.

5. Set up the data-collection mode.
   a. To select MODE, press [▲] once and press [ENTER].
   b. Select SINGLE POINT from the SELECT MODE menu.
   c. Select OK to return to the main screen.
   d. You are now ready to collect turbidity data. (See Measuring Turbidity, Step #8)
6. If the calculator screen has gone blank, press the **ON** key to power up the calculator and select **YES** from the **CONTINUE** menu.

7. Select **OK** to return to the main screen.

**8. Measuring Turbidity**

a. Gently swirl the sample or stir with pipet four times to mix in any particles that may have settled to the bottom. **Important:** Do not shake the sample. Shaking will introduce tiny air bubbles that will cause error in the turbidity calculation.

b. Empty the distilled water from the cuvette used in Step 4, and dry it with a lint free cloth inside and out.

c. Preparation of Turbidity Cuvette: Make a dilution of 1/20. First, swirl the 7 – 10 ml brine sample and take 1.0 ml of this sample and place it in a turbidity cuvette. Add 19.0 ml of distilled water (until the meniscus is on the full line). See Figures 17 and 18. It is important swirl the samples to suspend the particles, but avoid making bubbles. Be sure to only sample the fluid on the inside of the Kimchee fermentation bottle and not from the ridge on the outside.

   ![Fig. 24](image) Add 1.0 ml of brine solution from the brine layer of the Kimchee fermentation bottle to the cuvette (Fig. 24)

   Then add water (fill so the meniscus is at the top of the full line as shown in Fig. 25)

   ![Fig. 25](image)

   ![Miniscus](image)

   ![Fig. 25](image)

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   ![Fig. 25](image)

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   ![Fig. 25](image)

   ![Miniscus](image)
a. Remove the pH probe from its storage bottle. Rinse the probe tip with distilled water and dab it dry with a paper towel. Place the probe into the brine sample.
b. Select START to begin sampling.
c. After 10 seconds, the pH value will appear on the screen.
d. Record data in correct table.
e. Press ENTER to return to the main screen.
f. Place the conductivity probe into the brine sample.
g. Select START to begin sampling.
h. After 10 seconds, the conductivity value in µS will appear on the screen.
i. Record data in correct table.
j. Press ENTER to return to the main screen.

10. Physical observations. Record your observations of color of cabbage and brine conditions in the proper tables.
11. (Optional) Take a picture of the bottles at the different temperatures and record information about each image related to the picture number.

QUESTIONS
1. What causes the production of the brine when salt is added to “dry” cabbage?

2. a. Why is the brine important in making Kimchee?
   b. Explain what you think would happen to the microbes if brine was not present.

3. Describe what happens to the halophilic bacteria in the presence of oxygen. Explain how oxygen effects the microbe populations of the phyllosphere.

4. a. What is the evidence that fermentation occurred in the napa?
   b. Explain why fermentation of napa does not occur while the napa is growing in the field.

5. Is water produced during fermentation?

6. Why do phyllosphere microbes undergo anaerobic cellular respiration?

7. What is the influence of salt on growth and cellular respiration of extreme halophilic microbes of the napa leaves?

8. What is the influence of temperature on the rate of cellular respiration in microbes? Explain.

9. Why are the cabbage leaves important to the microbes of the phyllosphere?
   Explain how carbon dioxide influences pH during the experiment.

10. What evidence do you have that phyllosphere microbes are reproducing? Explain.

11. Make a graph of Rate of Carbon Dioxide Production vs. Time (use Graphical Analysis, Excel or graph paper). During what days is the production of carbon dioxide the greatest?

12. What evidence do you have that lactic acid is being produced? Explain.

13. Make a graph of pH vs. Time. If Kimchee is best to eat when the pH 3.4, what day is it best
to eat the Kimchee if it is made at:
   a. cool temperature
   b. room temperature
   c. warm temperature
   d. Explain your answers.

12. Using the data from this laboratory, make a recommendation on what you think the owner of the Kimchee Restaurant could do to modify their procedure to make Kimchee faster. Explain your recommendation.

EXTENSIONS
1. Compare the various leafy vegetables and fermentation by using the following: Bok choy, beet leaves, collard greens, spinach, kale, collards, broccoli, parsley, brussel sprouts, cabbages other than napa (Green: Grand Prize, Polar Green, Grenadier, Quick Step. Red: Red Rookie. Savoyed: Savoy Chieftain. Chinese: Yoko), celery, shard, Swiss chard, collards, kale, lettuce, parsley, radicchio, watercress and shallots.

2. Compare making Kimchee at different salt concentrations.

3. Compare making Kimchee with different salts: pickling salt, sea salt and iodized salt.


5. Compare making Kimchee in light and the dark conditions.

6. Make a PowerPoint Presentation that explains your experiment, results and your recommendations to the owner of the Kimchee restaurant about how they could make Kimchee faster. Include at least one (1) animation.
Table 1
Napa at Cold Temperature (Approximately 10 °C)

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<th>Days of Fermentation</th>
<th>DATE</th>
<th>pH</th>
<th>Turbidity (TDS) With Dilution of 1/20 (Turb. Sensor)</th>
<th>Turbidity (absorbance) With Dilution of ½ (Color. Sensor)</th>
<th>Conductivity</th>
<th>Rate of Respiration (PPT/s) (Change in [O₂])</th>
<th>Rate of Respiration (*PPT/s or #PPM/s) (Change in [CO₂])</th>
<th>TEMP (°C)</th>
<th>Observations of Cabbage and Brine</th>
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<td>Rate of Respiration (PPT/s) (Change in $[O_2]$)</td>
<td>Rate of Respiration (*PPT/s or #PPM/s) (Change in $[CO_2]$)</td>
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### Table 3
Napa at Warm Temperature (Approximately 35 °C)

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<th>Days of Fermentation</th>
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<th>Turbidity (TDS) With Dilution of 1/20 (Turb. Sensor)</th>
<th>Turbidity (absorbance) With Dilution of 1/2 (Color. Sensor)</th>
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<th>TEMP (°C)</th>
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REFERENCES:


Masterman, David and Holman, S.(2000) Biology with Computers. Beaverton, OR: Vernier Software and Technology. (CBL and calculator protocols and handout Format were derived from this book.)
Hey, Adele, You know that Korean restaurant by the north side of campus? Well, I’ve been eating there for lunch a couple of times a week with the guys from my biology class.

Oh, yeah, Pierre. Is that right? When are you going to take me there again?

We can go today. I really like it. They got this cabbage dish called Kimchee. It’s very good and you can eat it with everything, Adele.

How come you never eat cabbage at home, Pierre?
I don’t know, Adele, this cabbage is different.
Kimchee is prepared differently than we usually prepare our cabbage, Pierre. In Korea the cabbage is salted and peppers and other spices are added. It is often put in a fancy jar and placed under their house a few days for it to ferment. Do you know what else? Kimchee can be made with vegetables other than cabbage.

Well, you know, Adele, that restaurant is packed all the time and they can’t keep up with all the Kimchee that people order. They run out so often that they are looking for someone to help them make Kimchee.

I heard the same thing from your nephew Marcel. He said that his biology teacher, Ms. Napa, would have her biology class help to find the most efficient way to make Kimchee.

Why would the science class be making Kimchee, Adele? What is so scientific about Kimchee?

Well, Pierre, making Kimchee just happens to be an exercise in lactic acid fermentation. Kimchee undergoes anaerobic fermentation and produces lactic acid. That’s what gives it its characteristic taste. The science class will do other tests on it to measure other things about Kimchee, too. The data they will collect will help to find the most efficient way to make the Kimchee. They have lots of sensors to help to quickly collect the data.

Adele, I wonder why so many people are interested in Kimchee.

Well Pierre, the most interesting thing about Kimchee is the live microbes that are on the cabbage leaves, and the lactic acid they produce. I read that if you eat Kimchee, the lactic acid from it aids your digestion. Also, the organic acids control stomach secretions and fermentation produces vitamins B₁, B₂, B₁₂, and nicotinic acid amides. Also, the vegetable fibers keep the digestive track active. It is a great low fat food that is very tasty. I have been reading much about Kimchee on the Internet. I find the information fascinating.

Well Adele, now I know why I have been feeling so well since I have been eating Kimchee. I hope Ms. Napa’s class is able to help the restaurant to make more Kimchee faster. We need to learn more about Kimchee. Let’s go to the library to read more and to search the Internet.
Plants make sugar, storing the energy of the sun into chemical energy, by the process of photosynthesis. When they require energy, they can tap the stored energy in sugar by a process called cellular respiration.

The process of photosynthesis involves the use of light energy to convert carbon dioxide and water into sugar, oxygen, and other organic compounds. This process can be summarized by the following reaction:

\[
6 \text{H}_2\text{O} + 6 \text{CO}_2 + \text{light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2
\]

For most green plants red and blue light is absorbed the most and allows for the greatest rate of photosynthesis. Green light is reflected and thus not utilized by green plants.

Cellular respiration refers to the process of converting the chemical energy of organic molecules into a form immediately usable by organisms. Glucose may be oxidized completely if sufficient oxygen is available in the following reaction:

\[
\text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{H}_2\text{O} + 6 \text{CO}_2 + \text{energy}
\]

All organisms, including plants and animals, oxidize glucose for energy. Often, this energy is used to convert ADP and phosphate into ATP. Using the CO\(_2\) Gas Sensor, you will attempt to monitor the carbon dioxide consumed or produced by plants.

Pierre lived in a house with a vegetable garden in the backyard. The garden faced south and on the north side of the garden was a big red fence, which belonged to the playground he lived next door. Every year he planted tomatoes and they always grew big and had an abundant amount of fruit.

About a year ago they moved the playground to a larger area and people built houses on the old playground site. The family that moved next to Pierre took down the big red fence and put up a black fence when they built their house.

The next spring Pierre planted his tomato crop as usual. He watered the plants every day and anticipated his great harvest.

About one month later he noticed that the plants were not growing rapidly. He went back to the nursery and talked to Don, the owner.

“Don,” said Pierre, “I am disappointed in the tomato plants this year. They are growing very slowly and I think you are getting a bad variety this year.”
“Pierre, the tomatoes are the same kind I get every year. Nothing has changed. Are you doing anything different this year?”

“No, I am doing the exact same thing as I do every year. I don’t know what the problem is. I am watering the same amount and the plants are getting the same amount of light, even with the new fence next to them,” said Pierre.

“What new fence, Pierre? Did your new neighbors build a fence?”

“Yes, a black fence,” said Pierre.

“Pierre, I think that could be the problem.”

“How could a black fence be the problem, Don?” said Pierre.

“The black fence absorbs all colors of light and red reflects red light. Green plants absorb red light and utilize it in photosynthesis “ said Don.

“I never thought of that,” said Pierre.

“Come to my workroom and I will show you, Pierre.”

THE HUNT FOR READ MULCH: EFFECTS OF LIGHT WAVELENGTH ON PLANTS AND PHOTOSYNTHESIS (A CASE STUDY FOR THIS LAB)

The following is a possible scenario that could be occurring near your school campus.

The Red Fence

Pierre lived in a house with a vegetable garden in the backyard. The garden faced south and on the north side of the garden was a big red fence, which belonged to the playground he lived next door. Every year he planted tomatoes and they always grew big and had an abundant amount of fruit.

About a year ago they moved the playground to a larger area and people built houses on the old playground site. The family that moved next to Pierre took down the big red fence and put up a black fence when they built their house.

The next spring Pierre planted his tomato crop as usual. He watered the plants every day and anticipated his great harvest.

About one month later he noticed that the plants were not growing rapidly. He went back to the nursery and talked to Don, the owner.
“Don,” said Pierre, “I am disappointed in the tomato plants this year. They are growing very slowly and I think you are getting a bad variety this year.”

“Pierre, the tomatoes are the same kind I get every year. Nothing has changed. Are you doing anything different this year?”

“No, I am doing the exact same thing as I do every year. I don’t know what the problem is. I am watering the same amount and the plants are getting the same amount of light, even with the new fence next to them,” said Pierre.

“What new fence, Pierre? Did your new neighbors build a fence?”

“Yes, a black fence,” said Pierre.

“Pierre, I think that could be the problem.”

“How could a black fence be the problem, Don?” said Pierre.

“The black fence absorbs all colors of light and red reflects red light. Green plants absorb red light and utilize it in photosynthesis,” said Don.

“I never thought of that,” said Pierre.

“Come to my workroom and I will show you, Pierre.”

**OBJECTIVES**

In this experiment you will,
- use an CO₂ Gas Sensor to measure the amount of carbon dioxide consumed or produced by plants during photosynthesis and cellular respiration.
- determine the rate of cellular respiration and photosynthesis of a plants with various wavelengths of light.
- This laboratory is designed to help you solve this hypothetical problem, and is designed for groups. Various groups use plants with various wavelengths of light and compare results.
Figure 1

- Carbon dioxide sensor
- Circular fluorescent lamp
- 1-1/8 Inch Hole

32 oz Benzel’s Pretzel Jar or 3 oz. Nestea Instant Unsweetened Tea Jar Sensosphere

- Small Seedling
- Plastic wrap around roots and soil with rubber band
- Soil with roots
MATERIALS/GROUP SET-UP

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vernier computer interface</td>
<td>(1) 3 oz. Tall Nestea Instant Unsweetened Tea Jar Sensosphere or (1) 32 oz Benzel’s Bretzel pretzel jar</td>
</tr>
<tr>
<td>Power Macintosh or Windows PC</td>
<td>(1) Cabbage, tomato, cucumber or okra Seedling (With Roots and soil Wrapped in Plastic Wrap)</td>
</tr>
<tr>
<td>Logger Pro</td>
<td>(1) circular ballasted fluorescent Lamp (light: Sylvania CF30/830 FC8T9 (30 W, ring light ballasted lamp adaptors CF30EL/CIRC/830/MED 120 V 60 Hz. These are Sylvania to match the lights.)</td>
</tr>
<tr>
<td>(1) Vernier CO₂ Gas Sensor</td>
<td>(1) portable lamp screw mount sockets with on/off switch, electric cord and clamp</td>
</tr>
<tr>
<td>(1) 3/8 Inch Drill with 1-1/8 inch Drill Bit</td>
<td>Optional (2) Regular Fluorescent Lamps To be used in place of the circular lamp.</td>
</tr>
<tr>
<td>(1) Roll Aluminum Foil</td>
<td>Optional (2) 500-mL Tissue Culture Flasks for heat sinks. Only to be used if regular fluorescent lamps are used instead of circular lamps.</td>
</tr>
<tr>
<td>(1) Sandwich Ziplock or Plastic Wrap</td>
<td>Sheets of various red and black mulch</td>
</tr>
<tr>
<td>(1) Rubber Band or Twist Tie</td>
<td>(1)Balance</td>
</tr>
<tr>
<td>(1) Box large enough for the sensosphere and lining with mulch</td>
<td></td>
</tr>
</tbody>
</table>

PROCEDURE

1. Drill a 1-1/8 inch hole in the center of the plastic lid using the drill to create a 3 oz. tall Nestea Instant Unsweetened Tea Jar Sensosphere or the 32 oz pretzel jar. See Figure 1. (Your instructor will have this prepared for you.)

2. Plug the CO₂ Gas Sensor into Channel 1 of the LabPro interface.

3. Prepare the computer for data collection by opening the file in the Experiment 31B folder of Biology with Computers. (If the sensor is not an autoID sensor, select OK form the Sensor Confirmation screen.) The vertical axis has carbon dioxide concentration scaled from 0 to 2 PPT (parts per thousand). The horizontal axis has time scaled from 0 to 10 minutes. The data rate is set to 6 samples/minute.

Part I Dark Conditions

4. Obtain plant and the number of screens for that condition. Remove the plant from the cell pack (small pot). Wrap the soil and roots gently in plastic wrap with a rubber band or twist tie. See Figure 1.

5. Place the plant into the Sensosphere. Wrap the Sensosphere in aluminum foil so that no light reaches the seedling. Take the temperature at the beginning and the end of each experiment and record in Table 1.

6. Place the CO₂ Gas Sensor into the Sensosphere as shown in Figures 1. Gently twist the stopper on the shaft of the CO₂ Gas Sensor into the chamber opening. Do not twist the shaft
of the CO₂ Gas Sensor or you may damage it. Take the temperature at the beginning and the end of each experiment and record in Table 1.

Wait 3 minutes before proceeding to Step 7.

7. Click Collect to begin data collection. Data will be collected for 10 minutes.

8. When data collection has finished, determine the rate of cellular respiration:
   a. Move the mouse pointer to the point where the data values begin to increase. Hold down the left mouse button. Drag the pointer to the point where the data ceases to rise and release the mouse button.
   b. Click on the Regression button, to perform a linear regression. A floating box will appear with the formula for a best fit line.
   c. Record the slope of the line, \( m \), as the rate of cellular respiration in Table 1.
   d. Close the linear regression floating box.

9. Move your data to a stored run. To do this, choose Store Latest Run from the Experiment menu.

Part II  Light Conditions with Red and Black Mulches

10. Remove the aluminum foil from around the Sensosphere.

11. Place circular fluorescent lamp around the Sensosphere. See Figure 1. (Option: Fill a flask with water and place it between the lamp and the Sensosphere. The flask will act as a heat sink to protect the plant leaves. The circular lamp is the preference for best results and does not require a heat sink.)

12. Line the box with red mulch. Place the sensosphere in the box. Be sure there is at least 1 inch of space between the sensosphere and the box. Turn the circular lamp on. Place the lamp as close to the Sensosphere as reasonable. (If using an incandescent light, do not let the lamp touch the tissue culture flask.) Note the time. The lamp should be on for 3 minutes prior to beginning data collection.

13. After the three-minute time period is up, repeat Steps 7 – 8.

14. After the three-minute time period is up, click Collect to begin data collection. Data will be collected for 10 minutes.

15. When data collection has finished, determine the rate of photosynthesis:
   a. Move the mouse pointer to the point where the data values begin to decrease. Hold down the left mouse button. Drag the pointer to the point where the data ceases to decline and release the mouse button.
   b. Click on the Regression button, to perform a linear regression. (Select latest run if a dialogue box appears.) A floating box will appear with the formula for a best fit line.
   c. Record the slope of the line, \( m \), as the rate of photosynthesis in Table 1.
   d. Close the linear regression floating box.

16. Label a graph showing your photosynthesis and cellular respiration data.
a. Label each curve by choosing Text Annotation from the Insert menu. Enter “Photosynthesis with Red Mulch” in the edit box. Repeat to create an annotation for the “Cellular Respiration” data. Drag each box to a position near its respective curve.
b. Print a copy of the Graph window, with both data sets displayed. File, Print Graph and select Print Footer. Enter your name(s) and the number of copies of the graph you want.

17. Repeat steps 4-17 with black mulch. Complete Table 1.

18. Remove the seedling from the Sensosphere. Take the mass of the seedling without the plastic wrap. Record the mass in proper table. Return the plant to its original container without plastic wrap on its roots. Clean and dry the Sensosphere.

DATA

<table>
<thead>
<tr>
<th>Mulch Conditions</th>
<th>Seedling Mass (g)</th>
<th>Temperature °C</th>
<th>Rate of cellular respiration/photosynthesis (PPT/s)</th>
<th>Rate of cellular respiration/photosynthesis/mass (PPT/s/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Initial</td>
<td>Final</td>
<td></td>
</tr>
<tr>
<td>No mulch and no light (sensosphere wrapped in Al foil)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red mulch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black mulch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

QUESTIONS

1. Were any of the rate values a positive number? If so, which ones and what is the biological significance of this?

2. Were any of the rate values a negative numbers? If so, what is the biological significance of this?

3. Do you have evidence that cellular respiration occurred in some conditions? Explain your answer.

4. Do you have evidence that photosynthesis occurred in plant leaves of some conditions? Explain your answer.

5. Compare the rates of photosynthesis and cellular respiration among plants with various mulches over time in the light and the dark using Table 1. Which rate indicates the greatest
rate of photosynthesis? Explain why? Is this what you would expect and why?

6. List five factors that might influence the rate of carbon dioxide production or consumption in leaves. Explain how you think each will affect the rate.

7. How do you thing rate of photosynthesis would effect the sized of fruit produced and the growth of the plant? Explain.

8. Why do plants need to perform photosynthesis and under what conditions do they perform photosynthesis?

9. Why do plants need to perform cellular respiration and under what conditions do they perform cellular respiration?

10. How could you use a light sensor to gather more complete data about this farming problem?

11. Using the data from this laboratory, make a recommendation on what you think the Pierre should do with his garden. Explain.

EXTENSIONS

1. Make a PowerPoint Presentation that explains your experiment, results and your recommendations to Pierre about how mulch is influencing their crops. Include why you think mulch is more practical then fences.

2. Design and perform an experiment to test one of the factors that might influence the rate of carbon dioxide production or consumption in Question 6.

3. Compare the rates of photosynthesis and cellular respiration among various types of plants.

4. Compare the rates of photosynthesis and cellular respiration among various wavelengths of light using light filters.

5. Use gaseous oxygen sensor and carbon dioxide sensor to collect data.

REFERENCES:


Plants make sugar, storing the energy of the sun into chemical energy, by the process of photosynthesis. When they require energy, they can tap the stored energy in sugar by a process called cellular respiration.

The process of photosynthesis involves the use of light energy to convert carbon dioxide and water into sugar, oxygen, and other organic compounds. This process can be summarized by the following reaction:

\[
6 \text{H}_2\text{O} + 6 \text{CO}_2 + \text{light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2
\]

Cellular respiration refers to the process of converting the chemical energy of organic molecules into a form immediately usable by organisms. Glucose may be oxidized completely if sufficient oxygen is available in the following reaction:

\[
\text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{H}_2\text{O} + 6 \text{CO}_2 + \text{energy}
\]

All organisms, including plants and animals, oxidize glucose for energy. Often, this energy is used to convert ADP and phosphate into ATP. Using the CO₂ Gas Sensor, you will attempt to monitor the carbon dioxide consumed or produced by plants.

**MADE IN THE SHADE: EFFECTS OF SHADING ON PLANTS AND PHOTOSYNTHESIS (A CASE STUDY FOR THIS LAB)**

The following is a possible scenario that could be occurring near your campus.

Every spring Cotille plants a tomato garden in her backyard. The tomato plants bathe in the Louisiana sunshine and the tomatoes are always beautiful and abundant.

One spring her husband, Boudreaux, buys a shrimp boat. He parks the boat in the backyard when he is not out shrimping with it. He hangs his large shrimp nets to dry in the backyard over
where some of the tomato plants are planted. The ends of the garden are in the full sunshine and the nets shade the middle half.

Cotille has planted the same number of tomato plants this year as any other year. She gets her plants from the Louisiana State University Agriculture Department. However, over the next few weeks she sees the surprising results.

“Cotille,” says Boudreaux, “what’s the matter with those tomatoes in the middle of the garden. They are not big and healthy like the others. They must be a bad batch.”

Cotille looks at the plants closely and says, “Boudreaux, look what’s happening. It’s because of where they are planted. The plants that are dying are all under the shrimp nets. I water them all every day. The ones in the middle aren’t getting the same amount of sunlight as the ends of the garden are getting.”

“What difference does that make?” Boudreaux asked.

“Well, I remember from my biology class at LSU that plants need sunlight and water for photosynthesis, the process that the plant uses to make its food. If they don’t get enough of each, they don’t grow well. Those nets of yours are blocking the sunlight from the tomato plants.”

“Why don’t you just move the nets to some other place in the yard or keep them down by the marina. That should help the plants so they won’t die,” said Cotille.

“I don’t think so, Cotille, you have to prove that to me before I move the nets. I still think there is something wrong with those tomato plants,” Boudreaux said.

“OK, Boudreaux,” said Cotille, “I will set up my experiment right now!”

OBJECTIVES

In this experiment you will,
- use an CO2 Gas Sensor to measure the amount of carbon dioxide consumed or produced by plants during photosynthesis and cellular respiration.
- determine the rate of cellular respiration and photosynthesis of a plants with various amounts of light on its leaves.
- This laboratory is designed to help you solve this hypothetical problem, and is designed for groups. Various groups use plants with various amounts of light and compare results.
Figure 1

Carbon dioxide sensor

1-1/8 Inch Hole

Circular fluorescent lamp

32 oz Benzel's Pretzel Jar or 3 oz. Nescafe Instant Unsweetened Tea Jar Sensosphere

Small Seedling

Plastic wrap around roots and soil with rubber band

Soil with roots
### MATERIALS/GROUP SET-UP

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
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<td>Power Macintosh or Windows PC</td>
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<tr>
<td>Logger Pro</td>
<td>(1) circular ballasted fluorescent Lamp (light: Sylvania CF30/830 FC8T9 (30 W, ring light ballasted lamp adaptors (CF30EL/CIRC/830/MED 120 V 60 Hz. These are Sylvania to match the lights.)</td>
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<td>(1) portable lamp screw mount sockets with on/off switch, electric cord and clamp</td>
</tr>
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<td>(1) 3/8 Inch Drill with 1-1/8 inch Drill Bit</td>
<td>Optional (2) Regular Fluorescent Lamps To be used in place of the circular lamp.</td>
</tr>
<tr>
<td>(1) Roll Aluminum Foil</td>
<td>Optional (2) 500-mL Tissue Culture Flasks for heat sinks. Only to be used if regular fluorescent lamps are used instead of circular lamps.</td>
</tr>
<tr>
<td>(1) Sandwich Ziplock or Plastic Wrap</td>
<td>Sheets of screen to wrap around the Sensosphere.</td>
</tr>
<tr>
<td>(1) Rubber Band or Twist Tie</td>
<td>(1) Balance</td>
</tr>
</tbody>
</table>

### PROCEDURE

Note: Each group could use plants with different numbers of screens.

1. Drill a 1-1/8 inch hole in the center of the plastic lid using the drill to create a 3 oz. tall Nestea Instant Unsweetened Tea Jar Sensosphere or the 32 oz pretzel jar. See Figure 1. (Your instructor will have this prepared for you.)

2. Plug the CO₂ Gas Sensor into Channel 1 of the LabPro interface.

3. Prepare the computer for data collection by opening the file in the Experiment 31B folder of *Biology with Computers*. (If the sensor is not an autoID sensor, select OK from the Sensor Confirmation screen.) The vertical axis has carbon dioxide concentration scaled from 0 to 2 PPT (parts per thousand). The horizontal axis has time scaled from 0 to 10 minutes. The data rate is set to 6 samples/minute.

**Part I Dark Conditions**

4. Obtain plant and the number of screens for that condition. Remove the plant from the cell pack (small pot). Wrap the soil and roots gently in plastic wrap with a rubber band or twist tie. See Figure 1.

5. Place the plant into the Sensosphere. Wrap the Sensosphere in aluminum foil so that no light reaches the seedling.
6. Place the CO₂ Gas Sensor into the Sensosphere as shown in Figures 1. Gently twist the stopper on the shaft of the CO₂ Gas Sensor into the chamber opening. Do not twist the shaft of the CO₂ Gas Sensor or you may damage it. Wait 3 minutes before proceeding to Step 7.

7. Click to begin data collection. Data will be collected for 10 minutes.

8. When data collection has finished, determine the rate of cellular respiration:
   a. Move the mouse pointer to the point where the data values begin to increase. Hold down the left mouse button. Drag the pointer to the point where the data ceases to rise and release the mouse button.
   b. Click on the Regression button, to perform a linear regression. A floating box will appear with the formula for a best fit line.
   c. Record the slope of the line, \( m \), as the rate of cellular respiration in Table 1.
   d. Close the linear regression floating box.

9. Move your data to a stored run. To do this, choose Store Latest Run from the Experiment menu.

**Part II Light Conditions**

10. Remove the aluminum foil from around the Sensosphere.

11. Place circular fluorescent lamp around the Sensosphere. See Figure 1. (Option: Fill a flask with water and place it between the lamp and the Sensosphere. The flask will act as a heat sink to protect the plant leaves. The circular lamp is the preference for best results and does not require a heat sink.)

12. **Place the designated number of screens around the bottle (0, 1, 2 or 3).** Turn the circular lamp on. Place the lamp as close to the Sensosphere as reasonable. Do not let the lamp touch the tissue culture flask. Note the time. The lamp should be on for 3 minutes prior to beginning data collection.

13. After the three-minute time period is up, repeat Steps 7 – 8.

14. After the three-minute time period is up, click to begin data collection. Data will be collected for 10 minutes.

15. When data collection has finished, determine the rate of photosynthesis:
   a. Move the mouse pointer to the point where the data values begin to decrease. Hold down the left mouse button. Drag the pointer to the point where the data ceases to decline and release the mouse button.
   b. Click on the Regression button, to perform a linear regression. (Select latest run if a dialogue box appears.) A floating box will appear with the formula for a best fit line.
   c. Record the slope of the line, \( m \), as the rate of photosynthesis in Table 1.
   d. Close the linear regression floating box.

16. Label a graph showing your photosynthesis and cellular respiration data.
   a. Label each curve by choosing Text Annotation from the Insert menu. Enter “Photosynthesis with ___ Screens” in the edit box. Repeat to create an annotation for the “Cellular Respiration” data. Drag each box to a position near its respective curve.
b. Print a copy of the Graph window, with both data sets displayed. File, Print Graph and select Print Footer. Enter your name(s) and the number of copies of the graph you want.

17. Repeat steps 4-17 with a different number of screens. Complete proper tables.

18. Remove the seedling from the Sensosphere. Take the mass of the seedling without the plastic wrap. Record the mass in proper table. Return the plant to its original container without plastic wrap on its roots. Clean and dry the Sensosphere.

19. With data from Tables 1 – 5, complete Tables 6 and 7 and make graphs of the data from Tables 6 and 7 using Logger Pro, Graphical Analysis, Excel or graph paper.

DATA

<table>
<thead>
<tr>
<th>Seedling With # of Screens</th>
<th>Seedling Mass (g)</th>
<th>Rate of cellular respiration/photosynthesis (PPT/s)</th>
<th>Rate of cellular respiration/photosynthesis/mass (PPT/s/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (all light)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al foil</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

QUESTIONS

1. Were the rate values a positive number with some conditions? If so, which conditions and what is the biological significance of this?

2. Were any of the rate values a negative numbers? If so, what is the biological significance of this?

3. Do you have evidence that cellular respiration occurred in some conditions? Explain your answer.

4. Do you have evidence that photosynthesis occurred in plant leaves of some conditions? Explain your answer.

5. List five factors that might influence the rate of carbon dioxide production or consumption in leaves. Explain how you think each will affect the rate?

6. Why do plants need to perform photosynthesis and under what conditions do they perform photosynthesis?
7. Why do plants need to perform cellular respiration and under what conditions do they perform cellular respiration?

8. How could you use a light sensor to gather more complete data about this farming problem?

9. Compare the rates of photosynthesis and cellular respiration among plants with various screens over time in the light and the dark using Table 1. (You should plot the data from Tables 1 to help with your analysis.) With these results predict expected plant growth under each condition.

10. Using the data from this laboratory, make a recommendation on what you think the Cotille should report and request from Boudreaux? Explain.

EXTENSIONS

1. Make a PowerPoint Presentation that explains your experiment, results and your recommendations to Boudreaux about how the shading is influencing their crops.

2. Design and perform an experiment to test one of the factors that might influence the rate of carbon dioxide production or consumption in Question 5.

3. Compare the rates of photosynthesis and cellular respiration among various amounts types of light sources that emit light of various wavelengths.

4. Compare the rates of photosynthesis and cellular respiration among various types of plants in different light conditions.

5. Use gaseous oxygen sensor and carbon dioxide sensor to collect data.

REFERENCES:

Life of the aerobic microbes in the soil is important to plant survival. Soil organisms, bacteria, fungi, protozoa, nematodes, earth worms, are active in breaking down plant and animal remains in soil. Microbes (bacteria and fungi) carry out another very important function. They convert the organic chemicals into inorganic nutrients such as nitrate and phosphate, and plants use these nutrients for growth. In most soils, bacteria and fungi also direct the activities of pathogens, disease causing organisms. In soils useful to plants, all these groups of organisms live together in harmony and if one or more groups are affected for whatever the reason, then we know that the soil is not very healthy. In healthy soils aerobic bacteria metabolize organic matter and release N, P, K, and other nutrients for plant use. Healthy soils contain in excess of 10 million of these bacteria per gram. Cellular respiration rate is a measure of the level of native microbial activity in soils. Microbial activity is measured as the amount of CO₂ liberated by microorganisms. The respiration rate gives a measure of how active the total microbe population are whereas other microbe tests give a measure of the population of microbes in soil. Medium to higher levels will indicate a soil useful to plants.

Aerobic cellular respiration refers to the process of converting the chemical energy of organic molecules into a form immediately usable by organisms. Glucose may be oxidized completely if sufficient oxygen is available and is summarized by the following reaction:

\[
C_6H_{12}O_6 + 6 O_2(g) \rightarrow 6 H_2O + 6 CO_2(g) + \text{energy}
\]

Often, this *energy is used to convert ADP and phosphate into ATP, useable cellular energy. All organisms, including plants and animals, oxidize glucose for energy.

Without oxygen the aerobic microbes are not able to metabolize glucose, and they become dormant or die.

THE PRESSING ISSUE OF SOIL (A CASE STUDY FOR THIS LAB)

The following is a possible situation that could be occurring at a sugar cane farm in Louisiana or at a farm in your state. If trucks drive over the crop area or hard rain beats on the soil, the soil gets compacted and most the air is pushed out. The soil becomes anaerobic. If a crop is planted and is not growing well it could be that the important aerobic microbes are not getting oxygen for their metabolism. The farmers want the biology lab to help to determine if the compression of the soil could be causing the problem with the crops. They need to report scientific
information about the problem to the Farm Bureau. This laboratory is designed to help you solve this hypothetical problem.

The amount of compression has an impact on the important aerobic microbes. Using the CO2 Gas Sensor, you will monitor the carbon dioxide produced by microbes with and without soil compression.

The following is a scenario called “A Pressing Issue” and provides more background information.

**A PRESSING ISSUE**

Rene LeBlanc owns a sugar cane farm and each year in October he plants sugar cane stalks. The sugar cane reaches maturity by summer and is harvested every September.

Last year Rene did a lot of fishing in August and September and he was late harvesting the sugar cane crop. He hired a lot of men with a lot of trucks and they got the job done by mid October. He knew he then had to plant the crop for the coming year.

“Rene,” said his partner Jean, “We will have to get the men who are harvesting the cane, to plant the new crop or else the plants won’t be strong enough by winter.”

“Jean, don’t we have to clear the area and till the ground and break it up before we plant? We have never planted without preparing the soil before.” said Rene.

“Rene, if we wait any longer we may be too late.” said Jean.

“I understand we don’t have time so let’s just plant now.” said Rene

So several months later, the sugar cane crop was not growing well and Rene’s daughter, Mignon, said, “Papa, what’s wrong with the cane. It doesn’t look like it’s growing well.”

“I don’t know, Mignon. I’ve never seen the crop this bad before.” said Rene.

“Papa, I am studying plants in Biology class and know a little about their growth. If the cane is not growing there is a reason. What did you do different this year?” said Mignon.

“I don’t know, Mignon. We harvested the old crop and planted the new crop right away. It was all planted by mid-October. The only thing we did not do is turn the soil before planting, but I doubt if that had anything to do with it. “said Rene.

“Papa, there were a lot of trucks out there during the harvest and the ground was very hard. I bet that had something to do with it, too.” Said Mignon.

“Oh, I doubt that, Mignon.” said Rene.
“Papa, I will show you why that was bad. We will test a couple soil samples and I will show you what has happened.”

Later that day Mignon showed her dad the following experiment.

**OBJECTIVES**

In this experiment, you will

- use a CO$_2$ Gas Sensor to measure concentrations of carbon dioxide during aerobic respiration.
- study the effect of compression on cellular respiration.
- determine whether soil microbes respire.
- compare the rates of cellular respiration in compress and tilled soil.

---

![Figure 1](image1.png)

![Figure 2](image2.png)

![Figure 3](image3.png)
**MATERIALS**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Macintosh or Windows PC</td>
<td>(1) 18 oz. Peter Pan Peanut Butter Sensosphere or 32 oz. pretzel bottle</td>
</tr>
<tr>
<td>Vernier computer interface</td>
<td>(1) 3/8 Inch Drill with 1-1/8 inch Drill Bit</td>
</tr>
<tr>
<td>Logger Pro</td>
<td>(1) Warm Water Bath</td>
</tr>
<tr>
<td>(1) Vernier CO₂ Gas Sensor</td>
<td>(1) Thermometer or Temperature sensor</td>
</tr>
<tr>
<td>Soil from an active garden (enough soil to fill the bottle to 1 ½ inches below sensor)</td>
<td>(1) 12 oz. Orange Crush Drink Bottle or other no deposit bottle that fits in the sensosphere to compress the soil.</td>
</tr>
<tr>
<td>(1) Plastic gallon Ziplock bag</td>
<td>(1) Balance</td>
</tr>
</tbody>
</table>

**PROCEDURE**

1. Empty the peanut butter from the 18 oz. Peter Pan Peanut Butter bottle, wash and dry it.

2. Drill a 1-1/8 inch hole in the center of the plastic lid using the drill to create a Peter Pan Peanut Butter Bottle Sensosphere. See Figures 3. (Your instructor will have this prepared for you.) Also check to see that a line is drawn on the Sensosphere that is approximately 1 ½ inches from the tip of the carbon dioxide sensor when inserted in the Sensosphere. See Figure 1.

3. Plug the CO₂ Gas Sensor into Port 1 of the Vernier computer interface.

4. Prepare the computer for data collection by opening the file in the Experiment 11B folder of *Biology with Computers*. If the sensor is not an autoID sensor, select OK from the Sensor Confirmation screen. The vertical axis has carbon dioxide concentration scaled from 0 to 5000 ppm. The horizontal axis has time scaled from 0 to 5 minutes. The data rate is set to 6 samples/minute.

5. Make a warm water bath by placing 30º – 35°C water into a water bath. Measure the warm water bath temperature using a thermometer and record the temperature in Table 1.

**Part I: Uncompressed Soil**

6. Take the mass of the Sensosphere. See Figure 2. Remove the Sensosphere from the balance and record mass below. Place slightly moist soil from an active garden into the Sensosphere (enough soil to fill the bottle to 1½ inches below sensor the sensor is screwed on the Sensosphere). There should be a line drawn on your bottle that measures 1 ½ inches from the bottom of your sensor to the top of the soil. Record the mass in Table 1. Slowly push the carbon dioxide sensor into the Sensosphere to check that the end of the sensor is 1 ½ inches from the soil. If not adjust the soil. Be careful to keep the soil off the sensor!! Remove the sensor and take the mass of the soil with the Sensosphere. You now need to subtract the mass of the Sensosphere from the total mass to get the mass of the soil. Record the mass of the soil in Table 1. Place it in the 30º-35°C water bath and let equilibrate for 3 minutes.

\[
\text{Mass of soil and Sensosphere} = \text{_______ g}
\]

\[
\text{Mass of Sensosphere} = \text{_______ g}
\]

Substrate the above to get the mass of the soil. Mass of soil = ______g
7. Place the shaft of the CO₂ Gas Sensor in the opening of the Sensosphere. Gently twist the stopper on the shaft of the CO₂ Gas Sensor into the Sensosphere opening. Do not twist the shaft of the CO₂ Gas Sensor or you may damage it.

8. Wait one minute, then begin measuring carbon dioxide concentration by clicking ? Collect (collect). Data will be collected for 5 minutes.

9. Remove the CO₂ Gas Sensor from the Sensosphere.

10. Use a notebook or notepad to fan air across the openings in the probe shaft of the CO₂ Gas Sensor for 1 minute.

11. Determine the rate of cellular respiration:
   a. Move the mouse pointer to the point where the data values begin to increase. Hold down the left mouse button. Drag the mouse pointer to the end of the data and release the mouse button.
   b. Click the Regression button, , to perform a linear regression. A floating box will appear with the formula for a best fit line.
   c. Record the slope of the line, \( m \), as the rate of cellular respiration for uncompressed soil at room temperature in Table 2.
   d. Close the linear regression floating box.

12. Move your data to a stored run. To do this, choose Store Latest Run from the Experiment menu.

**Part II: Compressed Soil**

13. Using the Orange Crush returnable drink bottle (or some other bottle) compress the soil within the Sensosphere. See Figure 3. Press and twist the bottle on the soil until it feels very hard. Let sit 3 minutes.

14. Repeat Steps 7-12 substituting the uncompressed soil with compressed soil.

**Part III: Compressed Soil That is Tilled**

15. Use a spoon and till, break up, the soil. Till the soil for 2 minutes, and place it on top of a plastic bag. Let it in the air for 3 minutes. Return the soil to Sensosphere and repeat steps 7-11.
**DATA**

<table>
<thead>
<tr>
<th>Soil condition</th>
<th>Temperature (°C)</th>
<th>Mass (g)</th>
<th>Rate of cellular respiration (ppm/s)</th>
<th>Rate of cellular respiration/mass (ppm/s/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original soil placed in container</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retiled (Broken up after compression)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**QUESTIONS**

1. Do you have evidence that aerobic cellular respiration occurs in soil? Explain.

2. Why do soil microbes need to perform cellular respiration?

3. Why are actively metabolizing soil microbes important to plants?

4. What happened to the cellular respiration rate upon compression? Explain the change. Is this detrimental to the plant? Yes or No and Why?

5. Do you think your soil sample was more or less compressed before or after the experiment? Explain.

6. Make two diagrams:
   A) the tilled soil
   B) the compressed soil.

   Include the following in your diagrams with labels: soil particles and their relative closeness, microbes and other organisms, oxygen molecules, plant roots and a sketch of the graph of respiration vs. time for each.

7. How do your cellular respiration rates of your soil sample compare to other samples tested by other groups in your lab?

8. Predict what type of cellular respiration rate would present if the soil is baked for 30 minutes at 450°F.

9. Using the data from this laboratory, make a recommendation on what you will report to the farmers about their problem, and what you think they need to do for their crops. Explain your recommendation.

**EXTENSIONS**

1. Make a PowerPoint Presentation that explains your experiment, results and your recommendations to the farmers about how they could get their crops to grow better.
2. Compare the cellular respiration rate among various types of flours and bread (white, wheat rye, sour dough, etc.).

2. Compare the cellular respiration rates among different soil samples from different areas.

3. Compare the cellular respiration rates among different composition (e.g. sandy soil vs. soil with clay).

4. Compare the cellular respiration rate among the same soil with various amounts of moisture.

REFERENCES:

Masterman, D. and Holman, S. (2000). *Biology with Computers*. Beaverton, OR: Vernier Software and Technology. (Protocols and handout format were derived from this book.)

Biological Soil Tests Definitions, e-Lab Limited, 7, July 2004
<http://www.lifestyleblock.co.nz/_general/sfs/213_Soil_Biological_Testdefinition.htm>
INTRODUCTION

Yogurt is one of the oldest milk products known, and is believed to have originated 4,000 years ago in the Middle East. It spread with the migration of herders in search of water and pastures. It has only gained popularity in the United States over the last 25 years, and could have resulted from the use of sweeteners to cover up the tart taste. Yogurt is a solid, custard-like milk product fermented with a mixture of the bacteria *Streptococcus salivarius* subspecies *thermophilis* and *Lactobacillus delbrueckii* subspecies *bulgaricus*. In yogurt fermentation, glycolysis’ end-product, pyruvic acid, is converted to lactic acid, which is the molecule that gives the tart flavor to yogurt. For each mole of lactose metabolized by these bacteria, 4 moles of lactic acid are produced. The pairing of rod and coccus is important because there is an associate benefit between the two bacteria, symbiosis. The symbiotic relationship between bacteria results when the streptococcus grows first because of its higher oxygen tolerance. As oxygen and pH drops, *Lactobacillus* completes the fermentation by metabolizing the remaining lactose and the undigested milk protein. Usually once the desired pH of 4.3 to 4.5 is attained, the fermentation is stopped with refrigeration. (Mitchell, Warden and Crum, 1999).

The following will help to compare and to contrast aerobic and anaerobic respiration. Aerobic cellular respiration refers to the process of converting the chemical energy of organic molecules into a form immediately usable by organisms. Glucose may be oxidized completely if sufficient oxygen is available and is summarized by the following reaction:

<table>
<thead>
<tr>
<th>With Aerobic Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_6H_{12}O_6 + 6 O_2(g) -&gt; 6 H_2O + 6 CO_2(g) + energy</td>
</tr>
<tr>
<td>(glucose + oxygen)</td>
</tr>
</tbody>
</table>

Often, this energy is used to convert ADP and phosphate into ATP, useable cellular energy. All organisms, including plants and animals, oxidize glucose for energy, but not all organisms use oxygen.

If oxygen is not present, the anaerobic organisms undergo fermentation, anaerobic respiration. Fermentation reactions are anaerobic, proceeding without oxygen being present. Anaerobic reactions involve cellular food products and/or glucose sugar as their reactants. Without oxygen the fermentative microbes can produce combinations of ethyl alcohol (C_2H_5OH), carbon dioxide (CO_2), and lactic acid (C_2H_4OCOOH) as their products. Anaerobic yogurt microbes produce lactic acid.
THE YOGURT SHORTAGE (A CASE STUDY FOR THIS LAB):

The following is a possible scenario that could be occurring in a frozen yogurt shop near your school campus. There is a shortage of homemade yogurt. This laboratory is designed to help you solve this hypothetical problem.

There is a big demand for fresh homemade yogurt with active yogurt cultures. During the fermentation process, the yogurt is ready to eat when the pH is 4.3 - 4.5. It takes between 4 to 6 hours to ferment the milk, and refrigeration does not stop the fermentation. Many health food groceries and yogurt shops need more fresh yogurt with active yogurt cultures. The Yogurt Palace yogurt shop near the campus thinks that temperature would be a factor to change, but they are worried about buying an incubator to increase the temperature because of the cost of the incubator. Currently they grow their yogurt at room temperature on a counter top. They think that higher temperatures will help the milk ferment faster, but are worried about the quality of the yogurt and the cost of the incubator. Your goal is to see what influence temperature has on fermentation of milk. Overall there is a shortage of fresh yogurt and many are attempting to find new ways of producing yogurt quickly. This lab will give you an opportunity to participate in the yogurt research. The following is a scenario with the details about the Yogurt Palace’s problem.

THE HEAT IS ON

“Jeanine, how are things at the yogurt shop?” asked Boudreaux.

“Fine, Boudreaux. I wish there was some way making yogurt that wouldn’t take so long. I heard about this yogurt machine that is supposed to grow yogurt faster than just letting the culture sit out all day and night. It is sort of like an incubator.” said Jeanine.

“Oh, Yeah. Sounds great! How much do they cost?”

“About $1000, but I don’t know if it’s worth the money.” said Jeanine.

“If it would help make the yogurt faster it would be worth the money. Who could you ask about it?”

I was thinking about asking the people at the yogurt company. They should know. Then, again, I could ask my sister at LSU. She has probably taught students about bacteria.” said Jeanine.

“What does bacteria have to do with it, Jeanine?”
“Yogurt is a fermented milk product. Those special bacteria undergo fermentation with milk and lactic acid forms that causes thickening. Raising the temperature just right speeds up the process without killing bacteria.” said Jeanine. “My sister would be able to tell me how much faster the yogurt would take to culture.”

Later that day Jeanine said, “Boudreaux, my sister called me back and said it is easy to test the yogurt and we can test it right here in the kitchen. This is all we have to do…”

**OBJECTIVES**

You will

- Establish incubation temperature
- Compare the rates of fermentation of microbes during fermentation at different temperatures by comparing changes in pH
- Determine environment suitable for yogurt microbes

You will be able to monitor microbe growth, and environmental conditions with the pH, and Thermometer Sensors. Using your collected data, you will determine the difference in the rates of fermentation at various temperatures to answer this question concerning temperature and the fermentation of milk in the production of yogurt.

**MATERIALS**

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Macintosh or Windows PC</td>
<td>(1) half gallon (64 oz) of Grade A pasteurized milk</td>
</tr>
<tr>
<td>Vernier computer interface</td>
<td>(21) plastic Solo cups (approximately 8 oz)</td>
</tr>
<tr>
<td>Vernier Logger Pro</td>
<td>(1) roll aluminum foil or cup tops</td>
</tr>
<tr>
<td>(1) Vernier pH Sensor</td>
<td>Freeze-dried powdered yogurt culture available at the New England Cheese-making supply Company (<a href="http://www.cheesemaking.com">www.cheesemaking.com</a> and specifically <a href="http://www.cheesemaking.com/default-cPath-36_43.php">http://www.cheesemaking.com/default-cPath-36_43.php</a> or Yogourmet freeze dried yogurt starter available at most health food stores (Enough culture for a half gallon of milk)</td>
</tr>
<tr>
<td>(1) Vernier Stainless Steel Thermometer (or Traditional Thermometer)</td>
<td>Constant room temperature area at about 20° C</td>
</tr>
<tr>
<td>(2) Warm water baths –electric fry pan</td>
<td>100 ml Distilled Water</td>
</tr>
<tr>
<td>(1) Refrigerator at Approximately 10° C or large ice chest with ice</td>
<td>(Optional)Yogurt-plain with active yogurt cultures (various brands)</td>
</tr>
<tr>
<td>(1) one-cup measuring cup</td>
<td>(1) container or pot to boil milk</td>
</tr>
</tbody>
</table>

**PROCEDURE**

There are 2 parts to the lab set-up:
PART 1: MAKING YOUGUT AND SETTING UP INCUBATION CONDITIONS

PROCEDURE

A. Preparation of the Culture.

For best results, use freeze dried yogurt starter and follow the directions provided. The overall preparation involves the following:

1) Heat milk to at least 82° C, and then cooling it to 42-44° C.

2) The starter culture is usually dissolved in a small amount of warm milk and then mixed into the full amount of 42° C milk.

3) Pour 3 oz. of the inculcated milk into twenty-one (21) 8 oz containers and cover with aluminum foil.

4) The inoculated milk is then incubated at various temperature for this lab.

Optional Preparation Method:
Use preprepared plain yogurt (Dannon, Bryers or any of the other brands) with active yogurt cultures can be purchased from most groceries and used as a starter. Boil and cool the milk as described above. Mix equal portions of milk and preprepared yogurt. It will take almost 24 hours to accomplish full fermentation. The freeze-dried starter culture is more predictable and quicker.

B. Preparation of 3 Incubation Conditions:

1) Room Temperature: Place six 3 oz. containers of inoculated milk in an area of the room that has rather constant temperature of approximately 18-23 °C. Measure the temperature and record it in Table 1. Label each of these containers room temperature with the exact temperature, and record the start time (start time = ___________).

2) Warm Temperature: Place six 3 oz. containers of inoculated milk in a warm bath that has a temperature of about 42 °C. Measure the temperature and record it in Table 1. An electric fry pan with water that is set on the lowest setting usually good for this temperature. Instead of a fry pan, a heating pad with a blanket over the containers also provides the needed heat. Label each of these containers warm temperature with the exact temperature, and record the start time (start time = ___________).

3) Extra Warm Temperature: Place six 3 oz. containers of inoculated milk in a warm water bath that has a temperature of about 52°C. Measure the temperature and record it in Table 1. An electric fry pan with water that is set on slightly higher than the lowest setting usually good for
this temperature. Instead of a fry pan, a heating pad with a blanket over the containers also provides the needed heat. Label each of these containers extra warm temperature with the exact temperature, and record the start time (start time = ______________).

*Note: You will remove one container from each of the above conditions at specific times and place into a refrigerator to stop the incubation. See Collecting Samples section below for times.

4) Cold Temperature: Place three 3 oz. containers of inoculated milk in a refrigerator that has a temperature of about 10°C. Measure the temperature and record it in Table 1, and record the start time (start time = ______________).

PART 2: TRACKING FERMENTATION WITH PH SENSOR

People have developed many ways to prevent food spoilage that use fermentation and yogurt is one of them. Yogurt has a longer shelf life than milk.

As the anaerobic microbes grow and reproduce, they produce lactic acid. As a result of the fermentation of lactose, milk sugar. Using the pH Sensor, you will monitor the production of lactic acid, which also indicates the growth and fermentation of the microbes. You will also check the temperature of the environment.

PROCEDURE

PART A: COLLECTION OF SAMPLES

1) Place one container from conditions 1-3 (room temperature, warm and extra warm) into the refrigerator at the following times: 30 min, 1.5 hrs, 3.0 hrs, 4.5 hrs, 6.0 hrs and 24 hrs. Use these samples from the various temperatures and times for Part B. Different groups will be assigned different temperature conditions to collect data. Be sure to allow your samples to warm to room temperature to take the pH readings. All samples should be at the same temperature. Take the pH readings as soon as they equilibrate to room temperature.

PART B. COLLECTING PH DATA

1. Plug the Temperature Sensor into Channel 1 of the LabPro or CBL 2 interface. Use the link cable to connect the TI Graphing Calculator to the interface. Firmly press in the cable ends. Then plug a pH Sensor into Channel 2 of the LabPro or CBL 2 interface.

2. Turn on the calculator and press APPS and select the DATAMATE program. Press CLEAR to reset the program.

3. Set up the calculator and interface for the pH Sensors.
   q. Select SETUP from the main screen.
   r. If CH 1 displays THERMOMETER, proceed directly to Step 4. If it does not, continue with this step to set up your sensor manually.
   s. Press ENTER to select CH 1.
   t. Select THERMOMETER from the SELECT SENSOR menu.
u. Press ▼ once, then press ENTER to select CH2.
v. Select PH from the SELECT SENSOR menu.

4. Measure pH of your yogurt samples of the temperature that your group was assigned. Be sure to allow your samples to warm to room temperature to take the pH readings. All samples should be at the same temperature. Take the pH readings as soon as they equilibrate to room temperature.

k. Remove the pH probe from its storage bottle. Rinse the probe tip with distilled water and dab it dry with a paper towel. Place the probe into the yogurt sample.
l. Select START to begin sampling.
m. After 10 seconds, the pH value will appear on the screen.
n. Record data in Table 1.
o. Press ENTER to return to the main screen.

5. Rinse pH sensor with distilled water into a cup and then take pH of the next sample. Store pH sensor in distilled water.

6. After taking last pH, rinse well and place probe back into storage bottle.

DATA

<table>
<thead>
<tr>
<th>Time</th>
<th>Room Temp. (° C)</th>
<th>pH</th>
<th>Warm Temp. (° C)</th>
<th>pH</th>
<th>Very Warm Temp. (° C)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 hrs (30 min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5 hours</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>3 hours</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>4.5 hours</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>6 hours</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>12 hours</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

QUESTIONS
1. What causes the production of the lactic acid?
2. Why are 2 different types of bacteria used in the fermentation?
3. a. What is the evidence that fermentation occurred in the milk?
   b. Explain why fermentation of milk does not occur in fresh pasteurize milk.
4. Why do microbes undergo cellular respiration?
5. What is the influence of lactic acid on the growth and cellular respiration of the microbes?
6. What is the influence of temperature on the rate of cellular respiration in microbes? Explain.
7. What evidence do you have that microbes are reproducing? Explain.
8. Make a graph of pH vs. Time (use Graphical Analysis, Excel or graph paper). During what time period is the production of lactic acid the greatest?

9. What evidence do you have that lactic acid is being produced? Explain.

10. Make a graph of pH vs. Time using Logger Pro, Graphical Analysis, Excel or graph paper.

   A) If yogurt is best to eat when the pH is 4.3, what time is it best to eat the yogurt if it is made at:
      a. room temperature
      b. warm temperature
      c. very warm temperature
      d. Explain your answers.

   B) What time period is lactic acid production the greatest at each of the following temperatures:
      a. room temperature
      b. warm temperature
      c. very warm temperature
      d. Explain your answers.

11. Using the data from this laboratory, make a recommendation on what you think the owner of the Yogurt Palace could do to modify their procedure to make yogurt faster. Explain your recommendation.

EXTENSIONS
1. Compare the various milks and rates of fermentation by using the following milk: soy, goat, skim, and low fat.

2. Compare making yogurt at different starter culture concentrations including freeze-dried cultures vs. prepared yogurt from the grocery as starter cultures

3. Compare making yogurt with different sugar concentrations.

4. Compare using boiled milk and unboiled milk with the starter culture.

5. Make a PowerPoint Presentation that explains your experiment, results and your recommendations to the owner of the Yogurt Palace about how they could make yogurt faster. Include at least one (1) animation.
REFERENCES:


Making Chloroplast Models
Junior Mint® Chloroplast Model Study Kit

©2004
by: Jewel Reuter

This procedure allows one to build either a large or small chloroplast model.

**Large Chloroplast Model**

**Material:**
- 2 large aluminum disposable turkey baking pans
- 16 diner size paper plates
- 1 can of black spray paint
- 1 can of green spray paint
- 2 rolls of 2-sided tape
- 1 roll of clear masking tape
- 1 pair scissors

**Procedure:**
> Lay the paper plates down so that the bottom side is up.
> Paint the outside (bottom) of each paper plate. Paint 8 paper plates black and 8 paper plates green.
> Allow the paper plates sufficient time to dry.
> Cut one of the paper plates on half
> Tape the two halves together painted side out edge to edge to make a semicircle.
> Tape all the black plates together painted side out edge to edge to make three circles.
> Tape all the green plates together painted side out edge to edge to make four circles.
> Tape 3 black plates together in a stack and tape the semicircular plate to the top of the stack.
> Tape 4 green plates together in a stack to form a grana.
> Position the 2 stacks of 4 plates inside a turkey pan to simulate the chloroplast
> Tape the plates to the turkey plate with masking tape in two directions to freely support the paper plates.
> Cover the plate by placing the other turkey pan untapped on the top of the other turkey pan.

**Small Chloroplast Model: Junior Mint® Chloroplast Model Study Kit**

**Material:**
- 2 disposable aluminum potato baking dishes
- 8 Junior Mints®
- 1 roll clear tape
- 1 plastic knife

**Procedure:**
> Stack the junior mints 4 mints high.
> Tape the mints together with clear tape. Be careful not to hold the mints too tight or they will crush.
> Repeat the above steps with the remaining 4 mints.
> Position the two 4-mint stacks in the potato dish.
> Tape the 4 mint high stack carefully in the proper position in the potato dish.
>Tape the other 4-mint stack in its proper position.
>Cut one of the two top mints in half along its cross section with the plastic knife
>Place do not tape the other potato dish over the bottom potato di
Model of Mitochondrion Activity

© 2003
by: Jewel Reuter

Materials
1 Golden Yukon or Red Potato
2 Cup Cake Holders of Proper Dimension for the Potato
1 Melon Ball Scooper
1 Knife
10 Sewing Pins with Large Plastic Heads
10 Sewing Pins with Medium Plastic Heads
10 Sewing Pins with Small Metal Head
1 of Each of the Following Labels Printed

Methods
1. Cut potato lengthwise (along its longest length)
2. Scoop out most of the center of both halves of the potato with the melon ball scooper (leaving about 1/4 - 3/8 inch of the potato to form the space between the inner and outer membranes).
3. Line the inside of the cored potato with the cup cake holders.
   Place the large headed pins through the cup cake holders and with the pin heads facing the hollowed area.
4. With the labels identify: outer membrane, inner membrane, matrix, ATP synthase and cristae using the above labels.
5. Identify the area where the H+ ions accumulate during respiration to allow for chemiosmosis.
   Place the small metal head pins in that area. Place the H+ ion label near the pins.
6. Optional: Take a picture of your model and color the above labels.

Questions:
Use your model and your textbook to answer the following questions.

1. What is the function of ATP synthase?
2. Explain chemiosmosis using your labeled model.
3. Where is the electron transport chain located?
4. What is the final electron receiver in the electron transport chain?
5. Where does the Krebs Cycle occur?
6. What are the functions of the cristae?
7. Make a labeled diagram of your mitochondrion model.
The Ultra Structure of the Chloroplast and Mitochondrion

©2004
BY: JEWEL REUTER

Mitochondrion Electron Micrograph


Chloroplast Electron Micrograph

http://neptune.gsfc.nasa.gov/~branc/chloro.html
Radionuclides and Autoradiographs
Applications for Understand Photosynthesis and Respiration

©2004
by: Jewel Reuter

\[ 6\text{CO}_2 + 6\text{H}_2\text{O} \xrightarrow[\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2]{} \]

A) Use the materials provided (magnet and iron filings) to simulate the use of radionuclides (\(^{14}\text{C}, {}^{3}\text{H}, {}^{18}\text{O}\)) and autoradiographs to trace the path of designated atoms.
B) Explain the path of the atom of the molecules and the reactions that occur in various locations.
C) Name the destination molecule of the atom traced.
D) Is sun required in the process you are tracing? Explain.

1) in \(\text{O}_2\) in photosynthesis.
2) in \(\text{H}_2\text{O}\) in respiration.
3) in \(\text{H}_2\text{O}\) in photosynthesis.
4) \(\text{O}_2\) in respiration.
5) in \(\text{H}_2\text{O}\) in photosynthesis.
6) in \(\text{C}_6\text{H}_{12}\text{O}_6\) in respiration.
7) Which image(s) are of highest magnification?
8) Which image(s) are light micrographs?
9) What do the iron filings represent in each example and how does this relate to the autoradiographs?
10) Why do plants need to do photosynthesis and respiration?
11) How do the images and simulation activities help you to understand photosynthesis and respiration?

A radioactive nuclide. The term nuclide implies an atom of specified atomic number and mass number. In the study of biochemical processes, radioactive isotopes are used for labelling compounds that subsequently are used to investigate various aspects of the reactivity or metabolism of proteins, carbohydrates and lipids or as sources of radiation in imaging. The fate of the radionuclide in reactive products or metabolites is determined by following (counting) the emitted radiation. Prominent among the radionuclides used in biochemical research are: \(^{3}\text{H}, {}^{14}\text{C}, {}^{18}\text{O}, {}^{32}\text{P}, {}^{35}\text{Ca}, {}^{99m}\text{Tc}, {}^{125}\text{I}\) and \(^{131}\text{I}\).

An autoradiograph. An image produced on a photographic film or plate by the radiations from a radioactive substance in an object which is in close contact with the emulsion.
One Minute Rapid Fire Chloroplast Quiz

© 2004 by Jewel Reuter

One Minute Rapid Fire
Name________________

Chloroplast Quiz
Date______________

1. The Chocolate Covering of Jr. Mints represents which structure of the chloropl
   ________________

2. the White Mint Center of Jr. Mints represents which structure of the chloropl
   ________________

3. What color is the chloroplast in most plant cells? ________________

4. What is the color of the thylakoid membrane in the electron micrograph? __________

5) What color is the lumen in the electron micrograph? ________________

6) Why are the transmission electron micrographs black and white in color?

Answers:
1) thylakoid membrane
2) lumen
3) green
4) black (dark)
5) white (light)
6) a) preparation and b) viewing methods
APPENDIX T:

COMPARISON GROUP TRADITIONAL LABS AND ACTIVITIES
Visualizing the Oxygen Produced by *Elodea*

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by: Jewel Reuter

Visible light is part of the electromagnetic spectrum. The shorter wavelengths, violet light, have more energy than the longer wavelengths, red light. Absorption spectra of chlorophyll show that most green plants absorb red and violet light. Chlorophyll is a pigment which composes photosystem I and II. When chlorophyll absorbs light, water is split into protons, electrons and oxygen and electrons with each of the two photosystems jump to higher energy levels, and energy is used to produce ATP and NADPH. The Calvin cycle requires ATP and NADPH to fix carbon, the incorporation of carbon dioxide into organic compounds. The production of oxygen is indicator of the splitting of water and the activity of the light reaction. If the oxygen is rapidly produced it can be trapped in the water surrounding water plants. Research of has shown that bicarbonate ions increase the activity of photosystem II.

The following lab will help you visualize the byproduct of the light reaction of photosynthesis.

**Materials:**
- 2 Plastic cup
- 0.2% sodium bicarbonate (NaHCO₃)
- 2 large test tube
- 2 *Elodea* stems

**Procedure**

**Part A: Experimental Set-Up**

1. Fill 2 large plastic cup to about half full with sodium bicarbonate solution.
2. Place the 2 *Elodea* plant in two separate large test tube with the cut stem at the opening.
3. Fill the tubes with bicarbonate so that it is just overflowing.
4. Hold your finger over the mouth of the tube. Turn the tube over, and lower it into the bottom of the cup with bicarbonate. Be certain that no air is trapped in the tube.
5. Place one cup under light and cover the other with aluminum foil.
6. Observe. After at least 20 minutes, look closely at the *Elodea* leaves. Record your observations.
Analysis

1. Describe the appearance of the leaves after it was in the light and the dark.

2. What substance do you think is accumulating? Should that substance be considered a byproduct?

3. Explain how the substance is being produced and the importance of the process to photosynthesis.

3. Make a labeled diagram of the organelle that produces the substance. Identify the location of the production of this substance.

4. Explain the advantages of the experimental set-up for observing this byproduct.
Visible light is part of the electromagnetic spectrum. The shorter wavelengths, violet light, have more energy than the longer wavelengths, red light. Absorption spectra of chlorophyll show that most green plants absorb red and violet light. Chlorophyll is a pigment which composes photosystem I and II. When chlorophyll absorbs light, water is split into protons, electrons and oxygen and electrons with each of the two photosystems jump to higher energy levels, and energy is used to produce ATP and NADPH. The Calvin cycle requires ATP and NADPH to fix carbon, the incorporation of carbon dioxide into organic compounds. The production of oxygen is indicator of the splitting of water and the activity of the light reaction. If the oxygen is rapidly produced it can be trapped in the mesophyll cell in the leaf and thus cause the leaf to float if in water. Research of has shown that bicarbonate ions increase the activity of photosystem II.

The following lab will help you visualize the conditions that are most suitable for the light reaction to occur.

**Materials:**

- Fresh spinach
- 0.2% sodium bicarbonate (NaHCO₃)
- 250 ml flask or cup
- syringe as vacuum source
- #3 Cork borer or hole puncher
- Glass stir rod or spoons
- 6 Petri dishes
- 2 Reflector lamps
- 2 Support stands for lamps
- 2 1L or 2L beakers
- Forceps
- Cutting board
Procedure

Part A: Experimental Set-Up

Keep everything in the drawer and in the dark. Keep the lights on the table turned off.

1. Attach the fluorescent lamp to the support stand so that the lamp is approximately 25cm from the base. If an incandescent source is used, fill large beaker with cold water to act as a heat filter for the dish you will place under the lamp.

2. Pour 0.2% NaHCO$_3$ solution into 4 Petri dishes, making them 2/3 full. Pour NaHCO$_3$ solution into a 250-mL flask or cup.

Part B: Spinach leaf disks

3. Use spinach leaves and cut 40 to 50 discs with a cork borer, not including the large veins. Ten disks are needed per set-up. Not all will work (not all will sink), so cut 12-15 for each set-up.

4. Put the disks immediately into a Petri dish with bicarbonate buffer. (Do not keep the spinach leaves outside. They wilt and then cannot be cut.)

5. When all the disks have been cut, transfer them all into a syringe with bicarbonate buffer in it. Do not damage the disks. Use a spatula or spoon provided to transfer the disks from the Petri dish to the syringe.

6. Now insert the plunger and point the syringe upward and push out all the air.

Create a vacuum within the syringe by putting your finger over the syringe tip and pull back on the plunger. Pull back a little at a time so as not to damage the disks.

While still under vacuum remove your finger from the syringe tip. As the vacuum is released, the leaf disks fill with the bicarbonate buffer.

Repeat until all the disks sink in the buffer. Not all of the disks will sink. There needs to be approximately 10 disks for each of the 4 set-ups.

7. Use a spatula or spoon to remove those disks that float. Pour the rest of the disks into a Petri dish.

8. Discard floating discs.

Part C: Final Set-Up

9. Now transfer 10 disks to each set-up. You may need to tap the disks with a spatula or spoon for them to sink (surface tension of the water).

Set 1: Place one set directly in the light, and label it Set 1.
Set 2: Place one set in with one layer of screen wrapped around it and label it Set 2.
Set 3: Place one set in with two layers of screen wrapped around it and label it Set 3.
Set 4: Place one set in the dark by wrapping in aluminum foil, and label it Set 4.

10. Place all under the light for a controlled setting.

11. Turn on the light on the table.

13. Note the time:___________

**Part D: Observing the photosynthetic efficiency in different colors of light and in the presence of different drugs**

13. Note the number of disks that rise to the surface at the various times and note the number in the Table 1 and the percentage in Table 2.

<table>
<thead>
<tr>
<th>Time Started:</th>
<th>Table 1: Number of disks that rise to the surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time lapsed</td>
<td>1 min  2 min  3 min  4 min  5 min  10 min  15 min  20 min</td>
</tr>
<tr>
<td>Condition</td>
<td></td>
</tr>
<tr>
<td>Set 1: full light</td>
<td></td>
</tr>
<tr>
<td>Set 2: 1 screen</td>
<td></td>
</tr>
<tr>
<td>Set 3: 2 screens</td>
<td></td>
</tr>
<tr>
<td>Set 4: Dark</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time Started:</th>
<th>Table 2: Percent of disks that rise to the surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time lapsed</td>
<td>1 min  2 min  3 min  4 min  5 min  10 min  15 min  20 min</td>
</tr>
<tr>
<td>condition</td>
<td></td>
</tr>
<tr>
<td>full light</td>
<td></td>
</tr>
<tr>
<td>1 screen</td>
<td></td>
</tr>
<tr>
<td>2 screens</td>
<td></td>
</tr>
<tr>
<td>_____</td>
<td></td>
</tr>
</tbody>
</table>
PART E: Clean Up

14. Wash out all the beakers and wash the spinach discs down the drain

PART F: Questions:

1. What is the function of placing suction on the disks with the syringe?

2. What is the purpose of the sodium bicarbonate in the lab?

3. What are the purposes of the chlorophyll and light?

4. What is the source of the oxygen that is released in the experiment? Explain. Spinach -3

5. What evidence do you have that oxygen was released in some experimental conditions?

6. What is the effect of each condition on photosynthesis and explain each?

7. A) Explain what would the absence of oxygen production indicates? B) Explain what would happen to the plant if no oxygen was being produced and why.

References:


Carbon dioxide is required for the Calvin cycle. The carbon of carbon dioxide is fixed into glyceraldehyde-3-phosphate which is then converted to various organic compounds. The carbon dioxide that humans produced is used by autotrophs.

The following lab will help you visualize the consumption human carbon dioxide in the Calvin cycle of photosynthesis.

**Materials:**

- 2 Clear plastic cups
- Bromthymol blue solution
- 2 large test tube
- 2 Elodea stems
- 2 straws
- Goggles

**Procedure**

**Part A: Experimental Set-Up**

1. Fill 2 large test tubes about half full with bromthymol blue solution.

2. Place a straw into each solution and blow until the solution turns yellow. (CAUTION: Do not inhale through the straw.)

3. Place the 2 Elodea plant in two separate large test tube with the cut stem at the opening.

4. Observe. Record your observations.

5. Place one cup under light and cover the other with aluminum foil. Place each into a clear cup for stability.

6. Observe. After at least 20 minutes, look closely at the color of the bromthymol solution. Record your observations.

**Analysis**

1. Describe the appearance of the bromthymol blue after it was in the light and the dark with the
Elodea.

2. What substance do you think is being consumed? Should that substance be considered a reactant of photosynthesis?

3. Explain what the substance is being used for and the importance of the process to photosynthesis.

3. Make a labeled diagram of the organelle that uses the substance. Identify the location of the use of this substance.

4. Explain the advantages of the experimental set-up for observing the use of this reactant and how it can help you to relate photosynthesis to your daily life.
Basic Fermentation BioKit® Student Guide
(Carolina, 2005)
Firefly Bioluminescence BioKit®
Student Guide
(Carolina, 2005)
Lab Four: Plant Pigments and Photosynthesis
(CEEB, 2001)
Lab Five: Cell Respiration
(CEEB, 2001)
Lab Twelve: Dissolved Oxygen and Aquatic Primary Productivity
(CEEB, 2001)
Biology Lab Report Format

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by: Jewel Reuter

- **Title:** Feel free to be creative with your titles, but make certain that it gives your reader an idea of the nature of your experiment. You must include your section, date of the experiment and your lab partners.

- **Introduction:** This is a brief section that should include the purpose of the experiment and any background information necessary for the lab report. Even though this section must appear after the title, it is often a good idea to write this section after you have written the rest of your lab report. That way you will have a good idea what terms need to be defined in your introduction.

- **Hypothesis:** This is a section in which you briefly state your prediction and reasoning.

- **Materials:** Writing "see attached sheet" is usually sufficient. However, if there are any changes to the written Materials, this is the place to note any changes. **Methods:** Again, writing "see attached sheet" is usually sufficient unless there are changes to be made to the lab sheet.

- **Data:** This is the place for all observations made during the experiment. Even if you choose to rewrite your data for ease of reading, you must include your original data. This is also the portion that will include graphs and tables. These graphs and tables must include a sentence or two to summarize the data noting any trends (For instance "Notice that as the volume decreases, the circumference increases."). This is not the place for interpretation. If you find yourself using the phrases "this is because..." or "the reason..." you are writing material that belongs in the next section.

- **Discussion:** This is probably the most challenging section to write. This must be written in paragraph form and is the only section that will involve any interpretation of the data. The general rule of thumb is to never write factual information that is new. Every bit of factual information in your discussion must be found either in your introduction or in your data. This is the place for you to convince your reader that, in light of your background understanding of the material, the data does or does not make sense. You must also explain why the data does or does not make sense and what possible sources of error might exist. You should also try to suggest a follow-up experiment that could further clarify your understanding of the material or even improve the experiment as presented. Furthermore, there will often be discussion questions to be answered included on the lab insturction sheet that must be included within the body of your discussion. If there is any part that is best to hand in by itself as a rough draft, it is probably this section.

- **Conclusion:** Briefly state your conclusion.

- **Bibliography:** It is vital that you credit any resources that helped you in the writing of the lab report. Follow the guidelines as given in your English class.

Adapted from:
http://intranet.dalton.org/departments/Science/Biology1/lab_guidelines.html
# Lab Report Rubric

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by: Jewel Reuter

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scientific Concepts</strong></td>
<td>Report illustrates an accurate and thorough understanding of scientific concepts underlying the lab.</td>
<td>Report illustrates an accurate understanding of most scientific concepts underlying the lab.</td>
<td>Report illustrates a limited understanding of scientific concepts underlying the lab.</td>
<td>Report illustrates inaccurate understanding of scientific concepts underlying the lab.</td>
</tr>
<tr>
<td><strong>Question/Purpose</strong></td>
<td>The purpose of the lab or the question to be answered during the lab is clearly identified and stated.</td>
<td>The purpose of the lab or the question to be answered during the lab is identified, but is stated in a somewhat unclear manner.</td>
<td>The purpose of the lab or the question to be answered during the lab is partially identified, and is stated in a somewhat unclear manner.</td>
<td>The purpose of the lab or the question to be answered during the lab is erroneous or irrelevant.</td>
</tr>
<tr>
<td><strong>Experimental Hypothesis</strong></td>
<td>Hypothesized relationship between the variables and the predicted results is clear and reasonable based on what has been studied.</td>
<td>Hypothesized relationship between the variables and the predicted results is reasonable based on general knowledge and observations.</td>
<td>Hypothesized relationship between the variables and the predicted results has been stated, but appears to be based on flawed logic.</td>
<td>No hypothesis has been stated.</td>
</tr>
<tr>
<td><strong>Experimental Design</strong></td>
<td>Experimental design is a well-constructed test of the stated hypothesis.</td>
<td>Experimental design is adequate to test the hypothesis, but leaves some unanswered questions.</td>
<td>Experimental design is relevant to the hypothesis, but is not a complete test.</td>
<td>Experimental design is not relevant to the hypothesis.</td>
</tr>
<tr>
<td><strong>Variables</strong></td>
<td>All variables are clearly described with all relevant details.</td>
<td>All variables are clearly described with most relevant details.</td>
<td>Most variables are clearly described with most relevant details.</td>
<td>Variables are not described or the majority lack sufficient detail.</td>
</tr>
<tr>
<td><strong>Procedures</strong></td>
<td>Procedures are listed in clear steps. Each step is numbered and is a complete sentence.</td>
<td>Procedures are listed in a logical order, but steps are not numbered and/or are not in complete sentences.</td>
<td>Procedures are listed but are not in a logical order or are difficult to follow.</td>
<td>Procedures do not accurately list the steps of the experiment.</td>
</tr>
<tr>
<td>Data</td>
<td>Professional looking and accurate representation of the data in tables and/or graphs. Graphs and tables are labeled and titled.</td>
<td>Accurate representation of the data in tables and/or graphs. Graphs and tables are labeled and titled.</td>
<td>Accurate representation of the data in written form, but no graphs or tables are presented.</td>
<td>Data are not shown OR are inaccurate.</td>
</tr>
<tr>
<td>------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Analysis</td>
<td>The relationship between the variables is discussed and trends/patterns logically analyzed. Predictions are made about what might happen if part of the lab were changed or how the experimental design could be changed.</td>
<td>The relationship between the variables is discussed and trends/patterns logically analyzed.</td>
<td>The relationship between the variables is discussed but no patterns, trends or predictions are made based on the data.</td>
<td>The relationship between the variables is not discussed.</td>
</tr>
<tr>
<td>Conclusion</td>
<td>Conclusion includes whether the findings supported the hypothesis, possible sources of error, and what was learned from the experiment.</td>
<td>Conclusion includes whether the findings supported the hypothesis and what was learned from the experiment.</td>
<td>Conclusion includes what was learned from the experiment.</td>
<td>No conclusion was included in the report OR shows little effort and reflection.</td>
</tr>
<tr>
<td>Appearance/Organization</td>
<td>The layout is aesthetically pleasing and contributes to the overall message with appropriate use of headings and subheadings and white space.</td>
<td>The layout uses horizontal and vertical white space appropriately.</td>
<td>The layout shows some structure, but appears cluttered and busy or distracting with large gaps of white space or uses a distracting background. Formatting does not help visually organize the material.</td>
<td>The layout is cluttered, confusing, and does not use spacing, headings and subheadings to enhance the readability.</td>
</tr>
<tr>
<td>Calculations</td>
<td>All calculations are shown and the results are correct and labeled appropriately.</td>
<td>Some calculations are shown and the results are correct and labeled appropriately.</td>
<td>Some calculations are shown and the results labeled appropriately.</td>
<td>No calculations are shown OR results are inaccurate or mislabeled.</td>
</tr>
<tr>
<td>Drawings/Diagrams</td>
<td>Clear, accurate diagrams are included and make the experiment easier to understand. Diagrams are labeled neatly and accurately.</td>
<td>Diagrams are included and are labeled neatly and accurately.</td>
<td>Diagrams are included and are labeled.</td>
<td>Needed diagrams are missing OR are missing important labels.</td>
</tr>
</tbody>
</table>
Leaves are especially adapted for absorbing light and regulating gas exchange.

The Tangerine Section Model of Guard Cells:
The tangerine sections are excellent models of guard cells. When the guard cells are swollen, the stoma is open and when the guard cells are limp or flaccid, the stoma is closed. Soak tangerine sections in a saturated salt solution for a few hours. Place two flaccid sections on the overhead projector and two turgid sections (unsoaked) on the overhead projector to form open and closed stomata.

You can compare the model to Wandering Jew guard cells observed directly under the microscope.

Real Guard Cells and Stomata Without Preparation:
The Tradescantia of choice for this study has purple leaves, and the guard cells are green. Place the leaf on the stage of the microscope. No preparation is needed. Focus and you will see the guard cells. To compare open and closed stomata, place some leaves in the dark and some leaves in the light for 24 hours. Then compare the stomata. The leaves in the light will have open stomata and the ones from the dark will have closed stomata.

Students can design various lab to test the factors that influence the guard cells.
APPENDIX U:

POWERPOINT® TOOLBOXES, AND STUDENT WORK
Use the following toolbox of images to do the following task:

- Make a title slide.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order.
What’s Happening with the Data While Making Kimchee?

By:
Your Name(s)

Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize the anaerobic conditions.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.
Very salty solutions create anaerobic conditions.

Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize the phyllosphere.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.
Make a labeled diagram of the phyllosphere community of microbes.

Cabbage Leaf

Bacterium of Phyllosphere

Use the Following Toolbox of images to Accomplish the following task:

- Create a label diagram that helps your audience visualize why the Kimchee brine solution gets bubbly.
- Use the following title, image and labels from the next 2 slides. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation.
Why does the brine solution get bubbly?

1. CO₂ (gas) is one product of heterofermentation.
2. CO₂, lactic acid, ethanol, and net 2 ATP

Anaerobic Bacterium

Glucose

Lactic acid

Ethanol

Carbon dioxide

ATP
Recommendation to Restaurant

- Create a set of instructions for the restaurant chef to follow.
- Justify your recommendation with your laboratory findings.

The Finishing Touches to Your Presentation

- Add slide transitions and adjust timings.
- Preview it and make edits.
- Save presentation to designated location.
- Print a handout of your slides.
Use the following toolbox of images to do the following task:

- Make a title slide.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order.
What’s Happening with the Data While Making Kimchee?

By:
Baxter and Brooke

Use the following toolbox of images to do the following task:

☐ Create a label diagram that helps your audience visualize the anaerobic conditions.
☐ Use the following title, image and labels. You may add extra items.
☐ Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.
Very salty solutions create anaerobic conditions.

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- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.
Make a labeled diagram of the phyllosphere community of microbes.

Cabbage Leaf

Bacterium of Phyllosphere

Use the Following Toolbox of images to Accomplish the following task:

- Create a label diagram that helps your audience visualize why the Kimchee brine solution gets bubbly.
- Use the following title, image and labels from the next 2 slides. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation.
Why does the brine solution get bubbly?

CO\textsubscript{2} (gas) is a product of heterofermentation.

\[ \text{C}_6\text{H}_12\text{O}_6 \rightarrow \text{CO}_2, \text{lactic acid, ethanol and net 2 ATP} \]

http://www.ex.ac.uk/compbio/ijnwess/BCB18/Handout6.pdf
Recommendation to Restaurant

- Seal a mixture of fresh cabbage, salt, and water within a container in which little to no O2 is present.
- Given time and warm conditions, reactions will occur which will cause fermentation and the creation of kimchee.
- The warm environment allows the formation to be quicker.
- It is advisable to measure the pH of the kimchee at different intervals in creation to determine when it has finished.
- A CO2 sensor can be used to make sure the fermentation process is running smoothly.

The Finishing Touches to Your Presentation

- Add slide transitions and adjust timings.
- Preview it and make edits.
- Save presentation to designated location.
- Print a handout of your slides.
Use the following toolbox of images to do the following task:

- Make a title slide.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order.
What’s Happening with the Data While Making Kimchee?

By: Beth and Bunny

Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize the anaerobic conditions.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.
Very salty solutions create anaerobic conditions.

Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize the phyllosphere.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.
Make a labeled diagram of the phyllosphere community of microbes.

Cabbage Leaf
Bacterium of Phyllosphere

Use the Following Toolbox of images to Accomplish the following task:

- Create a label diagram that helps your audience visualize why the Kimchee brine solution gets bubbly.
- Use the following title, image and labels from the next 2 slides. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation.
Why does the brine solution get bubbly?

CO₂ (gas) is one product of heterofermentation.

C₆H₁₂O₆ → CO₂, lactic acid, ethanol and net 2 ATP

Anaerobic Bacterium

[Diagram showing a chemical reaction with glucose and products]
Recommendation to Restaurant

☐ Pack and seal fresh cabbage with a salt water solution in a tight container, making sure that it is airtight.
☐ Allow to ferment.
☐ Use CO2 sensors to test that there is CO2 production and microbes still alive, and pH tests to ensure increasing acidity of the kimchee.

The Finishing Touches to Your Presentation

☐ Add slide transitions and adjust timings.
☐ Preview it and make edits.
☐ Save presentation to designated location.
☐ Print a handout of your slides.
Use the following toolbox of images to do the following task:

- Make a title slide.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order.
What’s Happening with the Data While Making Kimchee?

By:
Bella and Bertha

Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize the anaerobic conditions.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.
Very salty solutions create anaerobic conditions.

Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize the phyllosphere.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.
A phyllosphere community of microbes.

Cabbage Leaf
Bacterium of Phyllosphere

Use the Following Toolbox of images to Accomplish the following task:

- Create a label diagram that helps your audience visualize why the Kimchee brine solution gets bubbly.
- Use the following title, image and labels from the next 2 slides. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation.
Why does the brine solution get bubbly?

$\text{CO}_2 (\text{gas})$ is one product of heterofermentation.

- CO$_2$, lactic acid, ethanol and net 2 ATP
Recommendation to Restaurant

- add salt
- conductivity to test salt
- To slow process, put in fridge
- To speed up, heat
- temperature sensor
- CO2 sensor for respiration rates

The Finishing Touches to Your Presentation

- Add slide transitions and adjust timings.
- Preview it and make edits.
- Save presentation to designated location.
- Print a handout of your slides.
Use the following toolbox of images to do the following task:

- Make a title slide.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order.
What’s Happening with the Data While Making Kimchee?

By: Brandon

Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize the anaerobic conditions.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.
Very salty solutions create anaerobic conditions.

Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize the phyllosphere.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.
Make a labeled diagram of the phyllosphere community of microbes.

Use the Following Toolbox of images to Accomplish the following task:

☐ Create a label diagram that helps your audience visualize why the Kimchee brine solution gets bubbly.

☐ Use the following title, image and labels from the next 2 slides. You may add extra items.

☐ Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation.
Why does the brine solution get bubbly?

\[ C_6H_{12}O_6 \]  glucose

\[ \text{CO}_2 \text{(gas)} \]  is one product of heterofermentation.

Anaerobic Bacterium

\[ \text{CO}_2, \text{lactic acid, ethanol and net 2 ATP} \]
Recommendation to Restaurant

- Make sure you compress the kimchee as much as possible so there is no oxygen in the container. Cover it with brine. Use a conductivity sensor to see if the brine has enough salt in it.
- If there is oxygen present, aerobic respiration will occur, which will ruin your crop. We want anaerobic respiration to occur instead.

The Finishing Touches to Your Presentation

- Add slide transitions and adjust timings.
- Preview it and make edits.
- Save presentation to designated location.
- Print a handout of your slides.
Use the following toolbox of images to do the following task:

- Make a title slide.
- Use the following title, image and labels.
  You may add extra items.
- Animate and time the items so that the items appear in a logical order.
What’s Happening with the Data When Red Mulch is Replaced with Black Mulch?

By:
Your Name(s)


Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize the different colors of visible light, and label the colors of light used by most plants for photosynthesis.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.
Photosynthesis Uses Visible Light Energy: The Visible Light Spectrum Related to Photosynthesis

Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize the results of the effective and non-effective light.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation. If there are no products, no animation is required.
Photosynthesis Non-EFFECTIVELY Using Visible Light Energy

Reactants

6 H₂O + 6 CO₂ → Organic compounds (e.g. C₆H₁₂O₆) + 6 O₂

☐ If _________ light, then _________.

Products

Photosynthesis EFFECTIVELY Using Visible Light Energy

Reactants

6 H₂O + 6 CO₂ → Organic compounds (e.g. C₆H₁₂O₆) + 6 O₂

☐ If _________ light, then _________.
Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize how light is required for the light reaction of photosynthesis.
- Label the diagram with the components available.
- Show where photolysis of water occurs.
- Animate the reactants and products of photolysis.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.
Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize how red mulch influences photosynthesis.
- Show the color of light reflected from the mulch.
- Animate the reactants and products if there is a reaction.
- Animate the relative amounts of glucose produced and the predicted growth of the plants. Use the following title, images and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.

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Red Vs. Black Mulch Experiment

- The impact of the red light on the plant is:
- Predicted growth of plants under the above conditions is:
Recommendation to Farmers

- Create a set of instructions for the farmer to follow for selecting mulch and growing a high yield crop.
- Justify your recommendation with your laboratory findings.
- Include other research that you know of that would support your findings.

The Finishing Touches to Your Presentation

- Add slide transitions and adjust timings.
- Add other research information that is important.
- Preview it and make edits.
- Save presentation to designated location.
- Print a handout of your slides.
Use the following toolbox of images to do the following task:

- Make a title slide.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order.
What’s Happening with the Data When Red Mulch is Replaced with Black Mulch?

By:
Bunny
Baxter

Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize the different colors of visible light, and label the colors of light used by most plants for photosynthesis.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.
Photosynthesis Uses Visible Light Energy: The Visible Light Spectrum Related to Photosynthesis

- Absorbed and used in photosynthesis
- Not absorbed and used in photosynthesis

Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize the results of the effective and non-effective light.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation. If there are no products, no animation is required.
Photosynthesis Non-EFFECTIVELY Using Visible Light Energy

Reactants

$6 \text{H}_2\text{O} + 6 \text{CO}_2$

Products

Organic compounds (e.g., $\text{C}_6\text{H}_12\text{O}_6$) + $6 \text{O}_2$

☐ If Green light, then X

Photosynthesis Effectively Using Visible Light Energy

Reactants

$6 \text{H}_2\text{O} + 6 \text{CO}_2$

Products

Organic compounds (e.g., $\text{C}_6\text{H}_12\text{O}_6$) + $6 \text{O}_2$

☐ If Red light, then Photosynthesis
Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize how light is required for the light reaction of photosynthesis.
- Label the diagram with the components available.
- Show where photolysis of water occurs.
- Animate the reactants and products of photolysis.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.

**Photolysis of Water Occurs If**

\[
\text{H}_2\text{O} \rightarrow 2\text{e}^- + 2\text{H}^+ + \frac{1}{2} \text{O}_2
\]
Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize how red mulch influences photosynthesis.
- Show the color of light reflected from the mulch.
- Animate the reactants and products if there is a reaction.
- Animate the relative amounts of glucose produced and the predicted growth of the plants. Use the following title, images and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.

Red Vs. Black Mulch Experiment

- The impact of the red light on the plant is: Growth
- Predicted growth of plants under the above conditions is: If in red light then there will be growth if black light, then there will be no growth.
Recommendation to Farmers

- Plants utilize Red frequencies of light the most effectively.
- For example, note the differences in growth between the cabbage in red plastic and the cabbage in black plastic.
- So, grow plants in red light, or with red mulch.
- And make sure there is enough water; good irrigation.

The Finishing Touches to Your Presentation

- Add slide transitions and adjust timings.
- Add other research information that is important.
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- Save presentation to designated location.
- Print a handout of your slides.
Use the following toolbox of images to do the following task:

- Make a title slide.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order.
What’s Happening with the Data When Red Mulch is Replaced with Black Mulch?

By: Brandon and Bertha

Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize the different colors of visible light, and label the colors of light used by most plants for photosynthesis.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.
Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize the results of the effective and non-effective light.
- Use the following title, image and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation. If there are no products, no animation is required.
Photosynthesis Non-EFFECTIVELY Using Visible Light Energy

Reactants

\[ 6 \text{H}_2\text{O} + 6 \text{CO}_2 \]

Products

\[ \text{Organic compounds (e.g. } \text{C}_6\text{H}_{12}\text{O}_6) + 6 \text{O}_2 \]

☐ If green light, then no absorption.

Photosynthesis EFFECTIVELY Using Visible Light Energy

Reactants

\[ 6 \text{H}_2\text{O} + 6 \text{CO}_2 \]

Products

\[ \text{Organic compounds (e.g. } \text{C}_6\text{H}_{12}\text{O}_6) + 6 \text{O}_2 \]

Calvin Cycle
Makes

\[ \text{g3P} \]

☐ If red light, then kick ass absorption.
Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize how light is required for the light reaction of photosynthesis.
- Label the diagram with the components available.
- Show where photolysis of water occurs.
- Animate the reactants and products of photolysis.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.

Photolysis of Water Occurs If sunlight is present

\[ 2e^- + 2H^+ + \frac{1}{2} O_2 \rightarrow H_2O \]
Use the following toolbox of images to do the following task:

- Create a label diagram that helps your audience visualize how red mulch influences photosynthesis.
- Show the color of light reflected from the mulch.
- Animate the reactants and products if there is a reaction.
- Animate the relative amounts of glucose produced and the predicted growth of the plants. Use the following title, images, and labels. You may add extra items.
- Animate and time the items so that the items appear in a logical order so that the animation assists you in your explanation/presentation.

Red Vs. Black Mulch Experiment

- The impact of the red light on the plant is: grows faster; more photosynthesis.
- Predicted growth of plants under the above conditions is: red grows better.
Recommendation to Farmers

- Grow plants in red mulch for most productive photosynthesis
- Black light is less efficient
- Use black to eliminate weeds
- Have proper irrigation so plants have enough water for photosynthesis

The Finishing Touches to Your Presentation

- Add slide transitions and adjust timings.
- Add other research information that is important.
- Preview it and make edits.
- Save presentation to designated location.
- Print a handout of your slides.
Purpose: To figure out the respirations rates comparatively of larvae and pupae. We are also comparing aerobic and anaerobic respiration.

Hypothesis:
The higher percent sucrose solution will be used up by the yeast faster than the other lower concentration. Also, we believe that the larvae will respirate faster than the pupae.

Procedure and Experimental Design:
Part 1: We added 10 ml of both the yeast and the 5 % sucrose solution. We also added a control of boiled yeast in 5% sucrose. We put the small vial inverted into a larger vial to simulate anaerobic conditions. Then we measured the displacement of the small vial every 5 minutes.

Part 2: For this part we obtained the respirator and absorbent and unabsorbent cotton. We packed the absorbent cotton and soaked it in KOH, then put the unabsorbent cotton above it. Next, we added the live organisms and capped the respirometer and then submersed the respirometer in water to make it a closed system. Now we can measure the respiration rates of the organisms.

Variables:
Part 1: 10% sucrose, 5% sucrose, 5% glucose.
Part 2: larvae, pupae or glass beads

Data: The control yeast had 0 displacements. Overall after 45mins the active yeast in 5% sucrose had a displacement of about 1 inch; however, we were unable to measure after a certain point because the surrounding fluid came out of the tube and obscured our view of the yeast displacement measurements.

<table>
<thead>
<tr>
<th>Displacement</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>5mins</td>
</tr>
<tr>
<td>0.6</td>
<td>12mins</td>
</tr>
<tr>
<td>1</td>
<td>17mins</td>
</tr>
</tbody>
</table>

Analysis: compared to the other displacements the 10% sucrose produced the most growth and the quickest, the 5% sucrose had the next most rapid rate of growth, and the 5% glucose had the lowest (the control had 0 growth).
Conclusion: In conclusion we have now become very learned in the ways of photosynthesis and respiration. Word.

Drawings/Diagrams:
AAHHHH!
CELLULAR RESPIRATION

By
Norman
Natasha
Norma Jean
Nicole Sonia
Natalie

Purpose

• To compare aerobic and anaerobic respiration

• To determine which solution produces the most CO2

• To compare different rates between living organisms and non-living
WHAT WE KNOW:

- Aerobic organisms need O2 and produce CO2
- Photosynthetic organisms need CO2 to produce O2
- KOH absorbs CO2

HYPOTHESES

- Higher concentration of sugar yields more CO2
- Meal worms will consume more O2 than glass beads
PROCEDURES

Anaerobic Respiration
1) In separate tubes:
   • 10mL of Yeast + 10% sucrose
   • 10mL of Yeast + 5% sucrose
   • 10mL of Yeast + 5% glucose
   • 10mL of boiled Yeast + 5% sucrose
2) Shake and turn upside down in larger tube
3) Measure amount of CO2 (air space) every 5 minutes

PROCEDURES, cont.

Aerobic Respiration
1. Prepare 3 respirometers
   - Pack absorbent cotton + KOH + nonabsorbent cotton in tubes and add:
     • Glass beads
     • Meal worms
     • Larvae/pupa
2. Place in water to simulate closed container
3. Measure amount of H2O entering respirometer
RESULTS

Anaerobic Respiration

- 10% sucrose
- 5% sucrose
- 5% glucose
- Boiled Yeast

RESULTS cont.

Aerobic Respiration

- Glass Beads
- Pupa MW
- Larva MW
DISCUSSION

Anaerobic

• 10% sucrose – produces must CO2
• 5% glucose – produces less CO2 than sucrose
• Boiled yeast is control group – no change

• SUCROSE produces most CO2, therefore most active in cellular respiration

DISCUSSION, cont.

Aerobic

• Beads are non-living, so minimal O2 consumption
• Larvae are living but non-motile, so require some O2 because living
• Pupae are living and motile, so require the most O2
CONCLUSIONS

- CONTAIN MORE ENERGY $\rightarrow$ produce more CO2

- REQUIRE MORE ENERGY $\rightarrow$ Consume more O2
VITA

Jewel Jurovich Reuter was born in New Orleans, Louisiana. She graduated from Newcomb College of Tulane University with a Bachelor of Science degree in biochemistry. She graduated from Tulane University with a Master of Arts in Teaching. She has taught secondary school science for twenty-five years.

Jewel has been interested in science since an early age. Her older brother was instrumental in Jewel’s initial interest in science. She was very active in science fairs and won the overall sweepstakes in the International Science Fair, when she was a high school senior.

Over the years Jewel has earned many teaching awards. In 1997 she was awarded a Woodrow Wilson Fellowship. In 1998 she received the Outstanding Science Teacher Award at the Pittsburgh Conference, the Toyota Tapestry Project Award, and the Toshiba America Foundation Classroom Projects Award. In 1999 Jewel received the NABT Outstanding Biology Teacher Award, the Toshiba Laptop Learning Challenge Award, and the Tandy/Radioshack Scholars Award. In 2000 she was a finalist for the Presidential Award of Excellence in Math and Science Teaching. In 2001 Jewel was the Presidential Award of Excellence in Math and Science Teaching 2000 Secondary Science Awardee for the State of Louisiana and was also awarded the Association of Southeastern Biologists Biology Teaching Award. In 2005 she was appointed to the National Biology AP Redesign Panel.

Jewel is married to James Reuter and has two children, Claire and James, IV. She has strived to find a balance between her family and her teaching and research.