POINT LOMA NAZARENE UNIVERSITY

Using a Data-rich problem (DRP) task to promote student understanding of cellular respiration within an ecosystem.

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by

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The thesis of Joshua S. White is approved, and it is acceptable in quality and form for publication:

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Chair

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I dedicate this thesis to my wonderful wife, Renee,

and to my beautiful kids, Eli, Evangeline, and Leo

who embarked on this crazy journey with me.

I could not have done this without your love and support.

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Abstract of the Thesis

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In this study a design-based research approach was applied in the creation of a data-rich problem (DRP) task intended to improve student achievement in cellular respiration at the ecosystem level; an identified area of difficulty and an area of focus in the Next Generation Science Standards covering Matter and Energy in Organisms and Ecosystems in High School Life Science. The respiration DRP task was embedded in an existing learning module developed by Maskiewicz (2006) using Ecospheres®. Qualitative and quantitative assessment data were collected from 100 high school biology students who participated in the weeklong Ecosphere® module. Results suggest that students from the experimental class, which participated in the Ecosphere® module with the DRP task, showed significant quantitative gains on posttest items focused on cellular respiration; whereas students from the control class, which participated in the Ecosphere® module without the DRP task, showed no significant quantitative gains in performance on cellular respiration items. Quantitative results also showed that students in the experimental class had greater posttest gains, as measured by g-values, than the control class in items that focused on matter transformation, decomposition, and energy transformation. Qualitative results from interviews and written responses showed that students from the experimental class progressed to deeper Levels of Achievement in cellular respiration than students in the control class. In conclusion, these findings provide evidence of the effectiveness of the design-based research approach in general and, in specific, the modified Ecosphere® module in promoting student understanding in cellular respiration, matter transformation, decomposition, and energy transformation.

Introduction

Year after year in my high school biology courses, classroom discussions reveal that my students not only have difficulty understanding the process of cellular respiration, but often think the process is exclusive to animal cells and does not occur in plants or other producers. In these discussions, students will often say that plants do not need cellular respiration since they obtain energy directly from photosynthesis. Other students seem to confuse the processes of cellular respiration and photosynthesis, creating a hybrid alternative conception that mixes the products and reactants of both biochemical processes. Despite my best instructional efforts, many students carry these alternative conceptions on with them when they move on to other science courses. This is hardly an isolated problem as many studies show that these alternative conceptions are not only common, but are robust and resistant to change (Anderson, Sheldon, & Dubay 1990; Songer & Mintzes, 1994; Tamayo & Sanmarti, 2007). Since cellular respiration is a significant topic in biology, it is not a surprise that alternative conceptions about cellular respiration in plants are connected with difficulties in other topics like energy flow and matter cycling (Lin & Hu, 2003; Mohan, Chen, & Anderson 2009; Songer & Mintzes, 1994). To foster more scientific thinking about cellular respiration and matter cycling in general, many studies suggest changes in instructional design (Anderson et al., 1990; Brown & Schwartz, 2009;

Canal, 1999; Kao, 2007; Lin & Hu, 2003; Mohan et al., 2009; Songer & Mintzes, 1994). Thus much research is still needed in the design, implementation, and effectiveness of instructional activities or strategies in the teaching and learning of cellular respiration, especially as the dawn of Next Generation Science Standards rises. The present study aimed at designing and implementing such an instructional activity to promote student understanding of cellular respiration within an ecosystem.

Theoretical Framework

A social constructivist perspective (Cobb, 1994; Kim, 2001) on learning was adopted for this study, in which learning occurs both in the internal realm of an individual's mind and in the external realm of socially influenced activity. Research supports the theory that knowledge is constructed as it is filtered through prior knowledge and experience (Piaget, 1964) and is refined through the evolution of a learner's prior, formative, and final conceptions (Harrison, Grayson, & Treagust, 1999). This refined knowledge is then applied in the external world as the learner articulates ideas, asks questions, makes predictions, solves problems, or finds real-life connections (Julyan & Duckworth, 2005). While cognitive knowledge is constructed internally, social learning takes place externally within the context, culture, and/or activity in which knowledge is formed and applied, and the ideas and questions of learners are elicited and constructed in this external realm through social interaction (Brown, Collins, & Duguid, 1989; John-Steiner & Mahn, 1996). In the social sphere of learning, participation in authentic activities allows meaningful, contextualized knowledge to be constructed in the mind of the learner (Brown et al., 1989; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000). Because learning is a highly social venture, the learning environment is an important aspect of conception formation; either promoting the formation of conceptions that align with the scientific consensus or, fostering the formation of alternative conceptions. In this view of learning, the construction of alternative conceptions occurs simultaneously with the formation of conceptions that align with accepted scientific views. Because of this, much of the research on cellular respiration in science education over the last 30 or more years has focused on the nature and formation of these alternative conceptions (Anderson et al., 1990; Brown & Schwartz, 2009; Canal, 1999; Kao, 2007; Songer & Mintzes 1994; Tamayo & Sanmarti, 2007). Understanding the nature and the sources of alternative conceptions can lead to instructional solutions that provide students the opportunity to construct scientific knowledge on cellular respiration in producers.

Literature Review

The Nature of Alternative Conceptions about Cellular Respiration

A scientifically comprehensive understanding of cellular respiration requires a working knowledge of the interaction between biological concepts related to metabolism and physiology in organisms, and chemical and physical concepts related to matter and energy transformation. Cellular respiration occurs in a biological context in which cells utilize oxygen and carbohydrates from their environment, and also in a chemophysical context in which matter ($C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2$) and energy (bond energy in carbohydrates → bond energy in ATP + heat) transformations are constrained by laws of conservation. Instruction and curriculum in which cellular respiration is placed in a biological context only (i.e. one that is disconnected from a chemical or physical science concepts) has contributed to specific difficulties in student achievement. For example, data obtained in one study found that college undergraduates have trouble with physical science concepts, such as tracing carbon as they reason through biological concepts like cellular respiration; these students did not differentiate between matter and energy, had trouble tracking matter when it becomes a gas, and were not able to follow matter through systems (Wilson et al., 2006). Similarly, only about 10% of high school students in Mohan et al.'s (2009) study could explain carbon cycling using either an atomic-molecular model or in terms of conservation of matter. Understanding carbon tracing and cycling is key in developing a deep understanding of the molecular changes that occur during cellular respiration in carbon dioxide and carbohydrates. Mohan et al. also found that even college students who had advanced instruction could not provide explanations about carbon cycling that were consistent with the scientific consensus. Because of these shortcomings in application of the conservation of matter and energy, students also commonly fail to form proper understanding of the ecological context of cellular respiration. Studies show that students have difficulty relating concepts across multiple hierarchical levels (i.e. level of the organism, cell, or molecule) and understanding respiration in an ecologically interrelated way (Brown & Schwartz, 2009; Lin & Hu, 2003, Maskiewicz, 2006).

Rather than understanding cellular respiration in terms of matter and energy flow, students tend to understand cellular respiration as an energy process that occurs in animals, but not plants (Cakir, Geban, & Yuruk, 2002; Carlsson, 2002; Songer & Mintzes, 1994). Kao (2007) found that students understood photosynthesis as a process that replaces respiration in plants, or that trees can survive without respiration if they had enough stored nutrients. Those students that understood cellular respiration as a process that occurs in plants saw it as a plant's method of "breathing" with the sole focus on the process of gas exchange (Anderson et al., 1990). In other studies, students understood plants as being animal-like; taking food in through their roots rather than mouths, breathing in CO_2 rather than O_2, and having the ability to suffocate and die like animals (Anderson et al., 1990; Canal, 1999).

Not only do students tend to create alternative conceptions of plant respiration based on unscientific understandings of animal respiration, they often create alternative conceptions of energy flow in respiration based on an anthropocentric worldview; that is, understanding respiration and other biological systems in terms of their benefit to humans (Nordine, Krajic, & Fortus, 2011; Southerland, Abrams, Cummings, & Anzelmo, 2001). In a study by Brown and Schwartz (2009), it was shown that preservice teachers had an understanding of plants as functionally analogous to humans, ecologically dependent upon humans, and fitting a societal function for humans. Not only are these conceptions nonscientific, they make difficult the formation of conceptions that align with accepted scientific ideas of respiration as a process of energy and matter transformation that occurs independent from human interaction.

Sources of Alternative Conceptions about Cellular Respiration

Experiments, textbooks, life experience, anthropomorphic explanations, analogies, and intuition have all been cited as sources of alternative conceptions about cellular respiration (Kao, 2007). However, much of the research has linked alternative conception formation to educational instruction. Early on, primary school students form alternative conceptions based on oversimplified and highly analogized instruction on cellular respiration, often from teachers who harbor many unscientific ideas of their own (Canal, 1999; Brown & Schwartz, 2009). Students then retain these alternative conceptions and also pick up additional ones in their secondary and post-secondary science courses, where even experienced biology students have been shown to have difficulties despite exposure to repeated and advanced instruction (Anderson et al., 1990; Mohan et al., 2009; Songer & Mintzes, 1994).

In addition, curricular divisions between life and physical science that are common in secondary and postsecondary education create an instructional context that fosters the formation of alternative conceptions on cellular respiration. In fact, the formation and persistence of alternative conceptions of cellular respiration has been connected to a lack in understanding physical science concepts such as the conservation of matter and energy (Anderson et al., 1990; Lin & Hu, 2003). Conservation of matter, conservation of energy, and similar physical science topics are not often specifically taught within a general biology course, while cellular respiration is not a topic generally covered in physical science courses such as physics and chemistry. Hartley, Momsen, Maskiewicz, and D'Avanzo (2012) analyzed textbooks and conducted interviews with several college science faculty members in biology, chemistry, and physics and found differences across these domains in the language, metaphors, and emphases (especially in the laws of thermodynamics) placed on explanations of matter and energy in systems. These differences are thought to contribute to alternative concept formation as students may receive conflicting instruction as they progress in their academic career. Even within biology courses, curricular context is important to the learning of cellular respiration, and placement within the course curriculum may vary. Songer and Mintzes (1994) suggested that the usual placement of instruction on cell respiration and photosynthesis within a unit on cellular physiology (rather than within a context of energy flow in ecosystems) was a source of alternative conception formation. Thus it continues to be a challenge to identify not only the best possible instructional activities, but the best possible instructional context.

Solutions Aimed at the Formation of Scientific Conceptions about Cellular Respiration

Studies show that even after science instruction, alternative conceptions about cellular respiration persist (Anderson et al., 1990; Songer & Mintzes 1994;Tamayo & Sanmarti 2007). In their study on conceptions of respiration and photosynthesis in college non-science majors, Anderson et al., (1990) found that even students who had previous biology instruction in high school and college gave definitions of respiration that differed markedly from the accepted scientific view. Despite repeated, advanced instruction Songer and Mintzes (1994) observed the persistence of a wide range of alternative conceptions about cellular respiration for many students in their study. In their case studies Tamayo and Sanmarti (2007) found that even though a molecular model for understanding respiration was introduced in class, the students in the study did not internalize or apply this model. My own pilot study also revealed, following instruction, the persistence of alternative conceptions on respiration in plant-like producers in nearly half of student participants (White, pilot study, 2012). In these studies, additional instruction had little or no effect on refining alternative conceptions or promoting the formation of new conceptions.

If alternative conceptions persist in the mind of the learner, what can be done to prevent their formation or promote proper concept formation? Some researchers have centered on an integrated curriculum in which biological phenomenon like cellular respiration is taught alongside physical phenomenon such as the conservation of matter and energy (Carlsson, 2002a, 2002b; Mohan et al., 2009; Nordine et al., 2011; Wilson, et al., 2006). Mohan et al. (2009) suggest curriculum changes that focus on conceptual coherence between physical sciences (with an emphasis on conservation of matter and energy) and life sciences; specifically, they argue that students must have practice tracing matter through biological processes like cellular respiration and photosynthesis in order to develop deep understanding and reasoning skills about global environmental issues. Nordine et al., (2011) found that instruction focusing on the principle of energy transformation increased student understanding of energy conceptions in cellular respiration in plants. In their work, Nordine et al. (2011) observed improvement in a cohort of student's energy conceptions as they were introduced to energy related biological concepts—photosynthesis and respiration—in a biology course without receiving specific instruction dedicated to the nature of energy. Carlsson (2002a, 2002b) found that the critical idea for students to progress toward more complex thinking about ecological relationships was the idea of transformation. Following instruction, students in the Carlsson (2002b) study understood energy as being conserved and transformed as it moves through biological processes such as photosynthesis and respiration, and progressed to deeper levels of understanding of those processes than students that understood energy as being created or consumed. In addition, Wilson et al. (2006) found that instructional adaptations can stimulate students' use of tracing matter as a reasoning strategy in explaining biological phenomena. Wilson et al. suggest allowing students to individually answer questions about tracing matter through photosynthesis and respiration and to then discuss their reasoning with peers before being prompted to answer those questions again.

These studies demonstrate the value of incorporating concepts that are traditionally reserved for physical science courses into biology curriculum; a value that can be seen in the development of the Next Generation Science Standards for High School Life Science (Achieve, Inc., 2013). Rather than simply teach respiration within a biochemical or physiological context, respiration is also embedded within standards that cover Matter and Energy in Organisms and Ecosystems, such as in HS-LS2-5, in which "students who demonstrate understanding can develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere" (Achieve, Inc., 2013). Thus, the writers of NGSS recognize the value of embedding cellular respiration, a topic that traditionally falls in the realm of life science, within the context of carbon cycling, a topic traditionally falling in the realm of physical science.

In addition to physical and biological concept integration, studies have suggested a shift in curriculum sequencing. In order to promote the development of scientific conceptions, Canal (1999) proposes that the concept of respiration as a process occurring in all plant and animal cells be introduced in biology course curriculum before more specific concepts of photosynthesis are introduced. In this way, students have less of an opportunity to confuse the processes and form alternative conceptions. These studies and others suggest that a simple sequencing change could promote a “systems” approach to learning difficult biochemical processes (Brown & Schwartz, 2009; Lin & Hu, 2003; Songer & Mintzes,1994).

Integrating physical science curriculum and adjusting the scope and sequence of cellular respiration instruction may help, but much research is needed in designing instructional strategies that offer students an opportunity to form accurate and useful conceptions. Design-based research (Collins, Joseph, Bielaczyc, 2004; Fortus, Dershimer, Krajcik, Marx, Mamlok-Naaman, 2004) addresses this need by introducing an approach to designing curricular activities and learning environments through which concepts may be contextualized into real-world, problem solving tasks. These activities or environments are designed with learning theories in mind, developed and tested in a continuous cycle of research and practice, analyzed in light of larger theoretical implications, and shared within a community of designers and researchers (Design Based Research Collective, 2003). Ann Brown, who pioneered design-based research along with Alan Collins, describes it as an “attempt to engineer innovative educational environments and simultaneously conduct experimental studies of those innovations” (Brown, p. 141, 1992). Many design-based researchers thus take on the roles of both educator and researcher (as did Ann Brown) in not only designing, but implementing and analyzing learning artifacts within the common theoretical framework of a community of design-based researchers. Studies adopting design-based research methodology have observed improved student concept formation in physical science on the topics of force, heat, and energy (Fortus et al., 2004), genetics topics involving genes and traits (Duncan & Tsang, 2011), and physiological topics including body organization and biological energy (Kanter, 2010).

I used Edelson's (2001) "Learning for Use" model in my design-based research, applying his three step design framework for developing curriculum: motivation, knowledge construction, and knowledge refinement. In the first step of Edelson's model, motivation, learners are given a problem that puts them in cognitive conflict or brings them to the limits of their own knowledge, motivating them to gain the knowledge or skill to solve the problem. In the knowledge construction step, students are presented with the raw material of experience or communication to construct new knowledge that can be connected with prior knowledge. In the knowledge refinement step students are encouraged to reorganize knowledge structures as they apply their knowledge to the problem.

A Design-Based Approach Toward Concept Refinement in Cellular Respiration

Adopting a design-based approach and following Edelson's "Learning for Use" framework, the task designed for this study builds upon a pre-existing module developed by Maskiewicz (2006) using Ecospheres ® (small, closed, self-contained, and commercially available ecosystems). The Ecosphere® module was designed with students' existing ways of thinking about biological systems and interpreting ecological problems in mind. In the module, students develop explanations for the functioning of the ecosphere by solving data rich problem (DRP) tasks. In the Ecosphere® module, students develop and discuss hypotheses about the functioning of the closed ecosystem and then test those theories by consulting the data given in the problem tasks. The data in the DRP tasks provides evidence for biological processes occurring in the sphere, which in turn guides students in describing the flow of matter and energy in the closed system. In the study, Maskiewicz (2006) found that during the Ecosphere® problem tasks students took ownership toward problem solutions and developed an understanding of matter cycling, biological processes, and observable phenomena that reflected ecologists' thinking patterns. More recently, Maskiewicz, Vanderburg, & Powell, (2012) found that the Ecosphere® module promoted significant gains in high school and undergraduate student understanding of the transformation of matter in ecosystems. In the same study, however, qualitative data showed that students had difficulty with the concept of cellular respiration occurring in all living organisms. Because of the conceptual difficulty with cellular respiration found in that study and many more (Anderson et al., 1990; Brown & Schwartz, 2009; Canal, 1999; Kao, 2007; Lin & Hu, 2003; Mohan et al., 2009; Songer & Mintzes, 1994; Tamayo & Sanmarti, 2007) cellular respiration became the conceptual focus of the DRP task designed for this study, in which students developed and defended hypotheses related to cellular respiration on an ecosystem level and then tested those hypotheses against data provided in the problem task.

Research Goal

Building on the Ecosphere tasks, I developed a data rich problem (DRP) situation that incorporates instructional strategies intended to lead to cognitive conflict followed by knowledge construction. The goal of the task is to improve student understanding of cellular respiration in plants at an ecological level. In the task, students are provided with a contextualized problem solving task, given experimental data to promote knowledge construction, and then are offered an opportunity to refine their hypotheses or explanations. Thus the following research question guided this study:

Does student completion of a data-rich problem (DRP) task focused on cellular respiration, embedded in the Ecosphere® problem set, improve students' understanding of cellular respiration at the ecosystem level?

Methods

Research Design

A mixed methods design was used in this study (Figure 1) based on Creswell & Clark's (2007) "Triangulation Design: Convergence Model" in which qualitative and quantitative data were separately collected, separately analyzed, then compared, and finally interpreted. During the pre-intervention stage, data was collected via written pre-tests (see Appendix C) and pre-instruction interviews with students (see Appendix B for pre/post-instruction interview protocol). Qualitative and quantitative pre-intervention data was then analyzed. During the post-intervention stage, data was again collected from post-instruction interviews and post-tests. Qualitative and quantitative post-intervention data was analyzed separately. Following pre- and post-intervention data collection and analysis, another round of analysis occurred in which pre- and post-intervention data was compared and contrasted. In the final stage, interpretation and discussion on pre- and post-intervention analysis was made. This type of triangulation design was used "to directly compare and contrast quantitative statistical results with qualitative findings" and "to validate or expand quantitative results with qualitative data" (Creswell & Clark, 2007, p.62). The data comparison and interpretation provided evidence regarding the effectiveness of the Ecosphere module in student achievement of the learning goals, and specifically of performance on the cellular respiration data-rich problem (DRP) tasks in improving student understanding of the role of cellular respiration in ecosystems. Since the Ecosphere® module has already proved to promote significant student gains in achievement in topics of matter transformation, decomposition, and energy transformation (Maskiewicz et al., 2012b) the module provided not only instructional context, but also a way to measure achievement gains in an experimental class that participated in the cellular respiration DRP task against a control class, which participated in an alternative activity. In the alternative activity given to the control class students created their own hypothetical experiment with the Ecosphere and then discussed reasons for the possible outcomes (Appendix D). This control activity allowed the instructional time for the Ecosphere module to remain constant between the control and experimental classes and yet test the effectiveness of the added respiration DRP task.

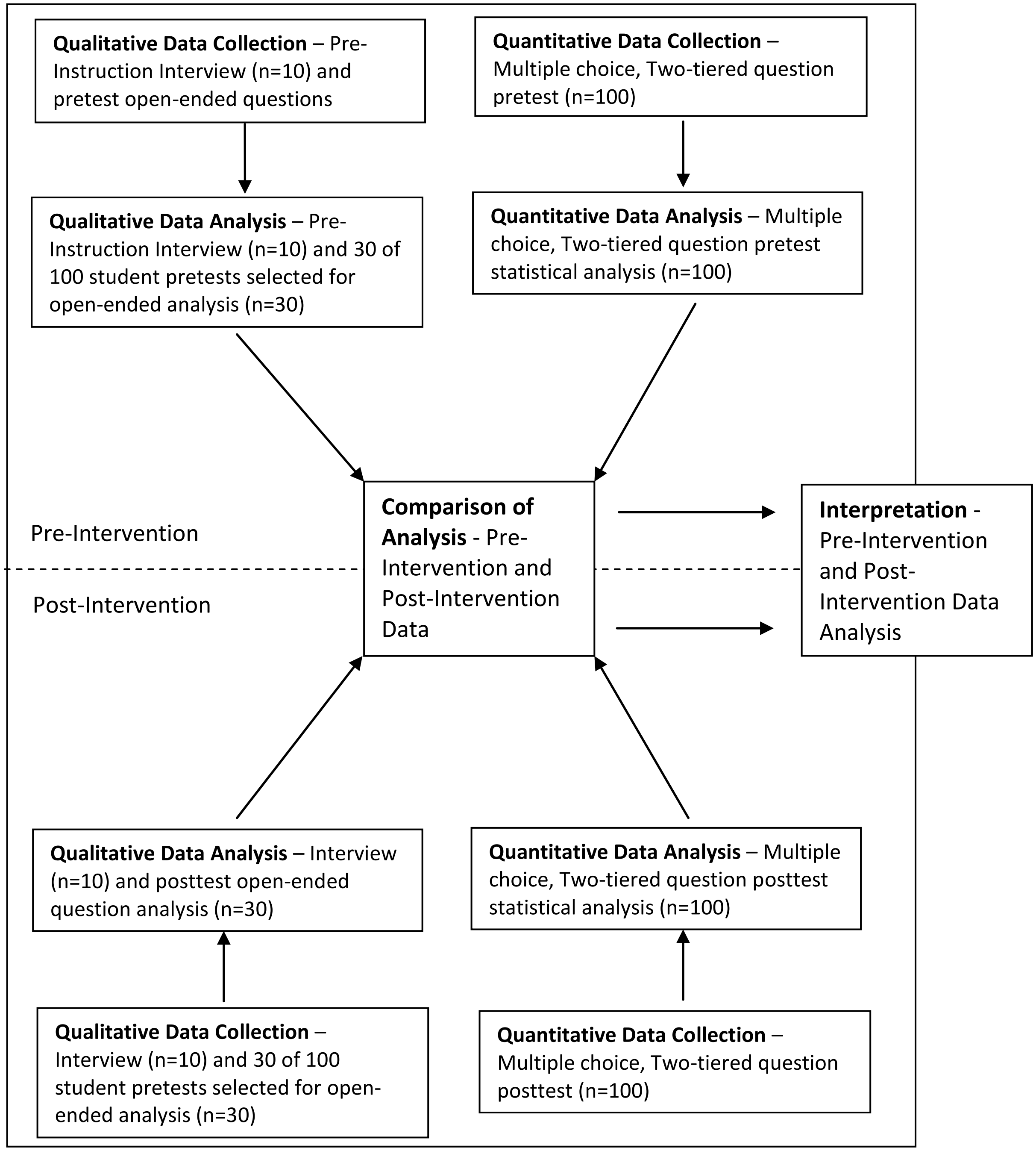

Figure 1: Convergence Model used in the Collection and Analysis of Student Assessment Data. (Creswell & Clark, 2007)

Study Site

This study was conducted at a comprehensive public high school in California with a student population of approximately 3,400. It is located in a suburban city of approximately 110,000. The student population of the high school is 47.5% Caucasian, 32.5% Hispanic or Latino, 5.4% African American, 4.3% Filipino, and 4.1% Asian. In this high school most incoming freshman take a College Preparatory Biology course, then go on to take either Chemistry or Earth Science their sophomore year. The average class size for the Biology courses is 33 students per class. The intervention in this study took place during the second semester of the Biology course in the spring.

Classroom Setting

The Ecosphere module along with the Cellular Respiration Ecosphere® Open Ended DRP Situation was embedded in a larger four week Ecology unit. Effort was made to ensure the consistency of classroom instruction and activities during the Ecology unit in both the control class and the experimental class so that the only difference in the curricular experience of the students was the respiration DRP task. The Ecology unit was designed to cover California state standards 6.a., 6.b., 6.c., 6.d., 6.e., and 6.f. in Biology/Life Sciences for grades 9-12 (California Department of Education, 1998), and the Ecosphere task itself focused on standards 6.d., 6.e., and 6.f (see Table 1). The Ecosphere module also is well designed to cover the Next Generation Science Standards HS-LS1-5, HS-LS1-6, HS-LS1-7, HS-LS2-3, HS-LS2-4, and HS-LS2-5 that are currently in the process of being adopted and implemented in California (Achieve, Inc., 2013).

Table 1: Ecosphere® Module Learning Objectives and Alignment

Instructional Blocks	Ecosphere® Task	Learning Objective(s)	California State Standards Alignment	Next Generation Science Standards	Pre-/Posttest Question Alignment
1	1	Understand the transformation of matter within an ecosystem (matter transformation)	BLS 6.b., 6.e., 6.f.	HS-LS1-6 HS-LS2-3 HS-LS2-4	1, 2, 3, 5, 11, 13, 14, 31a, 33a,b, e
	2				
2	3				
	4	Understand the role of decomposers and decomposition within an ecosystem (decomposition)	BLS 6.e.	HS-LS2-3 HS-LS2-4	6, 7, 8, 9, 10, 31b, 33c
	5				
	6	Understand the transformation of energy in an ecosystem (energy transformation)	BLS 6.d., 6.f.	HS-LS1-5 HS-LS2-3 HS-LS2-4	4, 12, 15, 16, 17, 32, 33d
3	7	Understand the role of cellular respiration in matter cycling (respiration)	BLS 6.d., 6.f.	HS-LS1-7 HS-LS2-5	18-19, 20-21, 22-23, 24-25, 26-27, 28-29, 30, 31a, 33a, 32
	8				
	9				
	10				

Participants

One hundred high school students (96 ninth grade, 3 tenth grade, 1 eleventh grade student) in three of my own high school biology classes participated in the study. All 100 students took the pre- and post-tests and participated in the Ecosphere® module described in this study. One class was selected as a control class and participated in the Ecosphere module without the cellular respiration DRP task. In its place, the control class participated in an alternative activity in which they designed their own hypothetical experiment with the Ecosphere and reasoned through expected results. One class was selected as an experimental class and participated in the Ecosphere module with the cellular respiration DRP task. Selection of the experimental class was determined after the experiment began based on a higher percentage of students present in that class for the entire Ecosphere module. The experimental class did not participate in the alternative activity completed by the control class. Ten students volunteered for pre- and post-instruction interviews conducted during the school day; three of the 10 were from the control class, and the remaining seven from the experimental class. Students who completed both the pre- and post-instruction interview were selected based on their willingness to participate, and were given a $10 gift card in appreciation for their time. Roughly two-thirds of student participants in the study were identified by the school as low-performing, being placed at the beginning of the school year in a specialized academic program that focuses on giving them additional assistance in core math, English, and science courses. Placement in the program was based on a combination of a low eighth grade GPA (below 3.0), basic or below basic state assessment performance, and teacher recommendation. Both control and experimental classes were characterized as having a majority of low-performing students.

Students were selected for interviews based on their willingness and ability to participate. An effort was made to select a diverse range of students both male and female, in both control and experimental classes, across a range of achievement levels from the students that returned parent consent forms and expressed interest in participating. Of the ten students, three were from the control class and seven where in the experimental class; five were male and five were female; two were high-performing, four were average-performing, and four were low-performing (based on their last semester and current semester grades in the course). Students were protected from knowing the basis for their selection. Pre-intervention interviews were conducted before the Ecosphere unit, and post-intervention interviews took place immediately following the Ecosphere unit (see Appendix B for interview protocol). All pre- and post-intervention interviews were 20-30 minutes in length, and student participants were given a $10 gift card in appreciation for their time.

Ecosphere® Module Implementation

The Ecosphere® Module (Maskiewicz, 2006) was designed to take place in an active learning setting, where students are engaged in problem solving. It focuses on four primary learning objectives on matter transformation, decomposition, energy transformation, and respiration (see Table 1). The Ecosphere® module is a series of problem solving tasks that require students to cooperate in groups, participate in class discussions, and defend and argue ideas and positions (see Appendix A for entire Ecosphere® module). During the first day of the Ecosphere® module, students working in randomly assigned groups of three were shown an Ecosphere® and then guided through an investigation of the miniature ecosystem of bacteria, brine shrimp, and algae enclosed within the Ecosphere®. (One Ecosphere® was obtained for this study, and although intriguing to students initially, the learning module is not dependent upon having one.) Through a series of tasks, students were asked to reason about how the organisms in the Ecosphere are able to survive for a relatively long period of time without the human maintenance that is required by fish tanks or terrariums that are more familiar to students. This reasoning is intended to promote understanding about matter and energy transformation, nutrient cycling, ecological roles and niches, and food webs. Day two of the Ecosphere module had students analyzing data based on experimental changes made to the Ecosphere, such as removing one of the three types of organisms. Based on the data, students constructed and defended their own ideas about the ecological roles of the organisms within the Ecosphere. Day one and day two were identical in both the control and experimental classes. Day three of the Ecosphere®

Module included the Cellular Respiration Open Ended DRP tasks designed by the author, and only students in the experimental class participated in these tasks. In the tasks, students were presented with data from an experiment in which the algae are the only living thing left in the Ecosphere®. The data is designed to promote student understanding of the role of cellular respiration and photosynthesis both at the organismal level, within algae, and at the ecological level, as oxygen and carbon dioxide cycle through the system. On day three, in the control class students designed a hypothetical Ecosphere experiment, predicted the data they would observe, and then discussed the reasons for the observed data. The control activity was designed to give the control class an equitable amount of time in the Ecosphere module, yet without participation in the respiration DRP task being tested in this study. Both revised Ecosphere® modules for the control and experimental classes were implemented over a period of three 100 minute instructional blocks, with additional time given for pre- and posttests.

Data Collection and Analysis Methods

Pretest and posttest data was collected from 100 students in three classes; however only two of those classes were chosen for analysis. The control class was initially selected, and then an experimental class was chosen from the remaining two classes based on the class with highest percentage of student participants for the week-long Ecosphere module. In the final analysis, data was analyzed from 31 students in the control class and 30 students in the experimental class who took a 33 item assessment created for this study, that contained a combination of open-ended, multiple choice, true-false, and two-tiered questions (see Appendix C) which align with the learning objectives of the Ecosphere module (see Table 1). The pretest and posttest assessment was developed with sensitivity to the degree of effectiveness or ineffectiveness of educational interventions, or a DEISA approach (Ruiz-Primo, Li, Wills, Giamellaro, Lan, Mason, Sands, 2012). In their research on creating instructionally sensitive assessments, Ruiz-Primo et al. (2012) suggest first defining the learning goals of the instructional module, identifying the big ideas of both the intervention and assessment, developing the assessment items, and then validating and interpreting the sensitivity of the assessment. I made an attempt to follow these guidelines in the selection of assessment items. Twenty nine of the pre/posttest items were a combination of multiple choice, true-false, and two-tiered questions adapted from Haslam & Treagust (1987) and Diagnostic Question Clusters (DQC) used by Maskiewicz, Griscom and Welch (2012a). The remaining four questions were open-ended questions, selected and adapted from the Diagnostic Question Cluster (DQC) tested by Ebert-May, Batzli, and Lim (2003) and Maskiewicz et al. (2012) based on their relevance to the Ecosphere Module in general, and their ability to elicit student understanding about the process of cellular respiration in producers. The open ended questions were selected and adapted with the goal of embedding the concept of cellular respiration within concepts of transformation and the conservation of matter and energy, which has been suggested as improving student understanding (Carlsson, 2002a, 2002b; Wilson, et al., 2006; Mohan et al., 2009; Nordine et al., 2011). Student responses to the pretest were collected prior to the Ecosphere module and without any discussion or explanation of expected answers. Immediately following the Ecosphere module, the same items were given to students again for the posttest. The pre- and post-tests, along with the Ecosphere® module took place as a part of regular class activities. Students received class credit for simply completing the activities and tests; however their scores on the tests or answers on the Ecosphere® module were not counted against their overall grade in the course. All of the students that participated in the interviews and contributed written responses for this study were given pseudonyms to protect their identities.

After collecting student responses to the quantitative portion (30 multiple choice, true-false, two-tiered items) of the pre- and posttest, class average scores were calculated. Statistical significance between class achievement on the quantitative pretest and posttest was analyzed using a paired t-test ($p < 0.05$).

Pre- and post-test scores were also analyzed by learning objective focus areas (matter transformation, decomposition, energy transformation, and respiration) using a paired t-test ($p < 0.05$). In addition, the mean of normalized gain ($\bar{g}$) was calculated, which factors in each individual student's pre-test score when measuring the gain on the posttest (Hake, 1998; Coletta & Phillips, 2005). Mean of normalized gain ($\bar{g}$) was calculated by taking the mean of individual student gains using the following formula:

$$\bar{g} = \frac{\sum_{i=1}^{n} \frac{\text{post score}_i - \text{prescore}_i}{\text{maximum score} - \text{prescore}_i}}{n}$$

where n = total number of students.

An additional calculation, the normalized gain of means (g), was calculated by first averaging the pretest and posttest scores for each class, and then calculating the normalized gain. Normalized gain of means is expressed by a slightly different formula:

$$g = \frac{\text{post score class average} - \text{prescore class average}}{\text{maximum score} - \text{prescore class average}}$$

These slightly different normalized gain calculations can provide insights into the types of gains made by individual students within a class. Bao (2006) suggests that when a class has a larger normalized gain of mean (g) value than mean of normalized gain ($\bar{g}$), students with lower scores on the pretest tend to make larger gains on the posttest than students with high pretest scores. If a class has a larger mean of normalized gain ($\bar{g}$) than normalized gain of mean (g) value, students with lower pretest scores make similar or even smaller gains on the posttest than students with high pretest scores (Bao, 2006). Normalized gain scores were compared between both control and experimental classes.

An “Explanatory Design: Participant Selection Model” (Creswell & Clark, 2007) was used to select 30 students (15 from the control class and 15 from the experimental class) from 100 students for qualitative analysis of their responses to the two open-ended questions. These 30 students were selected based on the length of their responses, which were long enough to provide adequate analysis. These open-ended question responses were analyzed for differences in Levels of Achievement between the pretest and posttest. Student responses to “matter transformation” items were coded and analyzed based on the coding scheme developed by Mohan et al. (2009). In the coding scheme, Mohan et al. (2009) identified four Levels of Achievement based on patterns in student thinking about carbon cycling in ecological systems from the most simplistic thinking (level 1) to the most complex and scientific (level 4). Descriptions of each level along with examples of student responses are shown in Table 2. By adopting a similar framework as Mohan et al. (2009), I developed the remaining descriptions of Levels of Achievement for decomposition, energy transformation, and respiration (Table 2).

Table 2: Scoring Rubric Showing Descriptions of Levels of Achievement for Open Ended and Interview Questions

	Description of Levels of Achievement in concept focus area			
Level	Matter Transformation (Mohan et al., 2009)	Decomposition	Energy Transformation	Cellular Respiration
1	Explanations in terms of separate objects and events, rather than connected biological and chemical processes.	Attempt to explain decomposition without a decomposer, or explanations that include organisms (e.g. "bacteria) and actions (e.g. "break down"), rather than connected biological and chemical processes.	Explanations of energy in separate objects and organisms, rather than in terms of flow through an ecosystem. No explanation of biological or chemical processes involved. Students may explain energy as being in living organisms only.	Explanations of natural phenomena in terms of separate organisms and actions (e.g. "breathing" "taking in") rather than actions connected to biological processes like cellular respiration.
2	Explanations of cause-and-effect sequences of events with hidden, underlying mechanisms for macroscopic events.	Cause-and-effect explanations with hidden, underlying mechanisms for macroscopic decay. Decomposers only accelerate decomposition.	Explanation of energy in terms of flow through ecosystem, with hidden processes, but without respect to transformation.	Cause-and-effect explanations of respiration as an energy related process in animals but not plants necessarily. Respiration as alternative to photosynthesis, only occurring at night, or a gas conversion process.
3	Explanations of sequences of events with descriptions of chemical change as underlying mechanisms for macroscopic events. Generally traced matter, but converted matter to energy and reluctant to attribute mass gain/loss to gases.	Cause-and-effect explanations with biological and chemical mechanisms for macroscopic decay. Generally included biological processes in explanation, but readily converted matter to energy and vice versa.	Explanation of energy transformation through various forms via biological or chemical processes within a system. Generally traced energy, but converted between matter and energy and/or attempted to explain energy as cyclical within the ecosystem.	Cause-and-effect explanations of respiration as an energy or matter transformation process occurring in plants, animals, and decomposers. Included description of chemical change. Readily converted between matter and energy without respect to conservation laws.
4	Descriptions of chemical changes constrained by physical laws like conservation of matter/energy, and complex explanations of key cellular and metabolic processes, and natural mechanisms.	Complex descriptions of decomposition included cellular respiration that are constrained by physical and natural laws such as matter and energy conservation.	Description of energy transformations in various forms and through various processes that constrained by law of conservation. Accounted for all energy in the system including that which is lost as heat.	Description of respiration as an energy and matter transformation process constrained by conservation that occurs in all living organisms.

Interview data was collected before the pre-test and then again after the intervention and posttest using audio/video recordings with ten students. The interview protocol consisted of three tasks, one of which was developed and tested to be useful in eliciting student conceptions by the author in a previously conducted pilot study (task #1 – A Mouse and Plant in a Jar). Task #2 (A Sunflower in the Dark) is adapted from an interview question used by Parker et al. (2012), and the remaining task (task #3 - Grandma Johnson) is adapted from a Diagnostic Question Cluster (DQC) tested by Ebert-May, Batzli, and Lim (2003) and Maskiewicz et al. (2012a). See Appendix B for interview protocol. Each interview task included questions that were designed to elicit student discussion of their conceptions about the learning objectives in matter transformation, decomposition, energy transformation, and respiration within an ecosystem. Interviews were estimated to take 20-30 minutes, but because of time limitations only Task #1 and Task #3 were used in most interviews. Each student received a $10 gift card in appreciation for their participation.

The same 10 students were selected for both pre-and post-instruction interviews in order to analyze qualitative achievement gains as a result of engaging in the Ecosphere® Module. Student pre- and post-instruction interview data was collected, and analyzed based on the same coding scheme described above for the open-ended items on the pre- and posttest (Table 2). "Levels of

Achievement" were used as descriptors of the depth of student responses. The Level of Achievement of responses in all four of the learning objectives were analyzed and compared qualitatively between pre- and post-instruction interviews.

In following Creswell & Clark's (2007) "Convergence Model", statistically significant quantitative differences in pre- and posttest data were compared with qualitative differences in pre-and post-instruction interview data. Thus the validity of the results is improved by the triangulation of two different sources of data. As such, more confident conclusions can be made about the effectiveness of the Ecosphere® module, and also specifically in answering the research question, "Does student completion of a data-rich problem (DRP) task focused on cellular respiration, embedded in the Ecosphere® problem set, improve understanding of cellular respiration at the ecosystem level?

Results

Quantitative Results

Quantitative Pretest. Prior to the implementation of the Ecosphere module, students in both the control class, which did not participate in the respiration DRP task, and experimental class, which did participate in the respiration DRP task, were given the quantitative pretest. Results from an unpaired *t*-test show that no significant difference was found ($p = 0.52$) between the mean pretest scores of the control class and the experimental class (Table 3). This finding shows that students in both classes began at similar reasoning levels and with similar knowledge about the Ecosphere focus concepts.

Table 3. Results of unpaired t-test on pretest comparison between classes prior to Ecosphere module implementation. The maximum possible score on the pretest was 30.

	Control Class	*Experimental Class*
Mean	11.61	12.23
Variance	13.97	14.53
N	31	30

$p = 0.5235$

Quantitative Posttest Overview. Posttest data analysis suggested that student participation in the Ecosphere module had an overall significant effect on student understanding as measured by mean pretest and mean posttest scores in both the control group ($p < 0.001$) and in the experimental group ($p < 0.001$, Table 4). The mean of normalized gain ($\bar{g}$) was calculated for each class by finding the normalized gains for each student and then taking the average of those gains (Hake, 1998; Coletta & Phillips, 2005). The mean of normalized gain ($\bar{g}$) takes into consideration each individual student's initial achievement level when measuring the gain between pretest and posttest scores. According to the data the experimental group had a larger mean of normalized gain ($\bar{g} = 0.40$) than the control group ($\bar{g} = 0.17$) which suggests that the experimental group had significantly higher gains in the posttest (Table 4). Additionally the normalized gain of means (g) was calculated by taking the normalized gain of the average pretest and posttest scores of the class (Bao, 2006).

Table 4: Changes in student understanding based on pretest and posttest scores following Ecosphere module implementation

Class	*N*	*Mean Pretest Score*	*Mean Posttest Score*	*p*	*g*	$\bar{g}$
Control (No DRP)	31	11.61	15.23	< 0.001	0.20	0.17
Experimental (DRP)	30	12.23	19	< 0.001	0.38	0.40

Quantitative Posttest by Concept Focus. The 30 questions (1 point each) and student responses on the posttest were analyzed based on the concept focus areas in matter transformation (7 questions), decomposition (5 questions), energy transformation (5 questions), and cellular respiration (13 questions). In the control class, which did not participate in the respiration DRP task, results of paired t-test measures of mean pre- and posttest scores in concept focus areas revealed significant improvements on questions focusing on matter transformation and decomposition (Table 5, Figure 2). No significant difference was found in the control class between the mean pretest and mean posttest scores on concept focus areas of energy transformation and respiration using a significance cutoff of $p < 0.05$ (Table 5). In the experimental class, the results showed significant gains in questions focusing on concepts of matter transformation and decomposition; just as with the control class (Table 5, Figure 2). However, results in the experimental class, which included the new respiration DRP task, also showed significant improvement in questions focusing on concepts of energy transformation and respiration.

Table 5: Changes in student understanding by concept focus based on pretest and posttest scores following Ecosphere module implementation in control class and experimental class

	Control Class					*Experimental Class*				
Concept Focus	*Mean Pretest Score*	*Mean Posttest Score*	*p*	*g*	*ḡ*	*Mean Pretest Score*	*Mean Posttest Score*	*p*	*g*	*ḡ*
Matter Transformation	2.74	4.16	< 0.001*	0.33	0.26	2.8	4.8	< 0.001*	0.48	0.47
Decomposition	2.06	2.64	0.01*	0.20	0.08	2.13	3.07	< 0.001*	0.32	0.28
Energy Transformation	1.87	2.32	0.10	0.14	0.05	1.97	2.97	0.001*	0.33	0.25
Respiration	4.90	6.03	0.06	0.14	0.08	5.13	8.1	< 0.001*	0.38	0.38

*p values denoted as significant, $p < 0.05$

Because pre- and posttest scores were collected and analyzed in four different concept focus areas (matter transformation, decomposition, energy transformation, and cellular respiration) a radar graph, or spider graph, was used to display mean percentage gains on the posttest in both the control and experimental classes. Radar graphs allow data with multiple variables to be displayed along several different axes in the same graph. For the data on concept focus areas, mean pre- and posttest percentages are visualized for the control class (Figure 2) and the experimental class (Figure 3). Note the distance between the line denoting the pretest and the line denoting the posttest for all four concept areas is greater for the experimental class (Figure 3) than the control class (Figure 2).

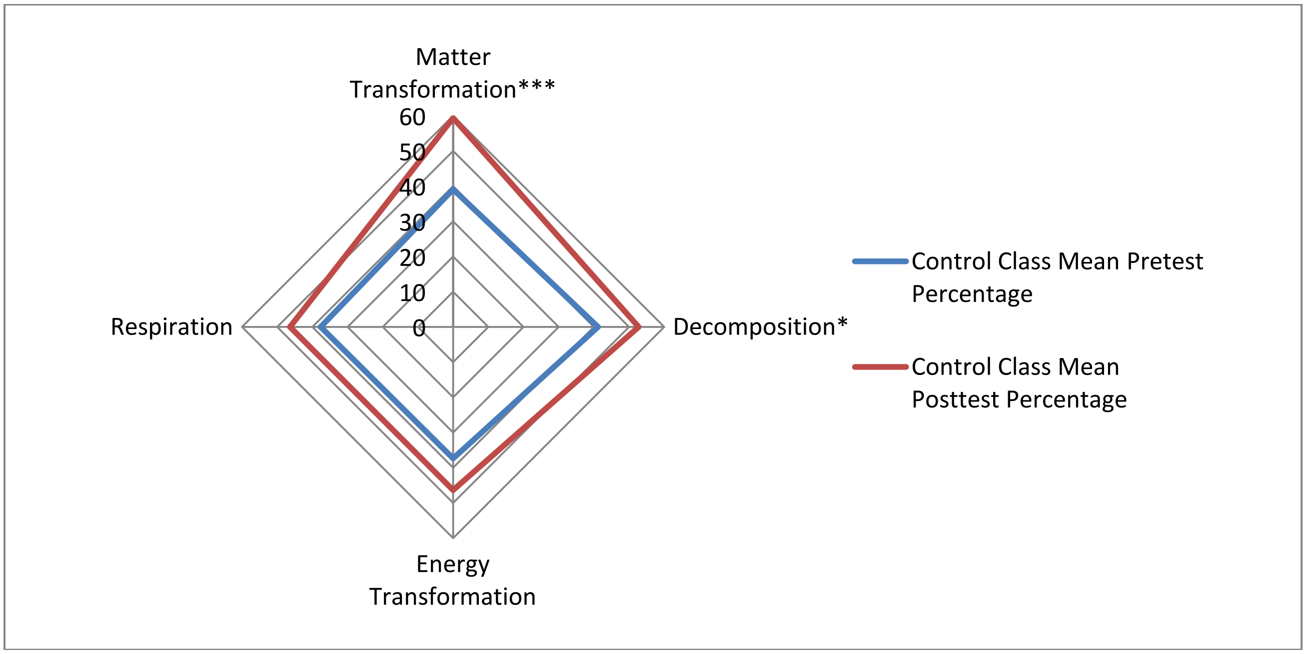

Figure 2. Mean pretest and posttest percentages in control class (no respiration DRP task) on concept focus areas of matter transformation, decomposition, respiration, and energy transformation

*** $p < 0.001$

* $p = 0.01$

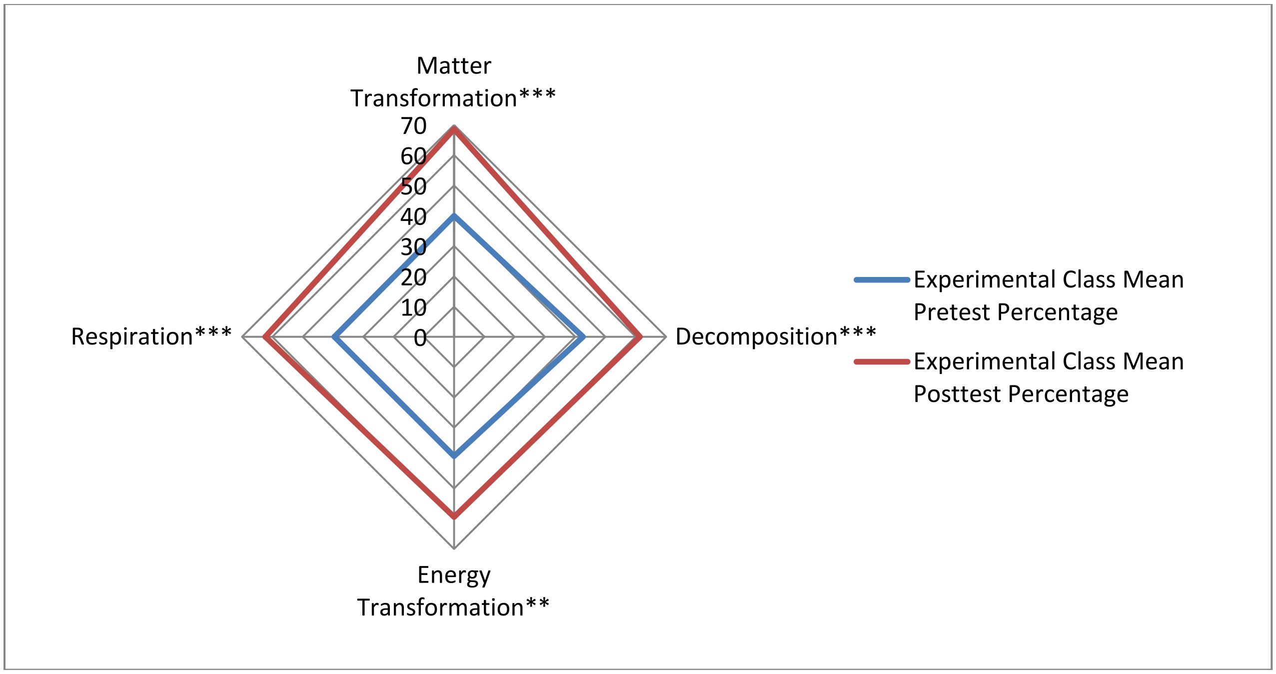

Figure 3. Mean pretest and posttest percentages in experimental class (participated in respiration DRP task) on concept focus areas of matter transformation, decomposition, respiration, and energy transformation
*** $p < 0.001$
** $p = 0.001$

In the control class, the mean of normalized gain ($\bar{g}$) value was largest for questions focusing on the concept of matter transformation ($\bar{g} = 0.26$), and was very small for questions with a focus on decomposition ($\bar{g} = 0.08$), energy transformation ($\bar{g} = 0.05$), and respiration ($\bar{g} = 0.08$). A similar pattern followed for normalized gain of mean (g) values for each of the focus concepts (Table 5, Figure 4).

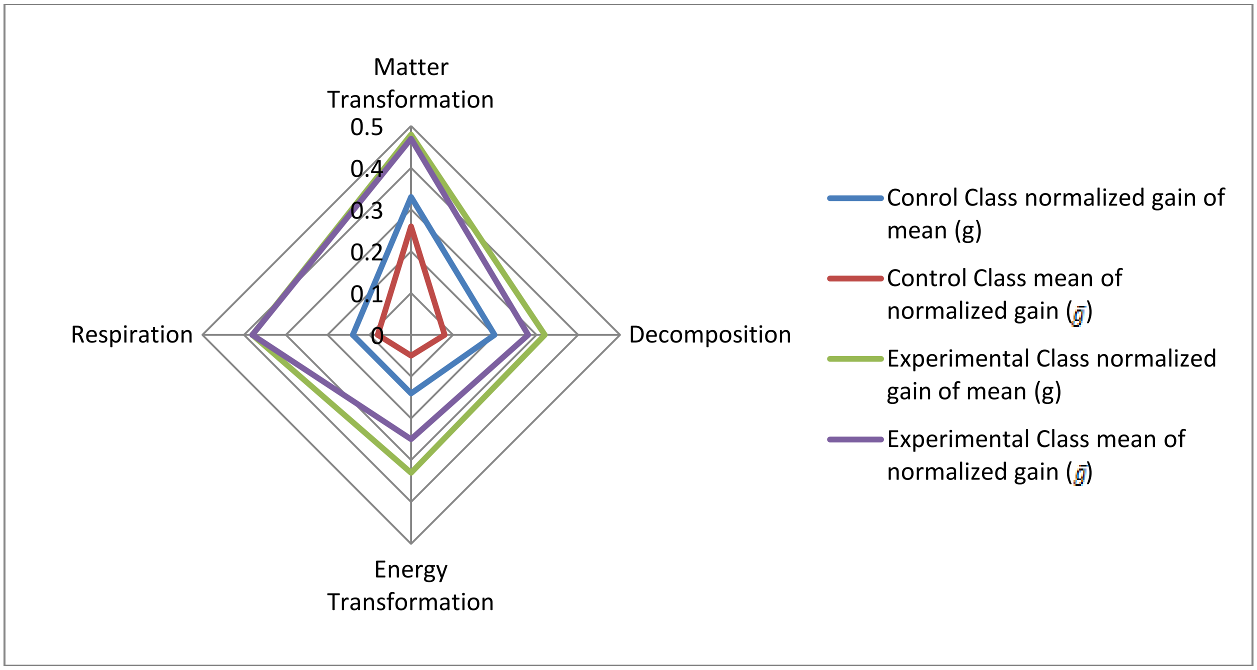

Figure 4: Normalized gain of mean (g) and mean of normalized gain ($\bar{g}$) values for control class, which did not participate in the respiration DRP task, and experimental class which did participate in respiration DRP task. Normalized gain of mean (g) calculated by averaging class scores and then calculating normalized gain of class average scores. Mean of normalized gain ($\bar{g}$) values calculated by averaging the normalized gain scores for each individual student.

In the experimental class, the mean of normalized gain ($\bar{g}$) value was also largest for questions focusing on the concept of matter transformation ($\bar{g}$ = 0.47), followed by questions with a focus on respiration ($\bar{g}$ = 0.38), then decomposition focus concept questions ($\bar{g}$ = 0.28), and finally energy transformation concept focus questions ($\bar{g}$ = 0.25) (Table 5, Figure 3). Normalized gain of mean (g) values followed a slightly different pattern (Table 5, Figure 3), revealing the largest gain for matter transformation questions (g = 0.48), followed by respiration (g = 0.38), then energy transformation (g = 0.33), and finally decomposition (g = 0.32). The experimental class showed higher $\bar{g}$ value gains than the control class, which did not participate in the respiration DRP task, in all four concept focus areas, but especially in areas of decomposition, energy transformation, and respiration (Table 5, Figure 4).

Qualitative Interview Results

Pre-instruction Levels of Understanding in Matter Transformation. Prior to participation in the ecosphere module, Level 1 understanding in matter transformation was common during student interviews (7 of 10 students) in which explanations were given in terms of separate objects and events, rather than being connected with biological and/or chemical processes (see Table 6 for example). Students with Level 1 understanding generally were not able to connect an organism's need for oxygen with the biochemical process of cellular respiration that requires it. In one of the interview tasks, students were asked to explain why a mouse left in a container would die if a plant, which had been inside the container, was removed. The movement of oxygen was routinely connected with breathing, but not with cellular respiration, evident in statements like, "…the plant provides the mouse with oxygen to breath, so without oxygen coming in it would suffocate" or "The mouse needs the oxygen to survive so it can breathe. Without oxygen it can't survive at all." In fact, prior to the Ecosphere module, none of the 10 students interviewed offered cellular respiration as a biological process involved in the transformation of matter or as the reason why the mouse left alone in the container would die.

Table 6. Matter Transformation Response examples and Levels of Achievement

Levels of Achievement	*Matter Transformation Levels of Achievement in Interview Responses*
Level 1	Lucy* - "…because the plant provides the mouse with oxygen to breath. So without oxygen coming in it would suffocate."
Level 2	Shawn - "Or the air, the plant goes through photosynthesis and creates the air and the mice breaths the air. But without the plant it has no air…like oxygen."
Level 3	Mary: "So it could use that carbon dioxide for photosynthesis and then it will use the oxygen produced from photosynthesis in cell respiration and then it will release [carbon] back as carbon dioxide…So then if the coyote eats the plant and breaks down the sugars in the bond energy in the sugars in the plant it will transform that energy into ATP, which powers any cell. Then it could be like motion energy for the leg."
Level 4	Author**: "During photosynthesis, carbon dioxide and water molecules are transformed into sugar molecules by transforming energy captured from sunlight into bond energy. In order to use that energy, plants break bonds within sugar molecules during cellular respiration, transforming sugar into water and carbon dioxide, and thereby release energy to be transformed into bond energy in molecules of ATP."

* all names used are pseudonyms
**no students provided Level 4 responses during interviews. For the purpose of demonstrating Level 4 achievement, a Level 4 explanation in Matter Transformation was provided by the author.

Three of 10 students began with Level 2 pre-instruction interview explanations with regards to matter transformation during photosynthesis. For these students, explanations were more cause and effect in nature with unexplained or hidden underlying mechanisms for observable phenomenon (see Table 6 for example). They understood photosynthesis as an underlying mechanism responsible for the transformation of carbon dioxide. They could not, however, provide any further description of the process of photosynthesis or the chemical change that occurred as carbon dioxide was transformed. For students with Level 2 understanding, photosynthesis was a "black-box" process in which carbon dioxide went in and oxygen comes out. This understanding was typified by a student who mentioned photosynthesis as an important process in plants, yet when asked, he responded that it was important "for the plant to make oxygen because the plant takes in the carbon dioxide because it is essential to the plant." Notice the circular reasoning (which was common in student interviews) in which he explains that the process is important because "it is essential to the plant." This reasoning marks the limits of students' pre-instruction interview knowledge about the biological and chemical processes behind matter transformation in living organisms.

In one interesting exchange during a pre-instruction interview, one student (a higher-performing student from the experimental class) with Level 2 understanding in matter transformation when discussing photosynthesis was confronted with a scenario that exposed to her the limits of her understanding in matter transformation during cellular respiration:

Interviewer: What do you predict will happen to the plant if the mouse is taken out of the container and it is then sealed?

Lucy: I think it will eventually die off because it doesn't have carbon dioxide.

Interviewer: How long might that take?

Lucy: I don't know, like two weeks.

Interviewer: What would you say if I told you that the plant actually lives? How is this possible?

Lucy: Well it does have sunlight. Maybe because plants produce their own food.

Interviewer: You said that carbon dioxide might be an issue though. How might the plant resolve that?

Lucy: Maybe by producing its own carbon dioxide.

Interviewer: Do you know of any processes where a plant would produce its own carbon dioxide?

Lucy: Not really, other than photosynthesis but that doesn't produce carbon dioxide.

Lucy was able to connect the transfer of carbon dioxide from the mouse to the plant for the process of photosynthesis. However, when presented with a scenario in which the plant received carbon dioxide from a source other than the mouse, she was unable to identify cellular respiration occurring in the plant itself as a carbon dioxide source, even though she correctly reasoned that the plant could have been “producing its own carbon dioxide.” This is indicative of a Level 1 understanding of matter transformation with regards to cellular respiration, in which there is no connection of the transformation of carbon dioxide with the connected underlying biochemical process in which it is transformed.

Further evidence of Level 1 understanding of matter transformation was provided in student pre-instruction interview responses to the “Grandma Johnson” interview task (Appendix B). Students were asked to trace a carbon atom from Grandma Johnson when she was buried to inside a coyote, with descriptions of the various forms that the carbon may take. Several of the interviewed students provided responses of the movement of carbon that were completely detached from biological or chemical processes, indicating Level 1 understanding. One student responded, “The molecules move, right? So, maybe the coyote was just walking over there and it was around her, breathing it in…and it’s going down, going through the body, and then it goes into the leg.” This student acknowledged the movement of matter as occurring without important matter transformation processes like cellular respiration or photosynthesis. Another student (a low-performing student from the control class) offered a similar, non-biochemical explanation:

Adam: Let's say the coyote is just walking around and the coyote wishes to urinate in the bush and so he does. Of course even the smallest touch of the floor--depending on how long Grandma Johnson was buried there--the carbon molecular structure which makes up Grandma Johnson could rise up due to-- give me a second to recall it-- no it wasn't condensation, that is the thing with the glass, not the glass the water. I forgot what it was called, but even the slightest part of the body decomposes with the soil, then even if the coyote barely touches the dirt of which Grandma Johnson is buried under, then it could get on the coyote even with a simple touch

Interviewer: Once it gets on the coyote, how would it get in the coyote down to its muscle?

Adam: being absorbed in through its skin follicles possibly, or even if the coyote was just sniffing around the bush and stuck his nose in the dirt and tried to lick off his lips or something like that.

Adam describes the decomposition of Grandma Johnson's body in general terms without mentioning how cellular respiration may be involved in transforming carbon-based molecules into carbon dioxide. In addition he explains the incorporation of the carbon molecule through absorption or inhalation, without reference to connected biochemical metabolic processes that include matter transformation. This Level 1 understanding, in which matter is an object moving independently from biochemical events, was common in the pre-instruction interviews of several students.

None of the students provided Level 3 or Level 4 pre-instruction interview responses about matter transformation prior to instruction. A Level 3 response would have included an explanation of the movement of matter that included descriptions of chemical change within biochemical processes like cellular respiration or photosynthesis (see Table 6 for example). In Level 3 responses, matter would have been traced, but may have been incorrectly converted to energy or vice versa. For example, Level 3 responses may have included explanations of the transformation of carbon dioxide to carbon-based sugar molecules during photosynthesis, but may have incorrectly included the conversion of those carbon-based sugar molecules into energy for the plant. In that way, Level 3 responses neglect the conservation of matter and energy. This is then, the dividing conceptual understanding that separates Level 3 responses from Level 4 responses. Level 4 responses (see Table 6 for Author example) describe matter and energy transformations occurring in biochemical processes in a way that recognizes constraining physical laws like the conservation of matter and energy (Mohan et al., 2009).

Post-instruction Levels of Understanding in Matter Transformation. One of the goals in the design and implementation of the ecosphere module and respiration DRP task was to see students progress into deeper levels of understanding; however it is understood that not all students will progress into Level 4 explanations. In fact, it has been shown that as few as 10% of high school students show evidence of Level 4 reasoning (Mohan et al., 2009). Analysis of post-instruction interviews revealed that no students progressed to achievement Level 4 on explanations for interview questions focused on matter transformation. However, 7 of 10 students interviewed demonstrated evidence of progress toward at least one deeper level of achievement on post-instruction interview questions focused on matter transformation. Three of the ten actually progressed two reasoning levels, and all three were in the experimental class that participated in the respiration DRP task. These gains correlate with the larger gains made by that class on the quantitative portion of the post-assessment for matter transformation questions. One student, Kenneth, an average-performing student from the experimental class, provided clear evidence of his progression from Level 1 reasoning to Level 3 reasoning in his explanation of the Grandma Johnson task (Appendix B). During his pre-instruction interview Kenneth describes the movement of carbon through the food chain without regard to chemical transformation or biochemical processes, which is typical of a Level 1 response (Table 7). Following the Ecosphere module with the respiration DRP task, Kenneth explained the transfer of carbon in a CO_2 molecule as it is released from Grandma Johnson by decomposers, taken in the creosote bush for photosynthesis, transformed into a carbohydrate, then eaten by a rabbit, which is then eaten by a coyote. Kenneth's explanation included his original ideas of flow through the food chain, but is nuanced with details about chemical changes ("the CO_2 molecule is…transferred as a carbohydrate") and associated biochemical processes ("the CO_2 molecule for…photosynthesis"). This depth of explanation was characteristic of a Level 3 response. Notice that at the end of his explanation he does convert matter to energy ("cellular respiration transfers [the carbohydrate] to an ATP molecule, which powers the leg muscle.") without respect to conservation laws. This matter to energy conversion is characteristic of Level 3 responses, and thus separates Level 3 responses from more in depth and scientifically accurate Level 4 responses.

Table 7. Pre-instruction interview and post-instruction interview responses and rubric scores for Kenneth, an average-performing student in the experimental class, which was given the respiration DRP task

Pre-instruction interview Response (Level 1)	*Post-instruction interview Response (Level 3)*
Grandma Johnson was buried under a creosote bush. The bacteria and fungi broke her remains down, which was eaten by a rabbit and from the food chain the coyote eats the rabbit and the carbon atom went to its leg muscle.	Bacteria and fungi broke down Grandma Johnson, which went into the atmosphere as a CO_2 molecule. Then the creosote bush it took in the CO_2 molecule for cellular respiration…no its photosynthesis. The rabbit eats the creosote bush and it's transferred as a carbohydrate to the rabbit. Then it's eaten by a coyote, which is transferred as a carbohydrate also. And cellular respiration transfers it to an ATP molecule, which powers the leg muscle.

Pre-Instruction Levels of Understanding in Decomposition. During the pre-instruction interview questions focused on decomposition, most students provided evidence in their responses of Level 1 Achievement, although three of ten students interviewed provided evidence of Level 2 Achievement in their responses to interview tasks. Level 1 understanding in decomposition is characteristic of descriptions of organisms involved (e.g. bacteria or decomposers) and their associated actions (e.g. break down) without a connection between biological and chemical processes involved. Students that provided responses with Level 1 reasoning were unable to connect decomposition with the biochemical processes that result in carbon, nitrogen, or phosphorous cycling. In fact, no students that displayed Level 1 reasoning even mentioned cellular respiration as a process used during the decomposition of the mouse in interview task 1 or the decomposition of Grandma Johnson in interview task 2 (Appendix B). Several students that displayed Level 1 understanding explained decomposition without the need for a decomposer; that decomposition could take place with “just the aging of it dying” or with only “air and a little bit of moisture in the air”. In the following exchange, Lucy, a high-achieving student from the experimental class, describes the involvement of decomposers in decomposition, but questions their necessity:

Interviewer: If the mouse does die, what might the container look like after a month?

Lucy: I think it would look pretty dirty, I guess, considering the mouse is probably going to rot.

Interviewer: How does the mouse rot?

Lucy: Decomposition

Interviewer: Are there any other living organisms that would be needed for decomposition to take place?

Lucy: Well probably insects and dirt.

Interviewer: If there were no insects at all would the mouse still rot?

Lucy: Yeah, I think so, from just staying in there for so long with no air flow coming in.

Notice that Lucy does mention the need for insects in the process of decomposition, however she then goes on to assume that decomposition would likely continue without insects “from just staying in there for so long with no air flow”. Kenneth, an average-achieving student from the experimental class, offers a similar explanation when pressed on whether decomposition could occur without decomposers, stating, “it would, but it would take a lot longer time…maybe months.” In his assessment, Kenneth assumes that decomposers aid in the rate of decomposition, but not the occurrence.

Other alternative conceptions on decomposition were apparent in the pre-instruction interviews including a surprising alternative conception that plants were decomposers. When asked to clarify his understanding of a decomposer, Shawn, a low-achieving student from the experimental class, offered, “isn’t a decomposer something that can make its own food, like a plant makes its own food from sunlight and energy.” Another student, Kenneth, also thought plants and decomposers were the same or similar functioning organisms, stating that decomposers “could have broke it down and since they are—I think they are—plants, so they could just probably give off carbon dioxide” (sic). Another student, Noelle, also assumed that plants were involved in the decomposition of

Grandma Johnson's remains, saying, "bugs kind of break it down and the plants and the dirt breaks down the body and breaks down the nutrients and puts it where it's needed." Noelle, like the other students mentioned, understood plants as active agents, rather than simply recipients, of decomposition.

Post-Instruction Levels of Understanding in Decomposition. Following the ecosphere module, nine of 10 students interviewed from both the control and experimental classes provided evidence in their post-instruction interview of an increase in at least one level of achievement in decomposition. Most students were much more likely in post interviews to consider whether or not decomposition would occur based on the presence or absence of a decomposer. Although Charles, an average student from the control class, stated that the only thing needed in the container for decomposition to take place was "air" in his pre-instruction interview, in his post interview the following exchange shows that he was careful to consider the presence of a decomposer:

Interviewer: If the mouse does die, what might the container look like after a month?

Charles: Depending on if there are any decomposers the plant, not the plant, the animal, or the rat would…the rat would stay the same if there wasn't anything to decompose it. And regarding the plant I think it would stay the same for a couple months.

Interviewer: What if there were decomposers in there. What would the rat look like?

Charles: It would probably look like a skeleton because the skin and fur would be decomposed, yeah.

Interviewer: Talk a little bit about what decomposers would do to the skin and fur.

Charles: They would use the nutrients from the dead organisms to carry on their processes of carrying on life and stuff.

Observe how Charles first considers a scenario where decomposers are absent from the closed container and explains that "the rat would stay the same". Charles later describes how decomposition would take place if decomposers were present in the container. Charles's explanation indicates Level 2 understanding since he describes a sequence of decomposition events occurring with non-descript, underlying mechanisms (e.g. "they would use the nutrients from the dead organisms to carry on their process of carrying on life and stuff."). Also characteristic of Level 2 understanding was the description of decomposition as being beneficial for the plants because of nutrient production, but without an understanding of chemical change. Brandon, an average-achieving student from the control class, demonstrated this in the following exchange:

Interviewer: If the mouse does die, what might the container look like after a month?

Brandon: Probably a little decomposed. I don't know, I'm not sure if there are decomposers in there.

Interviewer: Talk more about that.

Brandon: Like, well for the plant to survive there would need to be bacteria so the animal would decompose to the point where it would give off nutrients for the soil and the plant.

…

Interviewer: Could the death of the mouse provide anything for the plant? Let's say there are decomposers in there.

Brandon: It could provide nutrients for the soil

Interviewer: What do you mean by nutrients?

Brandon: I don't remember.

Brandon's understanding of nutrients at a macroscopic, rather than biochemical, level was characteristic of students with Level 2 Achievement. When asked to elaborate on the characteristics or makeup of nutrients, students like Brandon with Level 2 understanding are unable to describe chemical composition or chemical change within the context of biological or chemical processes.

Several interviewed students made similar gains, progressing from Level 1 to Level 2 in their levels of understanding, however five of 10 interviewed students (three from the experimental class and two from the control) progressed to Level 3 understanding in decomposition, evidenced in responses to the Grandma Johnson task (Appendix B). In Level 3 reasoning, student explanations included descriptions of chemical change occurring within biological processes. Notice the biochemical detail in Adam's response when asked to describe how decomposers may be involved in the transfer of the carbon atom from Grandma Johnson to a CO_2 molecule; he responds,

> *"If it breaths in oxygen and it uses respiration, which then the decomposer, converts the sugar into carbon, which then it through respiration converts that into an ATP molecule, which then it uses that ATP molecule. But through the process of respiration uses oxygen and converts it to carbon dioxide, so then the carbon dioxide's then breathed out.*

Although Adam's explanation is not without some error, he provides an account of the chemical change of carbon-based sugar to carbon dioxide through the process of respiration in decomposers. This explanation of change at a chemical level within the context of biochemical reactions is hallmark of Level 3 Achievement in decomposition (Table 8).

Table 8. Examples of student responses that indicate Level 3 Achievement in decomposition

	Student	*Decomposition Focus Responses*
Control Class (No DRP Task)	Adam	"If it breaths in oxygen and it uses respiration, which then the decomposer, converts the sugar into carbon, which then it through respiration converts that into an ATP molecule, which then it uses that ATP molecule. But through the process of respiration uses oxygen and converts it to carbon dioxide, so then the carbon dioxide's then breathed out."
	Shawn	"No, the decomposers will break it down, decomposers like bacteria will break down her remains…[carbon dioxide] goes to the bush, cause the bush absorbs what the decomposers decompose…[In] Cellular respiration…decomposition…the decomposers break down the remains and release. They decompose the carbon atoms and release carbon dioxide."
Experimental Class (DRP Task)	Mary	"It probably won't be recognizable at all of her body because of the bacteria in the soil and everything. She'll be fully decomposed by then… Well the decomposers, they do cell respiration and break down all the sugars and all the molecules in her body and it gets released into the atmosphere."
	Lucy	"Well the bacteria decomposes her body from when it was a carbohydrate. And they decompose it into a carbon atom, which can be like released as a carbon dioxide." (Interviewer: Are there any processes involved in that that you can think of?) "cellular respiration"

Also indicative of Level 3 understanding is the conversion of matter and energy in decomposition without respect to conservation laws. Notice how Rochelle's response includes the conversion of molecules into energy in the following interview exchange:

Interviewer: If Grandma J requests to be buried without a coffin, what will her gravesite look like 100 years from now?

Rochelle: It will be nothing. If anything there will possibly be bones because the decomposers decomposed her body's natural resources.

Interviewer: Where will the stuff that makes her up have gone?

Rochelle: It could be released into heat energy, to carbon, water, and it could just end up being soil.

Interviewer: Do you know of anything that might be produced?

Rochelle: Nitrogen, phosphorous, water, and carbon.

Interviewer: Describe how decomposers may be involved in the transfer of the carbon atom from Grandma Johnson to a CO_2 molecule.

Rochelle: So the matter is being deteriorated, it's going away so it's less and less. And the energy flow is turning the molecules into other energy forms, and it's being changed up, it's released.

Notice that Rochelle is able trace the decomposition of matter from Grandma Johnson at a macroscopic level to "nitrogen, phosphorous, water, and carbon" on an atomic and molecular level. However, she also includes "heat energy" in her list of "stuff" that made up Grandma Johnson's remains. Later she reveals her understanding that matter and energy are interchangeable further by stating that "energy flow is turning the molecules into other energy forms". This understanding marks the dividing line between Level 3 and Level 4 Achievement in decomposition. Level 4 Achievement includes complex descriptions of chemical change in decomposition within the context of biochemical processes explained with respect to physical laws of matter and energy conservation. No students in this study achieved Level 4 reasoning in decomposition.

Pre-Instruction Levels of Understanding in Energy Transformation. All interviewed students from both the experimental (participated in the respiration DRP task) and control (did not participate in respiration DRP task) classes provided evidence of Level 1 or 2 Achievement in energy transformation. Level 1 explanations in energy transformation focus on energy as an intrinsic property of living organisms, rather than flow through an ecosystem via biological and chemical processes. Seven of the 10 students in both the control and experimental class provided evidence in the pre-instruction interviews of Level 1 understanding in energy transformation. Three of those students interviewed provided evidence in their pre-instruction interview responses that they believed that energy was restricted to living organisms and that when an organism died the energy "died" along with them, or possibly leaked out after death. Take, for example, the exchange that occurred during the Grandma Johnson interview task (Appendix B) with Jacqueline, a low-achieving student from the experimental class:

Interviewer: Is there any energy left in Grandma Johnson's remains immediately after she is buried?

Jacqueline: No I don't think so

Interviewer: Where has energy gone?

Jacqueline: It's just gone, it is just dead, it's her bones

Interviewer: Any idea where it has gone?

Jacqueline: It is kind of in the dirt where she is buried.

Notice in Jacqueline's response her understanding of energy as a property connected with life; when Grandma Johnson dies and is buried, the energy is "dead" and "in the dirt where she is buried". Jacqueline was not the only student to explain energy in this way. Another student commented that the only energy left in Grandma Johnson's remains was in "cells that are still alive", and yet another responded that there is no energy at all left in her remains once she dies. Missing from Level 1 explanations was evidence of an understanding of the flow of energy through an ecosystem.

Level 2 Achievement was also common in the pre-instruction interview responses on focus questions in energy transformation. Level 2 explanations recognized energy flow through the ecosystem with unexplained, underlying mechanisms. These mechanisms were essentially "black boxes" through which energy was used and then moved on through objects and organisms. Absent from Level 2 explanations was evidence of understanding of energy transformation via biological and/or chemical processes. Lucy, a high-achieving student from the experimental class, demonstrates this common Level 2 initial conception in the excerpt from her pre-instruction interview that follows:

Interviewer: What different forms might energy take?

Lucy: Atoms? Like atoms and molecules? Probably like an energy molecule.

Interviewer: Where would that energy molecule come from?

Lucy: Well she got it from eating food that produces energy in your body.

Interviewer: Where did energy in that food come from?

Lucy: Well, for example if it were a salad, the plant that the salad came from would get it from photosynthesis, which is like energy from the sun and then she would eat the plant.

Interviewer: What if Grandma Johnson didn't like salad, she only liked steak?

Lucy: Then the animal that the steak came from would have consumed plants, and then they got their energy from the sun. That is how the cow got energy, and then she got her energy from the cow.

Interviewer: Where does energy ultimately go?

Lucy: After the coyote has released it, I think it just burns off, like calories.

Interviewer: So it would ultimately go where?

Lucy: Well when you are burning calories you are using your energy which comes off in sweat, and sweat is, I don't know, I guess in the dirt.

Here Lucy is able to trace the flow of energy through the ecosystem from organism to organism ("the animal that the steak came from would have consumed plants"), but does not mention any transformation of energy through various chemical or biological processes. She does mention photosynthesis, but describes it as "like energy from the sun". In her explanation, and that of many Level 2 responses, energy moves from the sun to a plant, where something unknown happens to it, then to an animal, where something unknown happens, and then to another animal, where it is simply "used".

In pre-instruction interview questions that focused on energy transformation, no students responded with explanations that included evidence of Level 3 or Level 4 reasoning.

Post-Instruction Levels of Understanding in Energy Transformation. Following student participation of the Ecosphere module, eight of 10 students that participated in post-instruction interviews from both the control and the experimental classes provided evidence of Level 2 or Level 3 reasoning in energy transformation. All eight of those students also showed evidence of progressing at least one achievement level in their understanding in energy transformation. The two students, one an average-achieving and the other an above average-achieving student, who did not progress from Level 1 understanding in energy transformation in the Grandma Johnson post-instruction interview task were both in the control class which did not participate in the respiration DRP task.

Examples of the types of gains made by students in the post-instruction interview energy transformation questions on the mouse and plant in a jar (Appendix B) are shown in Table 9. The key concept in progression to Level 3 reasoning was energy transformation via biological and/or chemical processes. Notice that in Lucy's pre-instruction interview she recognizes that energy flows from the sun to the plant to the mouse, but energy itself is not differentiated in forms. In her post-instruction interview response, Lucy distinguishes "light energy and solar energy" from "energy for the plant", and describes photosynthesis as the process involved in that conversion. Nearly all of the Level 2 pre-instruction interview responses followed in Lucy's level of reasoning (Table 9). In these pre-instruction interview responses, energy is nondescript and moves without transformation from sun to plant to mouse. In Level 3 post-instruction interview responses, like Lucy, several students add detail to their explanations about the different forms that energy takes as it flows and the biochemical processes of cellular respiration and photosynthesis that are involved. Mary speaks about the conversion of light energy to chemical energy in photosynthesis, Rochelle differentiates solar energy from other forms in food made by producers, and Noelle states explicitly that photosynthesis is a process that "transforms the energy because you can't make energy". These responses all show evidence of key understanding about the nature of energy transformation through an ecosystem.

Table 9. Examples of some of the student responses that indicate at least one Level of Achievement progression in Energy Transformation

Student	*Pre-instruction interview Energy Transformation Focus Excerpt*	*Level*	*Post-instruction interview Energy Transformation Focus Excerpt*	*Level*
Lucy	Sunlight provides the plant with energy and the plant turns it into food for itself…the mouse is consuming the plant's energy and the plant is producing its own.	2	[Plants] get [energy] through photosynthesis and cellular respiration…photosynthesis uses light energy and solar energy to produce energy for the plant, and cellular respiration doesn't need light to produce energy…The cells in the mouse…have to eat to get their energy so they can eat the plant to get their energy and through cellular respiration they produce some…energy.	3
Mary	They get [energy] from the sun and then [the plant] makes sugar from ATP…They get [energy] from food so [mice] could eat the plant or something.	2	Well the plant will get light energy and it then converts that to chemical energy. In photosynthesis oxygen is released, and that oxygen is used in cell respiration and that releases carbon dioxide in the air…Well because in photosynthesis I think it converts [energy] to ATP and ATP can power all of the cells.	3
Rochelle	[Plants] get [energy] through the sunlight and the water which creates glucose, and the plant uses that for energy…photosynthesis …the mouse cells have to eat food—it can't produce its own and it turns it into sugar and it goes throughout the body	2	Cells in the plant get [energy] from photosynthesis from the sun, from solar energy…Mouse cells get energy from breathing in oxygen and it goes through cellular respiration and then it gets [energy] from food from the producers.	3
Noelle	The sun gives the plant energy so it can grow and make the air and make its own food. [The mouse] gets [energy] from what food it eats and the water and the air	2	[Plants] get energy from the sun through photosynthesis, which transforms the energy because you can't make energy… Well [mice] could take up heat from the sun and with food, if they eat some of the plant, the mouse could take in some of the energy and transform it into something else…It could be energy for their muscles, for heat, most likely heat.	3

None of the students interviewed showed evidence of Level 4 Achievement in energy transformation. Unlike Level 3 Achievement in which students may convert matter and energy or explain energy as cycling in an ecosystem, Level 4 Achievement in energy transformation requires students to explain energy transformation in various forms through various systems while accounting for all of the energy, even that which is lost as heat, in the system. In her explanation, Noelle came close to Level 4 reasoning, as she was the only student that mentioned the transformation of energy to heat. However, her explanation was vague and did not demonstrate understanding of the loss of heat as a way of accounting for all of the energy in the system according to the law of conservation (Table 9). Other Level 3 post-instruction interview statements converted between energy and matter ("it converts [energy] to ATP", see Mary, Table 9) or seemed to explain energy as being created through respiration ("through respiration they produce some…energy" see Lucy, Table 9). These responses highlight the limits of student knowledge in the energy transformation concepts in this study.

Pre-Instruction Levels of Understanding in Cellular Respiration. Pre-instruction interview analysis revealed that students in both the control and experimental class had a very low level of understanding of cellular respiration prior to instruction. All of the pre-instruction interview responses analyzed revealed Level 1 Achievement in cellular respiration, except for one response which showed evidence of Level 2 Achievement. Level 1 Achievement in cellular respiration was evidenced by explanations in terms of the actions of separate organisms in the ecosystem that was disconnected from any biochemical processes. Examples of Level 1 student responses from both control and experimental class on one of the pre-instruction interview tasks focusing on cellular respiration are provided in Table 10. These responses were typical of all of the interviewed students' understanding prior to the Ecosphere instructional module, in which these students attempted to explain the movement of carbon dioxide *from* a bush or decomposing organism without cellular respiration. In fact, no students interviewed from either class offered cellular respiration as a process related to the transformation of carbon and/or the release of carbon dioxide. Rather, students explained plants releasing carbon dioxide for a wide range of reasons including "too much carbon dioxide", because carbon dioxide is "toxic", by "accident", or even as a part of "disgusting bubbles... cysts, even infections" (Table 10). Other pre-instruction interview explanations about the release of CO_2 from plants or decomposers were mechanical ("the decomposers could be decomposing her body and the air in her body could come out" or "it could just go out to the air"), or confused it with photosynthesis ("so the carbon dioxide goes into the bush and it just releases carbon dioxide…the bush has to go through photosynthesis to release" or "through photosynthesis"). Overall the pre-instruction interview evidence suggests that students in both control and experimental classes began at similar levels of understanding in cellular respiration prior to the Ecosphere instructional module.

Table 10. Examples of highest Levels of Achievement on pre- and post-instruction interview respiration focus responses to Grandma Johnson task questions asking students to "explain how a CO_2 molecule could be released by the creosote bush during its pathway of the carbon from Grandma J to the coyote, and describe how a CO_2 molecule could be released by decomposers during its pathway from Grandma J to the coyote." (Appendix B)

	Student	*Pre-instruction interview Respiration Focus Excerpt (Highest Scores)*	*Level*	*Post-instruction interview Respiration Focus Excerpt (Highest Scores)*	*Level*
Experimental Class (DRP Task)	Lucy	Well plants produce oxygen, so maybe [carbon dioxide] is released because [the plant] has too much carbon dioxide.	1	Well [decomposers] could decompose the plant, like a dead plant, and so they would have the carbohydrate they decomposed. Then through cellular respiration in their body they would let off carbon dioxide.	3
	Mary	Well as she is decomposing the plant is still living and taking in, like absorbing, some of the things she is decomposing. And then it could use that to help it survive. It would then release some of the things that are toxic to it, like carbon dioxide.	1	Well the carbon dioxide is taken from the atmosphere by the bush to complete photosynthesis, which then releases oxygen and that oxygen is used in cell respiration…in cell respiration it can break down the sugars…And then in cell respiration it releases carbon dioxide. Photosynthesis takes place when there is light energy from the sun, so it can only take place when that is present…[Cellular respiration] takes place all the time.	3
Control Class (No DRP Task)	Brandon	Well if the body is buried under the bush, I am pretty sure that somehow the CO_2 molecules can make its way through the roots and it will accidentally get let out into the atmosphere …decomposers have to take in oxygen and by taking in the carbon dioxide by accident they will release the carbon dioxide again by accident with other carbon dioxide.	1	Through cellular respiration. If [CO_2] goes through photosynthesis and it's turned into oxygen and taken back in to turn it into the carbon dioxide molecule through cellular respiration.	2
	Adam	As the decomposers breath in air they release CO_2 molecules and-- depending on the person who is buried-- there could be disgusting bubbles... cysts, even infections that could contain some CO_2 released by bacteria.	1	Respiration at night…respiration takes oxygen and shoots it out as CO2.	2

In another pre-instruction interview task, students were presented with a scenario in which they were asked to describe any processes that may provide energy for a plant placed in complete darkness (Appendix B). Only one student out of the 10 that were interviewed prior to instruction provided cellular respiration as an energy transformation process in plants, and a possible energy related process for a plant placed in complete darkness. This student, that mentioned cellular respiration, showed Level 2 Achievement in cellular respiration during the following exchange:

Interviewer: If a dark cloth was placed over the container, the plant would continue to have enough energy to survive for a few days. Where would this energy come from?

Mary: It could come from extra storage in cells--from like ATP storage.

Interviewer: Are there any processes that are involved in storage or taking out of storage?

Mary: Respiration maybe.

Interviewer: Talk a little bit about respiration. What do you know about respiration?

Mary: It's basically the process of letting them be able to breathe, kind of.

Interviewer: If the plant is taken out of the container and only the mouse is left, the CO_2 levels inside the container will quickly rise and the O_2 levels will quickly drop. Why does this happen?

Mary: Because the mouse is exhaling carbon dioxide and taking in the oxygen and once the oxygen gets low enough it would just keep filling up.

Interviewer: What do you predict would happen to the carbon dioxide levels and oxygen levels if the mouse is taken out of the container and only the plant is left?

Mary: I think the CO_2 levels would decrease and the oxygen levels would rise.

Interviewer: What if I told you that the CO_2 levels inside the container and the oxygen levels stay fairly stable. Why would that happen with only the plant in there?

Mary: Maybe if respiration is taking place it would balance out the O_2 levels.

Interviewer: Does respiration take place in plants?

Mary: Yes.

Although Mary mentions respiration as a process that may be involved in energy "storage" or "taking out of storage" her understanding of cellular respiration was rudimentary, evidenced by her explanation of respiration as "basically the process of letting [plants] be able to breathe". Also, she only suggests respiration as a CO_2 *producing* process when told that "the CO_2 levels inside the container and the oxygen levels stay fairly stable". Based on her responses, Mary's understanding of cellular respiration is best categorized as Level 2 Achievement, which describes cause and effect-based explanations of gas exchange without an explanation of the process of cellular respiration as an energy or matter transformation process. Mary's pre-instruction interview understanding of cellular respiration is a process that takes place in plants and produces carbon dioxide, but little more detail is known about the biochemical process of energy or matter transformation.

During the same pre-instruction interview task, all other students except for Mary showed Level 1 Achievement in cellular respiration. No other student mentioned cellular respiration as a process involved in energy transformation or use in plants. Many of the interviewed students explained that the plant utilizes stored energy "from what's left from before", from "energy it already had inside it", from "other cells that already had energy", from "the roots of the plant stored energy", or from the plant's "ability to store energy after it gets energy from the sun and [to use] that energy when it doesn't have sunlight". These types of descriptions are most closely categorized by Level 1 Achievement in cellular respiration in which students explain separate actions related to energy storage or release, without the connected, underlying, biochemical process of cellular respiration.

None of the students provided evidence in pre-instruction interviews of Level 3 or Level 4 Achievement in cellular respiration.

Post-Instruction Levels of Understanding in Cellular Respiration. Nine of 10 students provided evidence in post-instruction interviews of progression to at least one higher Level of Achievement. The majority of students showed evidence of Level 1 Achievement in pre-instruction interviews and progressed to Level 2 Achievement in cellular respiration during post-instruction interviews. Level 2 Achievement in cellular respiration is characterized by explanations of respiration as an energy-related process with unknown or hidden matter and/or energy transformation processes. Cellular respiration was essentially a "black box" in which oxygen entered, energy was utilized, and carbon dioxide exited. Many students displayed Level 2 understanding in which they offered cellular respiration as an explanation for carbon dioxide release, but were unable to provide an explanation of cellular respiration that satisfies current scientific research or in terms that show awareness of conservation laws of matter and energy. Both Adam and Brandon from the control class responded that cellular respiration was the underlying process that caused CO_2 to be released from the plant; however, their explanations of cellular respiration were not constrained by laws of matter conservation (i.e. CO_2 is "turned into oxygen and taken back in to turn it into the carbon dioxide molecule through cellular respiration" and respiration takes oxygen and shoots it out as CO_2", see Table 10), and contained alternative conceptions (i.e. respiration only occurs "at night", see Adam Table 10). Level 2 responses like these were common in post-instruction interviews and included explanations of cellular respiration that included mixed alternative and scientific conceptions (i.e. "when the plant is doing cell respiration it's giving off oxygen, it's also giving off carbon dioxide" or "cellular respiration, it uses...it happens during photosynthesis—like in that time too. It uses the oxygen and turns some of it into carbon because of the ATP storage"). In order to progress from Level 2 to Level 3 Achievement student responses would have to reflect an understanding of the molecular or chemical change and energy transformation occurring during cellular respiration.

The two students that did progress to Level 3 Achievement in cellular respiration were both from the experimental class which participated in the respiration DRP task. In the post-instruction interview Grandma Johnson task (Appendix B) one student from the experimental class, Lucy, was able to trace carbon from carbohydrates in Grandma Johnson's decomposing remains to carbon dioxide being released by decomposers during cellular respiration saying,

> *"Well [decomposers] could decompose the plant…and so they would have the carbohydrate they decomposed. Then through cellular respiration in their body they would let off carbon dioxide."* (See Lucy, Table 10).

This explanation bears the hallmarks of Level 3 understanding since respiration is described as a chemical process of matter transformation that occurs in plants (earlier in the same interview she explained that plants release CO_2 "through cellular respiration") and decomposers. Mary, another student from the experimental class, also provided evidence of Level 3 understanding in cellular respiration as she was able to describe cellular respiration as a process occurring in plants all the time, in which sugars were broken down and carbon dioxide was released. She said,

> *"oxygen is used in cell respiration…in cell respiration it can break down the sugars…And then in cell respiration it releases carbon dioxide…[Cellular respiration] takes place all the time."* (See Mary, Table 10)

During that portion of post-instruction interview, which was designed with questions meant to elicit discussion on cellular respiration, she focused on aspects of matter transformation during cellular respiration. This is characteristic of Level 3 Achievement in cellular respiration, in which cellular respiration is understood in terms of matter transformation or energy transformation, but not both. Also in Level 3 responses, lines between matter and energy are often blurred, with students readily converting matter to energy and vice versa.

Among the students that participated in post interviews, none provided explanations of cellular respiration that focused on energy transformation from bond energy in sugars to bond energy in ATP. A more dynamic explanation of cellular respiration that included matter and energy transformations limited by laws of conservation would have been characteristic of a Level 4 response. As such, none of the 10 students that participated in the post-instruction interviews provided evidence of Level 4 Achievement in cellular respiration.

A summary of the averages of pre- and post-instruction interview Levels of Achievement for student responses in each of the four concept focus areas is found in Table 11. Although interview data was coded, no statistical test was performed on these Levels of Achievement because there was such a low number of interview subjects (n=10). Notice that the averages of qualitative gains are larger in the experimental class for all four concept focus areas: matter transformation, decomposition, energy transformation, and cellular respiration. Not only are average pre- and post-instruction gains larger for the experimental class, but all average post instruction levels are higher in the experimental class (Table 11).

Table 11. Summary table of averages of qualitative pre- and post-instruction interview gains in Levels of Achievement in student responses in all four concept areas from students in both control and experimental classes

Concept Focus Area	*Average of Experimental Class (DRP Task) PRE-instruction Levels*	*Average of Experimental Class (DRP Task) POST- instruction Levels*	*Average of Control Class (No DRP Task) PRE-instruction Levels*	*Average of Control Class (No DRP Task) POST-instruction Levels*
Matter Transformation	1.25	2.33	1.56	2.25
Decomposition	1.50	2.38	1.50	2.00
Energy Transformation	1.75	2.63	1.67	2.00
Cellular Respiration	1.13	2.38	1.00	2.00

Qualitative Open Ended Written Response Results

Similar qualitative gains in student Levels of Achievement in matter transformation, decomposition, and energy transformation were observed in the analysis of written responses from the open ended questions in the pretest and posttest.

Matter Transformation Written Responses. In matter transformation focused questions on the pretest, a majority of written responses from the control class (10 of the 15 that were analyzed) and a majority of written responses from the experimental class (nine of 15) provided evidence of Level 1 Achievement. In their posttest responses, a majority of students in the control class (eight of 15) and in the experimental class (12 of 15) progressed at least one achievement level in matter transformation. Examples of achievement gains in student pre- and post-test responses are provided in Table 12.

Table 12. Examples of pre- and post- test written responses to matter transformation concept focused open ended questions

	Student	*Pretest Open Ended Matter Transformation Response*	*Level*	*Posttest Open Ended Matter Transformation Response*	*Level*
Experimental Class (DRP Task)	Alicia	The energy flow of the atom starts off with just being an oxygen molecule. Then Grandma takes that in and breathes out a CO_2 molecule; which the bush takes in and makes into oxygen	1	The decomposers would break down Grandma Johnson's remains, and send all the nutrients and energy into the bush through carbon dioxide. The bush would use the carbon to perform cellular respiration and let the CO_2 molecules out as oxygen.	2
	Carrie	Since Grandma Johnson is buried in the soil beneath a living bush, her body starts to decompose and release carbon. Since it is being released from her body and into the soil, the bush can use its roots to absorb the carbon within the soil. The plant can then use that carbon and respire when there is no sunlight, and release back into the atmosphere as a CO_2 molecule through the biological process of photosynthesis. Ultimately showing how the CO_2 went from grandma Johnson's remains to the air.	2	The carbon molecule moves from Grandma Johnson's remains back into the air like so: -First Grandma Johnson decomposes and creates sugar molecules from the carbon. -Then cellular respiration breaks down $C_6H_{12}O_6$ (sugar) -Cellular respiration then uses oxygen to release CO_2. This CO_2 travels up to the plant, where photosynthesis creates oxygen & $C_6H_{12}O_6$. Cellular respiration then takes place and releases CO_2 back into the air.	3
Control Class (No DRP Task)	Ed	The path that Grandma Johnson's CO_2 will rise and evaporate into the air once her body is fully decomposed under the creosote bush.	1	The path of a carbon atom to a CO_2 molecule is when the carbon cycle occurs, when this occurs the carbon atoms are then cycled through cell respiration. Then eventually transform into heat energy which is released.	2
	Kristen	Carbon in Grandma Johnson's remains seep through the soil and is absorbed by worms and fungi and other decomposers release the carbon molecules into CO_2 in the soil that is absorbed by the creosote bush and used in photosynthesis. those CO_2 molecules are turned into ATP, are used molecules are turned into ATP, are used at night for cellular respiration, and is once again CO_2	2	A carbon atom from Grandma Johnson's remains is transferred to the creosote bush through photosynthesis. The carbon atom is used in $C_6H_{12}O_6$, sugar, in the plant. At night cellular respiration occurs and energy is released from the sugar. The carbon atom is then released from the creosote bush as a CO_2 molecule.	3

Level 1 written responses in the pre-test focused on objects or individuals, such as Grandma Johnson or CO_2, and associated actions, like taking in or rising up, that were disconnected from biological or chemical processes such as respiration, photosynthesis, or decomposition (see Alicia and Ed's pre- and post-test, Table 12). A few students showed Level 2 understanding in the pretest and progressed to Level 3 in their posttest responses. Unlike their Level 2 pretest responses which stated, but did not describe, biological or chemical processes like respiration or photosynthesis, as mechanisms of chemical change, these students' posttest responses included a description of chemical changes within a biological process. For example, Carrie gives a nondescript mention of cellular respiration, writing that the "plant can use that carbon and respire when there is no sunlight" in her pretest, but in her posttest traces the molecular change of carbon through cellular respiration, stating that "cellular respiration breaks down $C_6H_{12}O_6$ (sugar)…then uses oxygen to release CO_2" (Table 12). This deeper level of understanding, in which a student recognizes the biological process through which matter can be traced, is evident in Level 3 Achievement in matter transformation.

Decomposition Written Responses. On pretest open-ended questions focusing on decomposition, a majority of responses from the control class (11 of 15 analyzed) and a majority of responses in the experimental class (11 of 15) provided evidence of Level 1 Achievement. In their posttest responses seven of 15 students in the control class and six of 15 in the experimental class gained at least one achievement level in decomposition. Examples of achievement gains in student pre- and posttest responses on decomposition are provided in Table 13. Qualitative gains similar to those observed during student interviews were noted in the open-ended written responses for decomposition. Students that provided evidence for Level 1 reasoning focused on the actions of organisms that were disconnected from any biological or chemical changes in decomposition. These Level 1 written explanations frequently focused on “decomposers” that “decompose”, “break down”, or “rearrange atoms” (see Kelly, Jen, Betty, Table 13), however the explanations were devoid of connected, cause-and-effect explanations of biological or chemical processes, hidden or otherwise. Students progressed to Level 2 Achievement in decomposition when they connected chemical change in decomposition to the biochemical process of respiration, even if certain alternate conceptions remain (see Betty, Table 13). Students that progressed to Level 3 described the type of chemical change occurring during respiration in decomposers as transforming glucose to carbon dioxide and releasing energy (see Kelly and Kristen, Table 13). Level 4 Achievement in decomposition was observed in one student in the experimental class whose written response included a complex description of decomposition in which all matter transformations were accounted for according to conservation laws (see Jen, Table 13). Gains in student written responses to open-ended questions in decomposition were not only qualitatively similar to gains observed in interviews, but were also qualitatively similar between experimental and control classes.

Table 13. Examples of pre- and post- test written responses to decomposition focused open ended questions

	Student	*Pretest Open Ended Decomposition Response*	*Level*	*Posttest Open Ended Decomposition Response*	*Level*
Experimental Class (DRP Task)	Kelly	The decomposers, such as bacteria and fungus, break down the remains of Grandma Johnson. Once broken down, the decomposers rearrange the atoms into a CO_2 molecule.	1	Without decomposers, Grandma Johnson's remains wouldn't decompose. The decomposers break down the glucose in the remains & transform it into CO_2 through the process of cell respiration.	3
	Jen	Decomposers break down the carbon atom. They do this so the carbon can transfer to the CO_2 molecule	1	The decomposers decompose Grandma J. As they are doing this, they release CO_2 and H_2O. The CO_2 and H_2O come from the sugar molecule $C_6H_{12}O_6$ in Grandma J. The decomposer releases the CO_2 as a buy product (*sic*.).	4
Control Class (No DRP Task)	Betty	Decomposers are involved because if she's dead her body like decomposes and the tree takes what's decomposed. Not the bones obviously.	1	Her body decomposes into the bush and it is given as CO_2 out of the plant when photosynthesis/ respiration occurs if respiration occurs it is because there is no light energy obtained 2 photosynthesis releases oxygen while respiration releases CO_2 AND uses it	2
	Kristen	Decomposers use the carbon atoms in the soil to fertilize it for the creosote bush to use in photosynthesis, and cellular respiration at night.	2	Decomposers break down Grandma Johnson's body and release organic nutrients into the soil. Those nutrients into the soil. Those nutrients are absorbed by the creosote bush and used in photosynthesis to create sugar. At night, cellular respiration occurs and releases the energy from the sugars, and the plant releases CO_2 as a biproduct (*sic*).	3

Energy Transformation Written Responses._On pre-test open ended questions with an energy transformation focus, evidence of Level 1 or Level 2

Achievement in their written responses was found in similar frequency in both the control class (15 of 15) and in the experimental class (14 of 15). In their posttest responses a majority of students in the control class (10 of 15) and a majority in the experimental class (nine of 15) progressed at least one achievement level in energy transformation. Examples of achievement gains in energy transformation from student pre- and posttest responses are provided in Table 14. In Level 1 responses in both classes students explained energy being "brought in", "tuned out", or used by living organisms without referring to biological processes, energy transformations, or flow through an ecosystem (see Jake and Joan, Table 14). Level 2 responses in both control and experimental classes explained energy flow through objects and organisms in an ecosystem ("…from the sun [which] gets absorbed by a plant…the coyote eats that plant" Michelle, Table 14) without respect to transformational forms such as solar or chemical energy. Student progression from Level 1 to Level 2 reasoning in energy transformation occurred in both classes in similar frequencies, as did progression from Level 2 to Level 3. Students that progressed to Level 3 reasoning explained energy flow in various forms ("solar energy", "bond energy", "chemical energy", Michelle and Riana, Table 14) transformed via biological processes of respiration and/or photosynthesis. Students at Level 3 reasoning often explained energy flow without respect to conservation laws and frequently converted matter and energy ("…molecules from the plant are broken down …and are used to power the coyote", Riana, Table 14). Level 3 responses also neglected to trace all of the energy in the system even that which is lost as heat (see Michelle and Riana, Table 14).

Table 14. Examples of pre- and post-test written responses to energy transformation open-ended questions

	Student	*Pretest Open Ended Energy Transformation Response*	*Level*	*Posttest Open Ended Energy Transformation Response*	*Level*
Experimental Class (DRP Task)	Jake	Energy is brought in by a plant during photosynthesis then turned out to the coyote. Also from grandmas body decomposing down their (*sic*.).	1	Energy flows from sunlight into plants in a process called photosynthesis. From there whatever herbivore eats the plant going energy from it and therefore owns it. After that the coyote being a carnivore will eat the animal that ate the plant with the sunlight energy and now has it passed on to him.	2
	Michelle	the light energy from the sun gets absorbed by a plant through photosynthesis it becomes a sugar and if the coyote eats that plant the sugar from photosynthesis can be used to power the leg	2	Solar energy can be absorbed by a plant and take place in photosynthesis. After photosynthesis that solar energy is now bond energy within a sugar molecule produced from photosynthesis. When the coyote eats that plant, the sugar from photosynthesis in the plant can now be used in cell respiration. That bond energy in the sugar can now be transformed into bond energy inside ATP which will power the leg muscle in the coyote.	3
Control Class (No DRP Task)	Joan	Once the coyote processes that energy into the nutrients it needs it and use the energy to survive in its environment.	1	A plant goes through photosynthesis using the sun. The plant gets eaten by an animal like a rabbit. The coyote eats the rabbit and uses the energy that transfers from the plant to the rabbit to power the leg	2
	Riana	Energy from the sun flows into plants in the coyote's habitat and will cycle in the plants to make the plants own energy (photosynthesis). Then the coyote would consume the plant and get nutrients from the plant that would be transferred throughout its body, like its leg muscle.	2	First, solar energy is used in a plant to be used in photosynthesis and makes sugar. Then through photosynthesis, the solar energy is transformed into chemical energy and is used in cellular respiration to make ATP. The coyote then eats the plant and molecules from the plant are broken down inside the coyote and are used to power the coyote and its leg muscle	3

Cellular Respiration Written Responses. Analysis of open ended written responses revealed further insight into student understanding of cellular respiration, and the differences observed between the control and experimental classes. In cellular respiration focused questions on the pretest, students in both the control and experimental class provided evidence of similar understanding before the Ecosphere module with a majority of responses from the control class (11 of 15 analyzed) and a majority of responses in the experimental class (eight of 15) providing evidence of Level 1 Achievement. Following the Ecosphere module, in their posttest responses, a qualitative difference was observed between the control and experimental classes in Level of Achievement gains in cellular respiration that was not observed in the other focus concepts. Examples of responses showing achievement gains in student pre- and posttest responses in cellular respiration are provided in Table 15. Although similar numbers of students improved in cellular respiration in both classes, more students in the experimental class (four of 15) than the control class (one of 15) progressed to deeper achievement levels (Level 3 or 4) in cellular respiration. In the control class none of the students that began at Level 2 Achievement in cellular respiration progressed to a higher Level of achievement, whereas two students in the experimental class progressed from Level 2 to 3, and one student in the experimental class progressed from Level 3 to Level 4 (Table 15). Students in the experimental class that progressed from Level 2 to Level 3 where able to describe the process of chemical change that occurred during respiration while tracing matter. In their posttest, these students recognized that CO_2 was released from plants during respiration as a result of "sugars" or "$C_6H_{12}O_6$" being "decomposed" or transformed (see Scott and Lucy, Table 15). Student responses analyzed from the control class that provided evidence of a Level 2 understanding on the pretest did not progress to any deeper level of understanding in cellular respiration (Table 15).

Table 15. Examples of pre- and post-test written responses to cellular respiration concept focused open ended questions in students that began at similar levels on pretest responses.

	Student	*Pretest Open Ended Cellular Respiration Response*	*Level*	*Posttest Open Ended Cellular Respiration Response*	*Level*
Experimental Class (DRP Task)	Scott	because during cellular respiration CO_2 is released	2	$O_2 + C_6H_{12}O_6$ = energy (ATP) + CO_2, by this formula we can see that CO_2 is released during cellular respiration.	3
	Lucy	because cellular respiration produces CO_2 gas.	2	Decomposers decompose sugars and with cellular respiration produce CO_2	3
Control Class (No DRP Task)	Ed	Because cellular respiration is the process of releasing CO2	2	because [CO_2] is released as bi product (*sic.)*	2
	Riana	Since cellular respiration occurs continuously and there is excess carbon dioxide that's released.	2	cellular respiration releases oxygen, not CO_2	1

Although none of the 10 students that were interviewed provided evidence of Level 4 Achievement in their interview responses in any of the four concept focus areas, three of the 30 students whose open ended written responses were analyzed provided evidence of Level 4 Achievement in at least one of the concept focus areas. Selections from these Level 4 responses are provided in Table 16. Level 4 responses are complex descriptions in which students account for the flow of all matter or energy in a system through various chemical changes within biological or chemical processes according to conservation laws. Level 4 understanding takes into account many factors and is rooted in an understanding of physical laws, so it is not surprising to observe Level 4 Achievement in one student in more than one concept focus area. For example, Kelly's Level 4 understanding in matter transformation is dependent upon her ability to trace matter during cellular respiration, and her Level 4 Achievement in cellular respiration is similarly dependent on her understanding on the transformation of glucose and carbon dioxide during the process (Table 16). Although this result could have been predicted, there were students that provided evidence of Level 4 reasoning in one concept focus, but not in others. One example is Greg who provided evidence of Level 4 achievement in energy transformation, but not in any of the other concept focus areas. In his description he explained energy being transformed "from bond energy in the glucose molecule to bond energy in ATP…used to power the cells in the leg muscle, and given off as heat energy" (Table 16), which is evident of a complex understanding of energy transformation and flow through processes and organisms. However, he does not explicitly describe the process as occurring during cellular respiration, and he is not very descriptive of matter transformations that occur during those energy transformations. This suggests that his understanding in energy transformation is deeper than his understanding in cellular respiration or matter transformation.

Table 16. Examples of Level 4 reasoning observed in post-test written responses on matter transformation, decomposition, energy transformation, and cellular respiration.

Concept Focus Area	*Student*	*Class*	*Posttest Written Responses*
Matter Transformation	Kelly	Experimental	Decomposers break down Grandma Johnson's remains through cell respiration. CO_2 is released through cell respiration. The creosote bush takes in the CO_2 and is transformed into $C_6H_{12}O_6$ through photosynthesis. The plant then breaks down the $C_6H_{12}O_6$ using cell respiration into CO_2, which is released into the air.
Decomposition	Jen	Experimental	The decomposers decompose Grandma J. As they are doing this, they release CO_2 and H_2O. The CO_2 and H_2O come from the sugar molecule $C_6H_{12}O_6$ in Grandma J. The decomposer releases the CO_2 as a buy product (*sic.*).
Energy Transformation	Greg	Control	Solar energy is absorbed by the plant and turned into bond energy in glucose through photosynthesis. This glucose is then eaten by a prey of a coyote, like a rabbit, which absorbs it, until it is eaten by a coyote. The coyote then transforms the bond energy in the glucose molecule to bond energy in ATP. This bond energy is used to power the cells in the leg muscle, and given off as heat energy.
Cellular Respiration	Kelly	Experimental	…glucose is broken down in cellular respiration. CO_2 is the by product and is released…The glucose is broken down in cell respiration & the energy transfers to bond energy in ATP. The ATP is used to power the leg muscle in a coyotes. Eventually, the bond energy will be released as heat energy into our atmosphere.

Discussion

This study provides further evidence of the effectiveness of the Ecosphere module in promoting student achievement gains among students in both experimental and control classes in the focus concept areas of matter transformation, decomposition, and energy transformation similar to those seen by Maskiewicz (2006) and Maskiewicz et al. (2012b). In their study of the Ecosphere module (without the respiration DRP task designed for this study) Maskiewicz et al., (2012b), identified student difficulties in understanding cellular respiration following instruction; difficulties which provided the impetus for the research goal in this study. The research question of this study—Does student completion of a data-rich problem (DRP) task focused on cellular respiration, embedded in the Ecosphere® problem set, improve students' understanding of cellular respiration at the ecosystem level?—guided the investigation into determining if the Ecosphere® module could be modified to improve understanding. As a result, evidence was shown that the development and implementation of the imbedded, design-based DRP situation focusing on cellular respiration is, in fact, effective in promoting significant gains in student achievement in cellular respiration. Although significant quantitative gains in focus concepts areas were shown in students from the control class, only students in the experimental class who participated in the respiration DRP task showed significant quantitative gains in the cellular respiration focus area. Qualitative data also showed that many of the students interviewed from both experimental and control classes gained at least one level of achievement in their post-instruction interview responses in concept focus areas of matter transformation, decomposition, and energy transformation. However in cellular respiration, students from the experimental class who participated in the respiration DRP tasks provided qualitative evidence of deeper levels of achievement in their post-instruction interviews and open ended responses than students in the control class. Findings from both qualitative and quantitative data collected in this study are consistent; this supports the validity of the data in showing the effectiveness of the respiration DRP task in improving high school student understanding in cellular respiration.

Although significant gains in focus areas of matter transformation and energy transformation occurred in the control class, larger normalized gains were observed in the experimental class. In addition, significant gains in the topic of decomposition were observed in the experimental class and not in the control class. These larger gains made by the experimental class in the three "non-respiration" focus concept areas may be explained by a deeper understanding of cellular respiration in students from the experimental class. Cellular respiration is a key concept that both draws from and lends to understanding in other concept foci. Thus, if a student understands the conversion of glucose to carbon dioxide during cellular respiration, she is likely to have a better grasp of the law of conservation of matter that involves transformations. Also, if a student understands that energy transformation through an ecosystem is constrained by energy conservation laws, she is more likely to be able to apply that knowledge to the transformation of bond energy occurring during cellular respiration. Additionally, since decomposition in the Ecosphere module highlighted the cycling of carbon, it is no surprise that students with a deeper level of understanding in cellular respiration were better equipped to discuss chemical change in decomposition within the context of the biological process of respiration occurring in decomposing organisms. This *overflow* effect of understanding one concept focus leading to increased understanding in another concept focus speaks to the need for similar curricular bridges between physical and biological sciences noted by others (Carlsson, 2002a, 2002b; Mohan et al., 2009; Nordine et al., 2011; Wilson, et al., 2006). It also gives greater credence to a "systems" approach to learning processes like cellular respiration or photosynthesis within the context of physical, biochemical, or ecological levels as has been suggested by some studies (Brown & Schwartz, 2009; Lin & Hu, 2003; Songer & Mintzes, 1994).

Although the Ecosphere module was originally designed in a college undergraduate setting, this study shows that it can be successfully implemented in a high school classroom setting and lead to improved understanding. Noteworthy is that fact that the gains in this study were observed in classes with a high population of low achieving ninth grade students. In fact, the analysis of g and $\bar{g}$ values provide insight into the types of gains made through the course of the Ecosphere module. Although, at first appearing to be the same calculation, Bao (2006) suggests that differences between these two normalized gain calculations (i.e. mean of normalized gain ($\bar{g}$) and the normalized gain of means (g)) can provide insights into the types of gains made by experimental groups. When a class has a larger normalized gain of mean values than mean of normalized gain, individual students with lower pretest scores tend to have higher gains than students with higher pretest scores. Similarly, when a class has a smaller normalized gain of mean (g) than mean of normalized gain ($\bar{g}$), students with lower pretest scores have either similar, or even smaller, gains than individual students with higher pretest scores (Bao, 2006). Larger normalized gain of mean (g) values than mean of normalized gain ($\bar{g}$) values in this study revealed that students in the control class that had low pretest scores tended to make larger gains in the posttest than the gains made by students that had higher pretest scores across all concept focus questions. Larger g values than $\bar{g}$ values for questions focused on matter transformation, decomposition, and energy transformation shows that students in the experimental class that had low pretest scores made larger gains in the posttest than the gains made by students that had higher pretest scores. For questions focused on respiration, g values and $\bar{g}$ values were the same, suggesting that there was no difference between the gains made by students who scored low and students that scored high on the pretest in the experimental class which participated in the respiration DRP tasks. These results suggest that the Ecosphere module along with the embedded DRP tasks can be very effective in promoting student achievement across a wide range of student performance levels and educational contexts.

This study, however, is not without limitations. Although evidence of Level 4 reasoning was observed in the open ended posttest written responses in every concept focus area (Table 13), there were only three students out of 30 that provided such a high level of achievement. These results parallel Mohan et al. (2009) who also found only 10% of high school students in their study could provide Level 4 explanations post-instruction. This suggests that although student understanding gains occurred, student gains were modest and did not result in learning that was scientifically complex and free from alternative conceptions. There are several possible reasons for this. First, students may not have been given adequate opportunity to express their complete understanding through interviews or open ended questions; that is, students may have provided responses that they felt were satisfactory for the assignment, but were not full descriptions of their knowledge on a given topic. This may be characteristic of a large population of low achieving students who may not have a long academic history of being encouraged to strive to be thorough in written or oral explanations. On the curriculum end, the activities and tasks may not have elicited the kind of deep thinking that leads to Level 4 reasoning. There is room for even more refinement of activities and tasks to engage all students in reasoning and problem solving that leads to Level 4 Achievement.

Although gains in student achievement in cellular respiration were observed, many alternative conceptions remained in student explanations in the post-test and post-instruction interviews. This result was not too surprising given research that suggests that alternative conceptions are resistant to change even after repeated instruction (Songer & Mintzes, 1994; Tamayo & Sanmarti 2007; Anderson et al., 1990). It does, though, suggest that improvements could be made to the Ecosphere® module or to the cellular respiration DRP tasks specifically, to challenge common alternative conceptions or improve the formation of scientifically accurate conceptions. If Level 4 reasoning is the goal, then modifications or improvements could be made to foster deeper thinking. This takes time. It is important to mention again that the Ecosphere® module in this study was implemented over a one week period. Students should be given additional time and opportunities to apply their knowledge to new problem-solving contexts.

Conclusions and Implications

Not only does this study provides evidence of the effectiveness of participation in a cellular respiration DRP situation to improve student understanding in cellular respiration, the student gains observed in this study show that it is possible to design and refine effective instructional modules that improve student achievement in concept focus areas targeted for growth. This type of instructional refinement through research and practice is the goal of design-based research (Collins & Bielaczyc, 2004; Fortus, et. al, 2004; Design Based Research Collective, 2003). This study focused on developing and testing curricular activities with real-world, problem solving tasks rich with analyzable data in one conceptual focus; cellular respiration. However, I am confident that, through this type of design-based approach, instructional refinement can be achieved in any targeted concept focus area, even in those with a well-researched and documented history of student alternative conceptions, like cellular respiration.

Design-based research provides the framework for further refinement and future study into ways in which to elicit complex, Level 4, reasoning in areas such as decomposition, cellular respiration, and matter and energy transformations within an ecosystem. Improvements or adjustments to the Ecosphere module used in the current study, or the design of new real world data rich problem solving tasks could provide effective, contextualized learning environments for future design-based educator-researchers to pursue. This is the call of a new era in education that is marked by not only new ways of teaching, but new ways for students to demonstrate learning within an educational context. As an educator-researcher in California, currently in the process of transitioning from NCLB California state biology standards to implementing Next Generation Science Standards, demonstrating learning is a call I hear loud and clear. The difference between the two standards is marked; no longer is it simply expected that "students know…" (the repeated phrase throughout the NCLB California Content standards in Science), but it is expected that "students who demonstrate understanding can…" (the repeated stem of the Next Generation Science Standards). The shift represents an important refocusing of the burden of education to provide students with the intellectual and experiential capital with which to demonstrate their understanding.

This study shows that student conceptions are capable of change when students are presented with sufficient and relevant data along with a motivating problem to which to apply their ideas. By giving students data to analyze and hypothesize over, rather than simple direct instruction, educators are able to design educational experiences that engage students in the process of socially constructed knowledge formation. In this way, students are given the motivational power to take control of their own knowledge formation and refinement, rather than being passive observers in the learning environment.

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APPENDIX A

Ecosphere® Module* with Cellular Respiration DRP

(*Ecosphere module found at https://sites.google.com/site/ecospheremodule/)

Instructional Block 1

Ecosphere Task 1: (With your group)

The ecosphere is a self-contained miniature ecosystem encased in glass. Inside each ecosphere are micro-organisms (bacteria), red brine shrimp, algae, and filtered sea water. The ecosphere is a self-sustaining ecosystem, so you never have to feed the life within. These small spheres can survive for more than eight years. The large spheres have been known to last for over 20 years. The ecosphere will thrive for over eight years without the owner having to add or remove anything from the sphere. However, this is not the case with any combination of organisms in a closed container. The company that created these spheres had to find the right combination of organisms that would survive together for an indefinite period of time.

Explain why this combination of organisms allows this sphere to survive for such a long time? Be specific. Provide a diagram to represent your ideas.

Group Discussion: Record your group's diagram on a white board and be prepared to share it with the class. (Information Sheets provided)

Ecosphere Task 2: (On your own)

A student analyzing the sphere hypothesized that if the algae, or the bacteria, or the brine shrimp were removed from the sphere, the other organisms in the sphere would not survive. Do you agree with this? Why or why not? Explain.

(Provide a detailed response that includes an explanation, your reasoning, and possibly a diagram if that would provide further support for your claim.)

Ecosphere Task 3:

When the algae or the bacteria are removed from the sphere, all the organisms in the sphere do indeed die. However, when the shrimp are removed from the sphere, the sphere is still able to survive indefinitely. The algae and bacteria continue to grow and survive. Explain why or how this is possible. Be specific.

[Hint: Data handout on the composition of the Ecosphere water over time can be used to solve the problem.]

Handout on the composition of the Ecosphere water over time

Ecosphere Water Quality Data - With Bacteria, Snails & Algae

Parameter	**After 100 days**
Turbidity	Within acceptable levels
Dissolved Oxygen	Within acceptable levels
Carbon Dioxide (CO_2)	Within acceptable levels
Oxides of Nitrogen (NOx)	Within acceptable levels
Ammonia (NHx)	Within acceptable levels
Dissolved Phosphorus (POx)	Within acceptable levels
Organic Phosphorus (P)	Within acceptable levels

*x stands for a number (2, 3, 4, etc).

Turbidity: measured in Nephelometric Turbidity Units
(NTU)
A measurement that provides an estimate of the muddiness or cloudiness of the water due to clay, silt, fine organic and inorganic matter, soluble colored organic compounds, plankton, and microscopic organisms. A nephelometer is used to measure how much light is scattered by suspended particles in the water. The greater the scattering, the higher the turbidity. Therefore, low NTU values indicate high water clarity, while high NTU values indicate low water clarity.

Carbon Dioxide (CO2): Carbon Dioxide dissolves in water and combines with other chemicals in the water to form various compounds.

Nitrogen and Phosphorus are essential to the growth of organisms. Nitrogen and Phosphorus present in water may be bound up in plant or animal tissue, in which case it is referred to as "organic".

Ecosphere Water Quality Data - No Algae. (has shrimp and bacteria)

Parameter	After 100 days
Turbidity	Just barely within acceptable range
Dissolved Oxygen	Significantly below acceptable levels
Carbon Dioxide (CO_2)	Above acceptable levels and increasing
Oxides of Nitrogen (NOx)	Within acceptable levels
Ammonia (NHx)	Significantly below acceptable levels
Dissolved Phosphorus (POx)	Within acceptable levels
Organic Phosphorus (P)	Significantly above acceptable levels

Ecosphere Water Quality Data - No Bacteria. (has shrimp and algae)

Parameter	After 100 days
Turbidity	Significantly above acceptable levels
Dissolved Oxygen	Within acceptable levels
Carbon Dioxide (CO_2)	Just below acceptable levels
Oxides of Nitrogen (NOx)	Significantly below acceptable levels
Ammonia (NHx)	Significantly above acceptable levels
Dissolved Phosphorus (POx)	Significantly below acceptable levels
Organic Phosphorus (P)	Significantly above acceptable levels

Ecosphere Water Quality Data - No Shrimp. (has bacteria and algae)

Parameter	After 100 days
Turbidity	Within acceptable levels
Dissolved Oxygen	Within acceptable levels
Carbon Dioxide (CO_2)	Within acceptable levels
Oxides of Nitrogen (NOx)	Within acceptable levels
Ammonia (NHx)	Significantly below acceptable measures (at 0).
Dissolved Phosphorus (POx)	Within acceptable levels
Organic Phosphorus (P)	Within acceptable levels

Ecosphere Task 4: (Class Discussion)

Consider the following statement: “Heterotrophic bacteria need carbon…They get their carbon from decaying organic debris.”

> Thinking about the sphere with algae and bacteria only, what is “organic debris” in this sphere? What is the mechanism for it decaying? In other words, does something decay it or does it decay on its own after it dies? What is your evidence?

In a sphere with algae only (bacteria and shrimp are removed),

- i) why does the algae die?
- ii) why doesn’t the algae breakdown/decompose/dissolve?

Ecosphere Task 5: (In Groups)

One of the functional roles of the bacteria is to keep the sphere clean by removing the shrimp waste. In the first trials to create a functioning sphere, the researchers used small snails similar to those in a fish tank. These snails are known to eat the waste of fish, brine shrimp and other marine organisms. Although the snails were able to keep the sphere “clean” the brine shrimp and algae did not survive for a long period of time. Explain why the snails were not able to keep the sphere alive.
[Hint: Data on the composition of the sea water with shrimp, algae, and snails is included below.]

Ecosphere Water Quality Data - No Bacteria
With Snails, Shrimp and Algae

Parameter	Acceptable Range	Day 1	Day 10	Day 20	Day 30	Day 100+
Turbidity	10 - 25 NTU	12	16	15	13	14
Dissolved Oxygen	> 5.0 mg/L	6.3	6.6	6.4	6.5	6.3
Carbon Dioxide	> 2.5 mg/L	3.1	3.5	3.2	3.3	3.2
Oxides of Nitrogen (NOx)	0.05 - 0.09 mg/L	0.06	0.057	0.053	0.05	0.041
Ammonia (NHx)	0.02 - 0.05 mg/L	0.03	0.035	0.041	0.045	0.044
Organic Phosphorus (P)	0.010 - 0.05 mg/L	0.015	0.025	0.029	0.038	0.037
Dissolved Phosphates (POx)	0.02 - 0.09 mg/L	0.05	0.045	0.039	0.031	0.009

Ecosphere Task 6: (In Groups and then Shared on Whiteboards)

Part A: If the sphere is placed in a closed box (a dark environment) after a period of weeks everything in the sphere dies. What role does light play in keeping each of the organisms alive? Brainstorm ideas with your group and be prepared to defend your answer to the class.

> The sun provides *light energy* to the plant. Create a diagram of the role of energy in keeping the system alive.

Part B: Consider the following statement: If energy cycles like matter does, then I should be able to put a plant in the sunlight for a week, then remove it from the light and it should survive in a box (or unlit place) for years because the energy it was supplied with would keep cycling. But we know that this is not true – the plant dies. How can you account for this?

> Now apply this idea to the ecosphere. If needed, revise your diagram from Part A.

Part C: Create a diagram showing the flow of 100 units of energy through the ecosphere. Begin with 100 units of energy coming from the sun to Earth.

Cellular Respiration Data-Rich Problem Task

Ecosphere Task 7: (In Groups, then class Discussion)

If both bacteria and brine shrimp are removed so that the algae is the only living organism left in the ecosphere the algae will die in a few weeks. Explain in detail why the algae die.

Ecosphere Task 8: (In your Group)

Below is a data table showing the water quality over the first 100 days of an experiment in which both bacteria and shrimp are removed so that algae is the only living organism. Does the data in the table support your explanation as to why the algae die (in Task 7)? Refer to specific parameters (turbidity, dissolved oxygen, carbon dioxide, etc) in the table to defend your explanation.

Ecosphere Water Quality Data – Algae Only
No Shrimp or Bacteria

Parameter	**Acceptable Range**	**Day 1**	**Day 10**	**Day 20**	**Day 30**	**Day 100**
Turbidity	10 – 25 NTU	12	13	11	13	12
Dissolved Oxygen	> 5.0 mg/L	6.5	6.6	6.6	6.5	6.3
Carbon Dioxide	> 2.5 mg/L	3.1	3.5	3.3	3.3	3.4
Oxides of Nitrogen (NOx)	0.05 – 0.09 mg/L	0.06	0.057	0.053	0.05	0.041*
Organic Nitrogen (N)	0.010 – 0.05 mg/L	0.021	0.026	0.034	0.041	0.052*
Organic Phosphorus (P)	0.010 - 0.05 mg/L	0.015	0.025	0.032	0.043	0.053*
Dissolved Phosphates (POx)	0.02 - 0.09 mg/L	0.05	0.041	0.032	0.021	0.011*

*outside acceptable range

Ecosphere Task 9: (On your own)

Look again at the data on dissolved oxygen and carbon dioxide. In the sphere that contains algae only (no bacteria or brine shrimp), where does the oxygen and carbon dioxide in the ecosphere come from? Explain in detail and include a drawing/diagram if it aids in your explanation.

If the sphere is placed in a closed box (a dark environment) for three days, the algae will not immediately die, but it will lose mass. Why does the algae lose mass and where does this mass go?

Ecosphere Task 10: (On your own)

Based on your explanation in task 8 and task 9, go back and revise your explanation in task 6, if necessary. In your explanation or revision make sure to refer to data in the table.

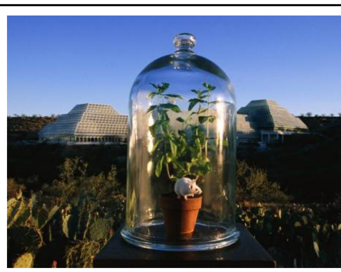
APPENDIX B
Interview Protocol

Topic: Student understanding of matter transformation, decomposition, energy transformation, and respiration within an ecosystem

Goal:
I want to know what subjects understand about the learning objectives (focusing on matter transformation, decomposition, energy transformation, respiration) of the Ecosphere tasks. How do students understand the transformation of matter and energy within an ecosystem? What conceptions do students have about the role of decomposers and decomposition in an ecosystem? What sense do students make of the role of respiration in the cycling of matter within an ecosystem?

Introduction Script:
Thank you for helping me with my research today. I will be asking you some questions, and I am interested in what you think and why you think it. If you don't understand something, just let me know. I really want to find out what you think about these ideas; I am not interested in right or wrong answers. Your ideas will be analyzed to help understand how people learn so that researchers, including myself, can develop better ways of helping people learn this topic.

Task #1: A Mouse and Plant in a Jar



Photograph by Peter Essick

Assuming the container in the picture is sealed, both the mouse and the plant will survive until they run out of food or water. However, if the plant is taken out of the container and the mouse is left in the container, it will die in a few minutes. Why?

Follow-up question(s):

Matter Transformation Focus

- What "stuff" does the plant provide to the mouse? Why is it so important that without it the mouse dies in just a few minutes?

- Is there anything that the mouse provides to the plant? Is that stuff as important as what is provided by the plant?
- What do you predict will happen to the plant if the mouse is taken out of the container and it is then sealed?
    - What would you say if I told you that the plant actually lives? How is this possible?

Decomposition Focus

- If the mouse does die, what might the container look like after a week? A month? A year?
- Could the death of the mouse provide anything for the plant? If so, what, how? If not, would it be any different if the same thing happened in a natural forest?
    - Are there any other living things that would have to be in the container for the dead mouse to provide anything to the plant?

Energy Transformation Focus

- How do the cells in the plant get energy? Is the way that plant cells in this container get energy different from the way that mouse cells get energy?
- If the mouse was removed from the container and it was resealed, would the plant be able to get energy? Why or why not? Where would it get energy from?

Respiration Focus

- If a dark cloth was placed over the container, the plant would continue to have enough energy to survive for a few days. Where would this energy come from?
- If the plant is taken out of the container and only the mouse is left, the CO_2 levels inside the container will quickly rise and the O_2 levels will quickly drop. Why does this happen?
- If the mouse is taken out of the container and only the plant is left, the CO_2 levels inside the container and the O_2 levels stay fairly stable. Why does this happen?

Task #2: Grandma Johnson

Grandma Johnson had very sentimental feelings toward Johnson Canyon, Utah, where she and her late husband had honeymooned long ago. Because of these feelings, when she died she requested to be buried under a creosote bush in the canyon. Describe below the path of a carbon atom from Grandma Johnson's remains, to inside the leg muscle of a coyote. Be as detailed as you can be about the various molecular forms that the carbon atom might be in as it travels from Grandma Johnson to the coyote. ***NOTE:*** *The coyote does not dig up and consume any part of Grandma Johnson's remains.*

Follow Up Questions:

Matter Transformation Focus

- After giving them an opportunity to answer, students are presented with cards on which the following is written:
  $C_6H_{12}O_6$ (carbohydrates) (4 cards), CO_2 (3 cards) Grandma Johnson, Coyote, Bacteria/Fungi, Creosote Bush, Photosynthesis, Cellular Respiration, Atmosphere, Rabbit
- Using any of the cards you would like, arrange the cards in any way that you think may help your explanation.
- Explain why you chose not to use some of the cards.

Decomposition Focus

- If Grandma J requests to be buried without a coffin, what will her gravesite look like 100 years from now? Will anything be left of her? Where will the stuff that makes her up have gone?
- Describe how decomposers are involved in the transfer of the carbon atom from Grandma Johnson to a CO_2 molecule.

Energy Transformation Focus

- Is there any energy left in Grandma Johnson's remains? If so, where is that energy located? If not, where has the energy gone? (Be specific)
- How does energy flow from Grandma Johnson to power the leg muscle in the coyote?
- What different forms does energy take?
- Where does the energy first come from? Where does the energy ultimately go?

Respiration Focus

- Explain how a CO_2 molecule could be released by the creosote bush during its pathway from Grandma J to the coyote.
- Describe how a CO_2 molecule could be released by decomposers during its pathway from Grandma J to the coyote.
- Are the processes that release CO_2 molecules in different organisms similar or different? In what ways?

Thank you for participating in my research. Your answers will provide valuable insight into teaching and learning about the biochemical processes in plants. Thanks!

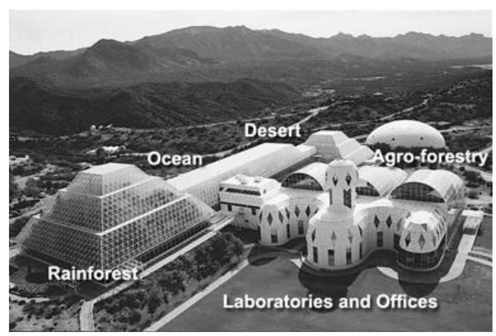
APPENDIX C
Pre- and Posttest

A potato is left outside and gradually decays. One of the main substances in the potato is the starch amylose ($(C_6H_{10}O_5)_n$). What happens to the atoms in amylose molecules as the potato decays? Choose True (T) or False (F) for each option.

1. T F Some of the atoms are converted into nitrogen and phosphorous: soil nutrients.
2. T F Some of the atoms are used up by decomposers and disappear.
3. T F Some of the atoms are incorporated into carbon dioxide.
4. T F Some of the atoms are turned into energy by decomposers.
5. T F Some of the atoms are incorporated into water.

What would happen to the carbon cycle if all decomposers suddenly died and were not replenished? Decide whether each statement is true (T) or false (F).

6. T F Carbon would accumulate in organic matter.
7. T F There would be more carbon in the soil for plants to absorb.
8. T F Carbon would cycle more rapidly without decomposers.
9. T F Carbon in the atmosphere would increase.



10. The biosphere is a dome like structure originally built to be a man-made, materially-closed ecological system in Oracle, Arizona. Imagine that all of the bacteria and fungus were removed from the biosphere (it was sterilized). The plants were left inside. After a couple of days the plants turned brown and appeared dead. What would the plants look like in 10 years?

a. You wouldn't be able to find the plants because they would have decomposed.
b. The plants would be barely recognizable leaves and stems because most of the plant
would have decomposed, but some parts do not decompose.
c. The plants would be brown but would still be recognizable as a dead plant
d. The plants would be gone but there would be new living plants in their place.

When the leaves in a compost pile decay, what do you think happens to the mass of the leaves? Circle True (T) or False (F).

11. T F The mass disappears when the leaves decompose.
12. T F The mass is turned into heat energy.
13. T F The mass is converted into soil minerals.
14. T F The mass is converted into carbon dioxide and water.

15. Sunlight helps plants to grow. Where does light energy go when it is used by plants? Please choose the ONE answer that you think is best.
    a. The light energy is converted into glucose of the plants.
    b. The light energy is converted into ATP in the plants.
    c. The light energy is used up to power the process of photosynthesis.
    d. The light energy is transformed into chemical bond energy.
    e. The light energy does not go into the plants' body.

16. Which of the following is an energy source for plants?
    a. Water
    b. Light
    c. Air
    d. Nutrients in soil
    e. Plants make their own energy.

17. Imagine 100 units of energy came down from the sun and we could keep track of it. Those 100 units go into a plant and transfer from light energy to chemical energy. Then a rabbit eats the plant and some of that chemical energy (20 units) goes into the rabbit and is used by the rabbit. Where did the energy go?
    A) Some of the 20 units of energy turns into nutrients that the rabbit needs
    B) 20 units of energy is eventually released by the rabbit as "sweat" or "poop"
    C) Some of the 20 units of the energy disappears as the rabbit uses it, and some stays in the rabbit
    D) 20 units of E is eventually given off as heat to the environment as the rabbit lives its life

18. Which gas is taken in by green plants/algae in large amounts when there is no light energy at all?
    A) Carbon dioxide gas
    B) Oxygen gas

19. The reason for my answer to #18 is because:
    A) This gas is used in photosynthesis which occurs in green plants/algae all the time.
    B) This gas is used in photosynthesis which occurs in green plants/algae when there is no light energy at all.
    C) This gas is used in respiration which only occurs in green plants/algae when there is no light energy to photosynthesize.
    D) This gas is used in respiration which takes place continuously in green plants/algae.
    E) ____

20. Which gas is given off by green plants/algae in large amounts when there is no light energy at all?
    A) Carbon dioxide gas
    B) Oxygen gas

21. The reason for my answer to #20 is because:
    A) Green plants/algae stop photosynthesizing when there is no light energy at all so they continue to respire and therefore they give off this gas.
    B) This gas is given off by the green plant/algae during photosynthesis which takes place when there is no light energy.
    C) Since green plants/algae respire only when there is no light energy they give off this gas.
    D) ____

22. Respiration is:
    A) A chemical process which occurs in all living cells of plants/algae and animals.
    B) A chemical process which occurs in plant/algae cells but not in animal cells.
    C) A chemical process which occurs only in animal cells but not in plant/algae cells.

23. The reason for my answer to #22 is because:
    A) Only plant/algae cells obtain energy to live in this way.
    B) All living cells of plants/algae and animals obtain energy to live through this process.
    C) Only animal cells need energy to live as they cannot photosynthesize.
    D) ____

24. Which of the following is the most accurate statement about respiration in green plants/algae?
    A) It is a chemical process by which plants/algae manufacture food from water and carbon dioxide.
    B) It is a chemical process in which energy stored in food is released using oxygen.
    C) It is the exchange of carbon dioxide and oxygen gases through plant stomata.
    D) It is a process that does not take place in green plants/algae when photosynthesis is taking place.

25. The reason for my answer to #24 is because:
    A) Green plants/algae never respire they only photosynthesize.
    B) Green plants/algae take in carbon dioxide and give off oxygen when they respire.
    C) Respiration provides the green plant with energy to live.
    D) Respiration only occurs in green plants when there is no light energy.
    E) ____

26. When do green plants/algae respire?
    A) Only at night (when there is no light energy).
    B) Only during the daylight (when there is light energy).
    C) All the time (when there is light energy or when there is no light energy).
    D) Never (when there is light energy or when there is no light energy).

27. The reason for my answer to #26 is because:
    A) Cells of green plants/algae can photosynthesize during the day when there is light energy and therefore they respire only at night when there is no light energy.
    B) Green plants/algae need energy to live and respiration provides energy.
    C) Green plants do not respire they only photosynthesize, and photosynthesis provides energy for the plant.
    D) ____

28. Which of the following comparisons between the process of photosynthesis and respiration in green plants/algae is correct? (Choose one)

	Photosynthesis	**Respiration**
A)	Takes place in green plants/algae only.	Takes place in animals only.
B)	Takes place in all plants.	Takes place only in all animals.
C)	Takes place in green plants in presence of light energy.	Takes place in all plants and in all animals at all times.
D)	Takes place in green plants in the presence of light energy.	Takes place in all plants only when there is no light energy and all the time in all animals

29. The reason for my answer to #28 is because:
    A) Green plants/algae photosynthesize and do not respire at all.
    B) Green plants/algae photosynthesize during the day and respire at night (when there is no light energy at all).
    C) Because respiration is continuous in all living this. Photosynthesis occurs only when light energy is available.
    D) Plants/algae respire when they cannot obtain enough energy from photosynthesis (e.g. at night) and animals respire continuously because they cannot photosynthesize.
    E) ____

30. A potted geranium plant sits in a windowsill, absorbing sunlight. After I put this plant in a dark closet for a few days (but keeping it watered), will it weigh more or less (discounting the weight of the water) than before I put it in the closet?
    A) It will weigh less because it is still doing cellular respiration.
    B) It will weigh less because no photosynthesis is occurring.
    C) It will weigh more because the Calvin cycle reactions (stage 2 in photosyn.) continue.
    D) It will weigh the same since no biomass is produced.
    E) It will weigh more because it still has access to water and soil nutrients.

Please answer the questions below as carefully and completely as you can.

31. Open-ended Question #1

Grandma Johnson had very sentimental feelings toward Johnson Canyon, Utah, where she and her late husband had honeymooned long ago. Because of these feelings, when she died she requested to be buried under a creosote bush in the canyon.

a. Describe below the path of a carbon atom from Grandma Johnson's remains, to inside the creosote bush, to finally being released into the air in a CO_2 molecule.
    Be as detailed as you can be about the various molecular forms that the carbon atom might be in as it travels from Grandma Johnson to the CO_2 molecule.
    Please specifically refer to and describe any biological processes that occur during the carbon atom's transfer.

b. Describe how decomposers are involved in the transfer of the carbon atom from Grandma Johnson to a CO_2 molecule.

32. Open ended Question #2 - Explain how energy flows from the sun to ultimately power the leg muscle in the coyote. What different forms does energy take? (Be specific)

33. Open-ended Question #3

Once **carbon** enters a plant, it can …

A) exit the plant as CO_2 during cellular respiration Circle *True or False*
Explain

B) become part of the plant cell walls, protein, and fat. Circle *True or False*
Explain

C) be consumed by an insect feeding on the plant and become part of the insect's body.
Circle *True or False*
Explain

D) be turned into energy for plant growth. Circle *True or False*
Explain

E) exit the plant as O_2 during photosynthesis. Circle *True or False*
Explain

Appendix D
Ecosphere Day 3 Tasks for Control Class

Instructional Block 3

Ecosphere Extension Activity

Ecosphere Task 7:
DESIGN: With you group design an experiment to perform with the ecosphere similar to those experiments we have been discussing. Brainstorm ideas and be ready to share your ideas with the class.

Ecosphere Task 8:
For your group's experiment answer the following questions:

1. What is your hypothesis?
2. What is the independent variable (the condition you *change* in the experiment) of the experiment?
3. What is the dependent variable (the condition that you *measure* in the experiment)?
4. How will you measure the dependent variable?
5. What is the control (the condition that you do NOT change in the experiment)?
6. What materials are you going to use?
7. Describe the procedure of the experiment.

Ecosphere Task 9:
Fill in the data table below with the data that you expect to obtain from your experiment.

Ecosphere Water Quality Data

Parameter	Acceptable Range	Day 1	Day 10	Day 20	Day 30	Day 100
Turbidity	10 – 25 NTU	12				
Dissolved Oxygen	> 5.0 mg/L	6.5				
Carbon Dioxide	> 2.5 mg/L	3.1				
Oxides of Nitrogen (NOx)	0.05 – 0.09 mg/L	0.06				
Organic Nitrogen (N)	0.010 – 0.05 mg/L	0.021				
Organic Phosphorus (P)	0.010 - 0.05 mg/L	0.015				
Dissolved Phosphates (POx)	0.02 - 0.09 mg/L	0.05				

Ecosphere Task 10:
Based on the data in Task 9, what kind of results would you expect in your experiment. What do these results teach you about how the ecosphere functions?