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Understanding Photosynthesis and Plant Cellular Respiration as "Nested Systems": The Characterization of Pre-Service Teachers' Conceptions

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UNDERSTANDING PHOTOSYNTHESIS AND PLANT CELLULAR RESPIRATION AS “NESTED SYSTEMS”: THE CHARACTERIZATION OF PRE-SERVICE TEACHERS’ CONCEPTIONS

by

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UNDERSTANDING PHOTOSYNTHESIS AND PLANT CELLULAR RESPIRATION AS "NESTED SYSTEMS": THE CHARACTERIZATION OF PRE-SERVICE TEACHERS' CONCEPTIONS

Mary H. Brown, Ph.D.

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This dissertation project focused on pre-service elementary teachers' conceptions of the plant processes of photosynthesis and cellular respiration as being connected, occurring at multiple ecological levels, and working within "nested systems." Participants enrolled in a biology course designed for elementary education majors provided their views of the processes through a series of tasks with a peer, a semi-structured interview, and clarified both photosynthesis and plant cellular respiration directly following classroom instruction on the two topics. The instructor of the course was interviewed after a preliminary analysis of the participants' responses. Data were analyzed using the qualitative analysis computer program *The Ethnograph* v.5, with attention to whether the participants viewed the energy reactions as interconnected, within multiple ecological levels of the plant system, and as "nested systems" of the global ecosystem.

Participants did view photosynthesis as an energy process, but were less committed to cellular respiration as an energy process. While most participants described the processes within multiple ecological levels of the plant system, their accuracy of the concepts within the levels varied. Responses suggested a level of understanding that included few of the ecological levels with descriptions focused primarily on the organism level. Instruction included all multiple ecological levels with focus on the biochemical level. Many participants simplified the two processes in a manner that matched the

evaluation of their instruction. Few participants held a “nested systems” view of the global ecosystem. Justifications provided for their explanations were authoritarian, and anthropomorphic, with teleological and tautological reasons also expressed. The pre-service teachers did compare plant functions with analogous human functions; potentially suggesting an intuitive conception. In general, the pre-service teachers viewed plants as dependent on humans, and having use within human society.

This project may have implications for the instruction of photosynthesis and cellular respiration. Analogy of plant processes with humans’ use of energy, and the utility of plants for human society may be a motivating factor for instruction. Instruction that focuses on the organism level first, and provides explicit signposts when moving from one ecological level to another may provide clearer understanding of the processes.

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Mary H. Brown

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Introduction:

Years ago a college biology student in one of my classes pointed to the mitochondria on a plastic model of a typical plant cell and explained that plant cells do not need mitochondria because “they get their energy directly from the sun.” The student failed to see the need for plant cellular respiration, not recognizing that both photosynthesis and cellular respiration are energy reactions within a biological system. Photosynthesis uses inorganic materials from the environment and produces an organic molecule. The organic molecule is then broken down, and the energy within the chemical bonds is transformed and available for use in metabolic processes within the system. The products of these two processes are extremely important on two levels: the level of the individual plant, and the global ecological level. Students’ failure to see the two processes as connected strongly suggests a conception of biological processes that bypasses the concept of systems and the levels of components within.

Both photosynthesis and plant cellular respiration are challenging to the learner for a number of reasons. Both processes have multiple steps and occur simultaneously within plants. As suggested in the opening paragraph, students who compartmentalize function and specialization of organelles at the cellular level, may not consider the two processes as interconnected, and miss the significance of the plant as an independent biological system functioning in the global ecosystem.

This chapter will argue the importance of both plant processes by considering them integral to the understanding of the biological world in terms of systems, or interconnected processes with many dynamic interactions. It will also advocate that learning biology is dependent upon the understanding of systems, which are interconnected with the physical world. These positions are supported in science education reforms.

Systems as a Unifying Theme:

Science for All Americans (AAAS, 1990) lists common themes that transcend discipline boundaries, and provide opportunities for direct explanation, theory, observation and design. One of the common themes is systems. A collection of items as a system suggests influences. A systems approach draws attention to what needs to be included in order to make sense of the entire interaction and the relationships of other systems of influence. Systems must be defined with enough components to make sense of the purpose. In the case of photosynthesis and plant cellular respiration, the purpose is transformation of radiant energy to chemical energy in a useable form for plant metabolism. The two processes interconnected form two levels of systems, one with the purpose of plant metabolism, and the other with the purposes of global energy flow and matter cycling.

Benchmarks produced from goals articulated in *Science for All Americans*, advocate systems awareness as early as kindergarten (AAAS, 1993). These benchmarks suggest that by second grade students should recognize “when parts are put together, they can do things they could not do by themselves” (p. 264). In understanding plant functions, second graders should be able to understand the concept that “humans and other living organisms are dependent on plants for food.” Within the common themes benchmarks, fifth grade students should know that “ something that consists of many parts, the parts usually influence one another", and "something may not work as well (or at all) if a part of it is missing, broken, worn out, mismatched or misconnected." These two benchmarks suggest that students as young as ten should recognize the many levels within an ecosystem, and the potential for disruption.

In the matter and energy benchmarks, second graders should know that "many materials can be recycled and used again, sometimes in different forms" (p. 119). There are two benchmarks from the fifth grade section which are directly applicable: "almost all kinds of animals' food can be traced back to plants" and "some source of 'energy' is needed for all organisms to stay alive and grow." Combined, these benchmarks suggest that students should recognize the importance of plants within the ecosystem, view them as a source of energy, as biological systems themselves, and within a more global view of the ecosystem.

. In general, an understanding of systems as applied to plants is advocated, as early as kindergarten, and by the end of the fifth grade, all students should recognize plants as the source for food for nearly all organisms.

In the narrative on systems, *Benchmarks for Science Literacy* (AAAS, 1993) suggest that children tend to think of the properties of the system as belonging to the individual parts of the system, and not the interaction of the parts. Conversely, when children think of systems in terms of interactions, it is necessary to account for concepts such as input, output and conservation. Only when the child recognizes that properties within the system are not the same as the properties of the components is there recognition of the interconnectedness of the components and the emergent properties of the complex system.

In the *National Science Education Standards,* produced by the National Research Council (1996), systems are also considered a unifying concept to which all students need to develop an understanding. The standards suggest young students tend towards viewing the components rather than resulting interactions within the larger system. Students view the components of the system as being similar to the larger system and discount the results of interactions within the components as being significant. Rather than recognizing the system, students compartmentalize.

Two Related Plant Processes:

This section summarizes photosynthesis and cellular respiration with a brief overview. The argument will then be advanced that the two processes are inter-connected and for an understanding of energy transformation both processes should be viewed as components interacting within systems.

What are the two processes of photosynthesis and plant respiration? The answer to that question could be exhausting in its detail. Such detail will be deliberately reduced, to avoid compartmentalization and sacrifice of the systems view. Research suggests that even students with factual recall of the two plant processes do not have a conceptual understanding of photosynthesis (Gifford, 2001). Therefore, this description will aim for a broad understanding and deliberately reduce terminology, microscopic anatomical structures of the plant, and complex biochemical pathways.

Photosynthesis:

When people consider photosynthesis, they often think the process happens only within green plants. This isn’t entirely true. It also happens within certain bacteria and some single celled organisms. There are also variations within the reactions of photosynthesis. This project, however, focused on photosynthesis in its most common form as performed by green plants.

In all of the photosynthesizing organisms, carbon dioxide, which is an inorganic compound, is converted to an organic compound, a carbohydrate, most generally glucose. The plant can use glucose (glucose is a monomer or a building block molecule) to form other organic molecules, such as starch, and cellulose. Reactions that form glucose are quite complex. The reactions use carbon dioxide from the atmosphere, and water. The gas carbon dioxide is reduced (gains electrons) from the hydrogen atoms of water. Through a series of reactions, the carbon atom is removed from carbon dioxide, and ultimately becomes part of the glucose molecule. Molecular oxygen is produced, which actually comes from the water molecule, and not the carbon dioxide. The energy reaction that allows for the reduction of carbon dioxide gas comes from the radiant energy of the sun.

Plants absorb only a small fraction of the visible light for their reactions. This light energy is captured by pigments (primarily chlorophyll and cartenoids), and is transferred to a “reaction center” which contains the pigment and associated proteins. There are actually two reaction centers, photosystem I and photosytem II. These two reaction centers work concurrently, but in series. Photosystem II is involved in the light reactions. It is the only known protein complex that can oxidize water, and release oxygen to the atmosphere. In the light, photosystem II feeds electrons to photosystem I.

The molecules formed in the light dependent reactions provide the energy and the electrons to fuel the next series of reactions. These reactions were previously known as “dark reactions” but are now more accurately termed “light independent.” Light energy powers the initial photosynthetic reactions, but the Calvin cycle, or the photosynthetic carbon reduction cycle does not require light. The reactions include an electron flow through an electron transport chain that causes hydrogen ions to move across the membranes within the chloroplast, ultimately capturing the energy into the chemical bonds of ATP, i.e. adenosine triphosphate molecules. The ATP produced provides the energy for the light independent reactions. Some thirty separate enzymes, with several intermediates are involved in the reactions that move molecules within the plant cell's organelles, the chloroplast. About fifty of these chloroplasts, reside in each cell within the leaves of the plant. The resulting ATP serves as an energy source for plant metabolic processes.

Green plants are known as producers, or autotrophs, as they are "self feeders" producing their own food, which is the carbohydrate produced at the conclusion of the series of reactions.

Respiration:

Photosynthesis by itself does not sustain life. Although it is commonly said that photosynthesis produces food, the energy within the food must be extracted prior to use in metabolism. This is true of all organisms. The process of extracting the energy within the chemical bonds of carbohydrates and other organic molecules used as food is respiration. Respiration is a series of chemical reactions that take place at the cellular level within a specialized organelle called the mitochondria.

Mitochondria, within plants and other organisms "harvest" the energy within the chemical bonds of the organic molecules (including carbohydrates) and forms an energy rich molecule known as ATP. The same molecule was used in photosynthesis to start the chain of events that ultimately produced glucose. The molecule ATP made available to the plant through cellular respiration is then available for a number of complex metabolic processes, which support the various functions needed for survival and reproduction.

Cellular respiration requires oxygen be present within the system in order to yield relatively high amounts of ATP. When oxygen is not in high amounts the pathway to ATP production is called fermentation, and an alcohol compound is produced.

Concepts of Interconnected, Multiple Ecological Levels and "Nested Systems:"

Specific concepts used to characterize photosynthesis and respiration are crucial to the understanding of this project. These concepts are "inter-connected" or "inter-related"; "multiple-levels", "multiple ecological levels" or "multiple-system levels" and "nested systems." These concepts are clarified in the following section, with illustrations to provide elucidation of the systems and sub-systems they represent.

Interconnected Processes:

Photosynthesis and plant cellular respiration are interconnected processes ("inter-related" or "connected") in that the two processes combine to provide energy for use by the plant. Photosynthesis transforms radiant energy from the sun into chemical bond energy within the carbohydrate molecule. The chemical bond energy is transformed again, to a smaller unit of chemical bond energy within the ATP molecule.

The energy within the ATP molecule produced during cellular respiration, allows photosynthesis to continue. The two processes occur simultaneously, and continuously, with variations, throughout the life span of a green plant.

The inter-connection between the two processes is illustrated in Figure 1.

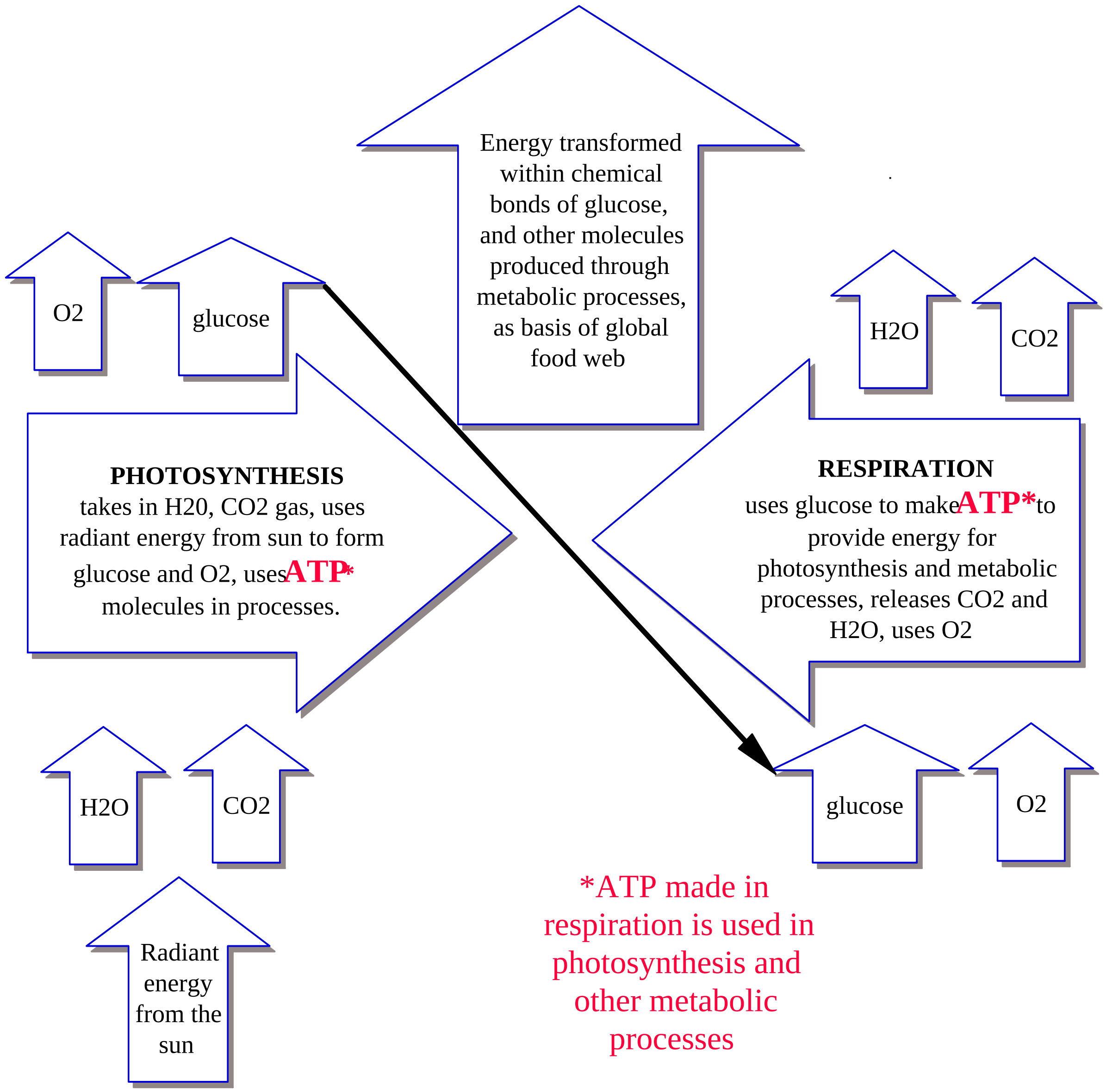

Figure 1: Connection between Photosynthesis and Cellular Respiration

The arrows suggest the interdependency between the two processes within the plant. Photosynthesis uses radiant energy from the sun to produce glucose from the raw materials of water and carbon dioxide. Glucose is used by respiration to form the energy molecule ATP, which makes possible cellular processes, such as photosynthesis. These cell processes make other plant molecules too. Plant cellular respiration does not occur without the carbohydrate produced from the actions of photosynthesis, nor does photosynthesis occur without cellular respiration and the energy transformations in those reactions.

These two processes are related to each other, causing some text authors to suggest to learners that they are “opposite” reactions. Respiration is exergonic, which means that it results in a net output of free energy available to the biological system, in the form of ATP molecules. Photosynthesis, however is endergonic, which means that it requires a net input of ATP to produce the carbohydrates, which we commonly refer to as food.

The details of both processes require knowledge in chemistry and physics. The chemical reaction for photosynthesis is often summarized as $CO_2 + H_2O \rightarrow O_2 + C_6 H_{12} O_6$. Conversely, the reactions of cellular respiration are often summarized as $C_6 H_{12} O_6$. $+ O_2 \rightarrow CO_2 + H_2O$. Pairing of the two summary equations maybe partially responsible for misconceptions learners have. Seymour and Longden, (1991), Songer, (1994), and Canal, (1999) documented students’ conceptions that both processes do not happen simultaneously, and plants do not respire. Learners viewed the two processes as “opposites” of one another.

The inter-relatedness of the two plant processes is fundamental to the survival of the organism. Survival in the living world is directly tied to energy use. Energy must be available in useable amounts to allow for the metabolic processes that characterize life. Students should recognize that both processes are energy reactions, operate on multiple ecological levels within a system, and are crucial to the functioning of the global ecosystem.

Multiple Ecological Levels:

From this brief explanation of the two processes, it is apparent that the plant itself can be considered a system. The components of the plant, the leaves and the roots bring the raw materials for photosynthesis together in a cellular compartment. The components of the biological system plant can be defined as the gross anatomical structures of the plant. However, once the raw materials are assembled, the view changes, and the cellular level with the actions within the chloroplasts becomes predominate. The learner should consider the multiple ecological levels as occurring all simultaneously and continuously, and not as step-by-step processes.

Photosynthesis and plant cellular respiration take place at multiple levels within multiple systems. Waheed and Lucas (1992) refer to these interactions as occurring on "multiple ecological levels."

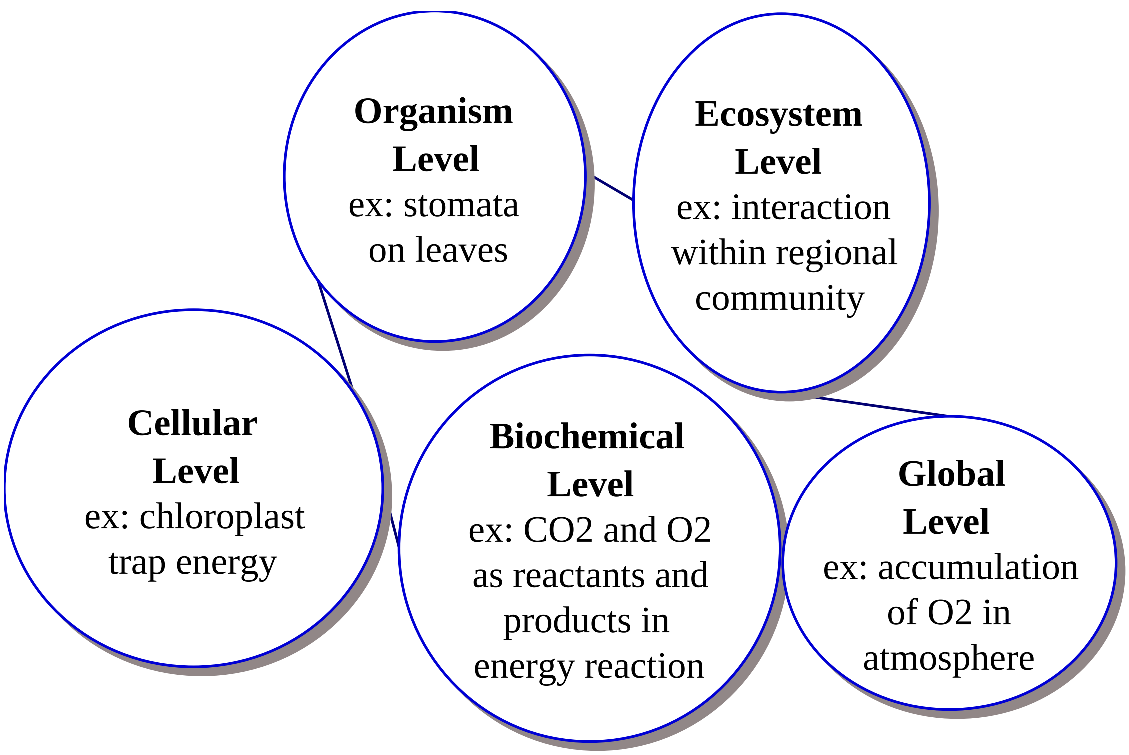

Figure 2: Multiple Ecological Levels

In figure 2, these multiple ecological levels are shown existing simultaneously for the learner. Interactions occur in all levels, and all levels contribute to the overall output within the system. At the biochemical level, individual molecules such as carbon dioxide and oxygen serve as reactants within the dynamic physical system of a chemical reaction. At the cellular level, the chloroplast of the plant is a crucial component of the system, as it traps radiant energy. At the level of the organism, the anatomical structures of the plant become crucial. The structure of the stomata and the ready access to carbon dioxide from the atmosphere are important, as well as the access to water through the xylem. At the ecosystem level, plants have valuable interactions within the regional community and compete for light and physical space. Contributions of all these components input into the global ecosystem a significant amount of oxygen. It may be difficult to recognize the significance of the reactions involving oxygen at the biochemical level, until the global level is considered.

The detail of the varying multiple levels provided in many texts may confuse the student and the global perspective in which the plant functions may become secondary in importance to the learner. If so, this suggests that students may have a compartmentalized view of the two processes, perceive them as independent, and may be unaware of the function of the plant as a biological system nested within the global ecosystem.

The approach used in instruction may emphasize compartmentalization to the sacrifice of systems-level thinking. Textbooks and other instructional materials may promote compartmentalization by the level of detail provided at each ecological level.

How would future teachers characterize the gap between a systems approach to photosynthesis and plant cellular respiration, and a compartmentalization of the two processes? Are they aware of the gap? How do they recognize the inter-connectedness of the two processes, or have they compartmentalized each step of the processes, and removed it from the systems-level interactions? Does a perceived disconnect between the two systems-levels foster the misconceptions expressed by students?

“Nested Systems:”

Besides the levels being present as illustrated within Figure 2, the levels also interact with each other. The components influence each other. For a complete understanding of photosynthesis and plant cellular respiration, attention must be given to how the components interact (AAAS, 1990). “Drawing the boundary of a system well can make the difference between understanding and not understanding what is going on” (p. 166). One reason photosynthesis and plant cellular respiration may be difficult to understand is that the boundary drawn as too localized, leaving learners questioning the significance of the processes.

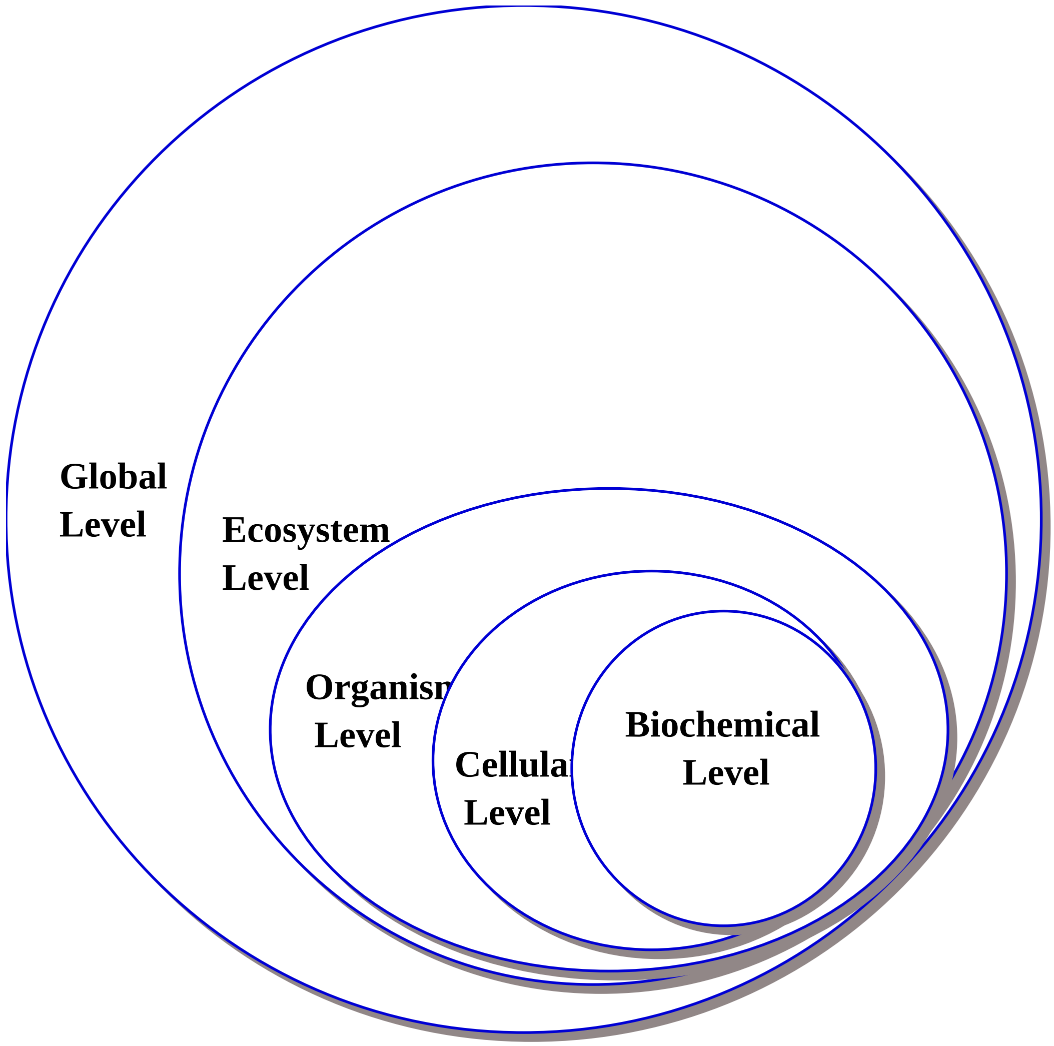

Figure 3: “Nested Systems”

Figure 3 suggests that all of the multiple ecological levels interact, from the biochemical level showing molecular interactions; the cellular level providing detail to the cellular components within the plant; the organism level provides function for the cellular components of the plant and the ecosystem level providing a context for the interactions of the plants within the community. The global level not only provides the input of the carbon dioxide for photosynthesis, but also recycles matter. Viewing the two processes as components of nested systems provides a frame of reference for many related ecological concepts, such as food webs and nutrient cycling.

Both processes are complicated biochemical processes. Within the last twenty years, many researchers (Anderson, Sheldon & DuBay, 1990; Barker & Carr, 1989a; Barker & Carr, 1989b; Barker & Carr, 1989c; Bell, 1985; Canal, 1999) have shown that students do not have a clear understanding of either plant process. Students lack a view that situates either process to the level of their importance within the ecosystem (Brumby, 1982). Considering the importance of photosynthesis and respiration to an understanding of the biosphere, it seems relevant to consider these two processes and to characterize the conceptions students have when attempting to understand the two plant processes. Knowledge of photosynthesis and plant cellular respiration is the basis for an understanding of energy flow within the ecosystem. It is integral for an understanding of other biological concepts.

The complexity of the living world is different from the linear and circular causality of a physical system. Any part of a system may also be considered a system, with its own components and interactions. Biological systems with their reliance and interactions within the physical world are challenging to define. The biosphere is a set of network interactions (Lin & Hu, 2003) which rely on the combination of the components, and the interdependencies among the components, even crossing different levels within the entire system. Photosynthesis and plant cellular respiration are complex dynamic processes, which interact at multiple levels. These processes are “nested systems” in that the plant is a biological system in its own entity, and is a component within the larger global ecosystem. Both plant processes are necessary for survival at both levels of their system interaction.

Biological Literacy:

One goal of science education is to promote scientific literacy (AAAS, 1990) so that individuals can intelligently face global problems, such as the shrinking of tropical rainforests and pollution of the environment. Science literacy is a broadly defined entity. This project involves a subset of scientific literacy, which has been referred to as biological literacy (BSCS, 1993). There is within life sciences education recommendations promoting understanding of the underlying themes of biology, the impact of humans on the biosphere, and the processes within scientific inquiry as they apply to the biological world.

Biological literacy extends well beyond the memorizing of scientific terms. The BSCS biological literacy model (1993) suggests that high school students often come to their course work with a "nominal" level of literacy. They may recognize biological terms but cannot provide scientifically accurate explanations of phenomena observed. They have misconceptions. Students at the functional level of literacy can define terms correctly, but have memorized the information and have little understanding. Students may be structurally literate if they can construct appropriate information from their classroom experiences and can explain these concepts in their own terms. Students are at the multidimensional level, if they can apply knowledge gained to solve real world problems, with integration from other disciplines. The Biological Science Curriculum Studies (BSCS) committee recommends students reach the structural and multidimensional levels of biological literacy prior to course completion.

The biological sciences have unifying principles that organize the discipline. Living systems have common characteristics that apply to all organisms (BSCS, 1993). Among the unifying principles identified by BSCS (1993) is "Interaction and

Interdependence." This principle suggests that living systems interact with their environment and are interdependent with other systems. BSCS (1993) identified major biological concepts that should influence the core curriculum of biology. Within the principle of "Interaction and Interdependence" are six major biological concepts that all high school and college students should understand at the conclusion of a biology program. The six concepts are:

- Environmental factors and their effects on living systems
- Carrying capacity and limiting factors
- Community structure, including food webs and their constituents
- Interactions among living systems
- Ecosystems, nutrient cycles, and energy flow
- The biosphere and how humans affect it.

This dissertation project directly relates to three of these concepts. Energy flow within an ecosystem is understood from the prospective of the plant processes of photosynthesis and plant cellular respiration. Food webs must start with the plant producer. Nearly all life on the planet is directly related to the capture of the sun's radiant energy and the synthesis by plants into complex energy rich molecules from carbon dioxide and water. Interactions within living systems encompass the notion of viewing these processes from multiple ecological levels and within nested systems.

Biologically literate individuals should recognize photosynthesis and plant cellular respiration as components of systems, and should be able to make sense of environmental claims that may disrupt any ecological level within the systems. They should be able to make decisions regarding plants and their role within the ecosystem that may lead to wiser practices towards sustainability.

Eugene P. Odum (BSCS, 1993) describes ecology in the 1990s as having twenty “great idea” concepts for the decade. These concepts are appropriate knowledge for an environmentally literate individual. His first concept is the concept of ecosystem. He suggests that students need to be aware that an ecosystem is an open system and should understand what is coming in and what is going out, especially in terms of energy, materials and organisms. The future depends on the understanding that the ecosystem is not a self-contained ecological unit. Odum’s description of the ecosystem relates to this project directly with energy flow through the processes of photosynthesis and plant cellular respiration.

In this dissertation project, the participants are pre-service elementary education majors. These pre-service teachers have great potential for promoting biological literacy in their future classrooms. Knowledge of pre-service teachers conceptions on the flow of energy through the ecosystem through the processes of photosynthesis and cellular respiration should provide information for improvement of classroom instruction of these two processes, and an enhancement of biological literacy.

Systems:

In his text, *A New Scientific Understanding of Living Systems: The Web of Life*, Capra (1996) provides an historical view of the classical tension between viewing living organisms as integrated wholes, or as the subunits within. He suggests the tension between the two views is as old as science itself, crediting Aristotle with the first distinction between matter, processes and patterns. In the sixteenth and seventeenth centuries, scientists such as Descartes and Galileo advanced a philosophy that suggested that living organisms, although very complicated could be understood in terms of their physical and chemical components. Later centuries saw each view as having significant scientific proponents. It wasn't until the early twentieth century that a new idea regarding life's organization arose from the reflections of biologists such as Ross Harrison and Lawrence Henderson (Capra, 1996).

This new view of the living world incorporates a level of organization that goes beyond the physical and chemical components, the idea of being part of a system. A system has come to mean an integrated whole, whose properties come from the relationships of the components within the whole. Understanding living organisms must include chemical and physical elements within their organizing relationships. One of these organizing principles of life is the tendency to form multiple system levels. Each level forms a whole with respect to its parts but at the same time is part of a larger whole. Each level has its own properties, which generally contribute to the property of the whole, but some properties do not exist at specific levels. In the case of plants, the property of green pigmentation does not exist below the cellular level. The molecules that comprise the chlorophyll molecule are not green. It is only when assembled as chlorophyll and in the presence of light is chlorophyll a green pigment. Such properties, which exist at certain levels, are termed emergent properties, as their properties exist only at higher levels of organization.

Essential properties within a living system are properties of the whole. None of the individual components of the system has, by itself, properties of the whole system. Focusing on individual components or properties of individual components by compartmentalizing may mask the essential properties of the system. According to Capra (1996), ecology was founded in the early twentieth century from the reflections of scientists proposing a systems view of the living world. Ecologists change their focus from organisms to ecosystems and back, applying concepts to the different systems levels. Add the cellular and biochemical level, as in most introductory level college courses, and the complexity is very challenging.

Learning Issues:

Despite goals of achieving structural and multidimensional levels of literacy, and advocating a systems approach, photosynthesis and cellular respiration remain challenging for the learner. There may be multiple reasons for the difficulties experienced by the learner. Both processes are complex and within the multiple ecological levels, learners may lose the purpose of the processes. In their efforts to seek understanding, learners may use reasoning that is not scientifically sound. Learners may also rely upon intuitive conceptions in response to questions regarding the processes.

Distinction between Categories of Matter and Process:

Researchers such as Chi (2001) suggest that such relationships as exist in biological systems are extremely difficult to learn. She characterizes them as “complex dynamic processes” because of their abstractness, and the multiple systems-levels. Such processes are often invisible to the learner and need only to be at two system levels to be considered complex.

Another property of complex dynamic processes is that the two system levels are not identical. Photosynthesis and cellular respiration are opposite (Canal, 1999) at the microscopic level in terms of chemical reactions and yet are complementary on the global level. One of Chi's criterion of complexity is that the emergent mechanism of the levels unites the two system levels. This is certainly the case with photosynthesis and respiration. The overall energy reaction is the "emergent mechanism." Explanations of the phenomenon at the organism level, or biochemical level, do not account for the emergent mechanism. This explanation seems to fit well the difficulties of photosynthesis and plant respiration.

Waheed and Lucas (1992) identified four levels of interaction in photosynthesis. They suggest a complete understanding of how photosynthesis acts as a bridge to the abiotic (non-living) world includes a view of photosynthesis as being ecological, biochemical, anatomical-physiological and as being an energy reaction.

Use of Reasoning Modes:

Southerland, Abrams, Cummins and Anzelmo (2001) used reasoning strategies to categorize student conceptions of biological processes. They noted that explanations for biological processes used human attributes as a causal agent (anthropomorphism), the end result as the causal agent (teleological), or specified a divine agent (pre-determined). They also categorized the mechanistic reasoning provided by students for their explanations. Some mechanistic reasoning suggested attention to only one level within the system (mechanistic proximate), while another form (mechanistic ultimate) expressed more of an interactive or systems-based explanation.

Intuitive Conceptions:

Southerland *et al*. (2001) considered the possibility that students' conceptions of biological processes were formed spontaneously as queried. They suggested students were providing spontaneous constructions of their knowledge, based upon intuitive conceptions. Intuitive conceptions suggest a lack of a conceptual framework, or a framework still under construction. Such conceptions do not exist in the form of a coherent theory, but rather are provided "on the spot" as the need for an explanation arises.

When processes are extremely difficult to understand, as has been often noted within the physical sciences (diSessa, 1993), learners intuitively rely on these deep cognitive structures to provide an explanation. Intuitive conceptions are so internalized that the learner may be unaware of their use. Called phenomenological primitives, or p-prims, these "snippets" of knowledge suggest the learner is just beginning to construct a knowledge system to explain a phenomenon. These primitive intuitions are the beginnings of knowledge construction.

Learning Issues with Pre-service Teachers:

Ontological categories, modes of reasoning, and intuitive conceptions are a few perspectives that are useful in considering student conceptions of photosynthesis and plant cellular respiration. Pre-service elementary teachers' conceptions of photosynthesis and respiration need to be known in order to promote instructional practices that will move their conceptualization progressively towards a scientific conception of both processes as connected, occurring on multiple ecological levels and as "nested systems." This project asked pre-service elementary teachers their conceptions of photosynthesis and plant cellular respiration and considered if their conceptions included systems awareness.

Prior to this project only a few researchers have investigated the conceptions of pre-service elementary teachers in regards to these two plant processes. Most recently, Carlsson (2002) used a phenomenological approach and described pre-service teachers' conceptions of photosynthesis in four categories:

- Category 1: plants take in and use components and produce others, independent of intake
- Category 2: the ecosystem is a functioning whole, in which plants are basic.
- Category 3: plants have respiration and therefore, can be regarded as more or less independent organisms.
- Category 4: photosynthesis creates order and resources.

Carlsson regarded category four as a significant category because it suggests that some pre-service teachers recognized photosynthesis and cellular respiration as energy reactions capable of creating sugar and eventually structure for the organism. She regarded category four as an important finding.

Although Carlsson's research will be analyzed in more depth in the following chapter, it is interesting that she suggests pre-service teachers have attained an understanding of systems within the fourth level. Previous research, as reviewed in the following chapter does not support this finding. Within her study, Carlsson did not consider other frameworks within the literature, suggesting rather that a phenomenological approach reveals experiences more reflective of pre-service teachers' conceptions.

If Pre-service Teachers Compartmentalize:

In *Examining Pedagogical Content Knowledge,* Gess-Newsome (1999) asserts that in order to teach as advocated by reforms, teachers must hold "deep and highly structured content knowledge that can be accessed flexibly and efficiently for the purposes of instruction" (p. 53). Elementary teachers, as a group, have more concerns about their subject matter knowledge than secondary teachers, who are required to take more college course work within their specific science discipline.

Gess-Newsome refers to the notion of compartmentalizing concepts as having a "content-specific teaching orientation" (p. 57). Orientations include a molecular approach, or an ecological approach. While the content knowledge of two teachers may be the same, the orientation signifies the relative importance of some concepts and the pedagogical approach as viewed by the teacher. Orientation is complex, involving content knowledge, beliefs and values, and has impact for "what and how students learn their content" (p. 58). Even when confidence levels are high among pre-service teachers, most do not understand the content they are to teach in a "conceptually rich or accurate manner." Their knowledge is often "fragmented, compartmentalized" and poorly organized, making it very challenging to access.

D. Smith (1999) describes her investigation of pre-service teachers' conceptions about photosynthesis and their views of plant growth. Students in her class commented on how counterintuitive the processes are. Smith asserted that it was important to consider pedagogical content knowledge (PCK) for the teaching of photosynthesis. Smith suggests that teachers may reinforce children's misconceptions because they do not recognize them as inaccurate, chose activities that do not address the misconceptions, and may limit the discussion of the process. Smith summaries her experiences, "clearly, a strong and useful pedagogical content knowledge cannot be built on a shaky content knowledge" (p. 181).

Tullberg (1998, as cited in Carlsson, 2002, p. 682) found that only three of twenty-eight secondary teachers had a scientifically appropriate conception of the chemical unit of mole. When he investigated the way the teachers taught the mole concept to their students, he found it was very much in accordance with their own understanding. Chemistry students mirrored the conceptual understanding of their teacher. Only one of the thirty students interviewed had a scientifically appropriate concept despite the teacher's alternate conception. Tullberg's research suggests that potential students of these pre-service teachers will someday mirror their teachers' scientifically accurate conception.

This project investigated the conceptualization of photosynthesis and plant cellular respiration, with the implication that such knowledge may have classroom implications in the future. If pre-service elementary teachers have a more scientific conception of photosynthesis and plant cellular respiration, then as Tullberg suggests, they may provide their future students with a scientifically accurate conception of the processes.

Problem Statement:

Pre-service elementary teachers should view the two processes of photosynthesis and cellular respiration as having components that operate on a number of multiple ecological levels, as biochemical, cellular, organism level, ecosystem and global. They should further recognize both processes as energy reactions connected to the global environment; as a set of "nested systems" with the components of the systems operating within multiple ecological levels and interacting with each other. Because elementary level benchmarks address these goals, it is important to examine pre-service elementary teachers' conceptions relative to photosynthesis and plant cellular respiration

Research Questions:

This project was guided by the following research questions:

1. What are pre-service teachers' conceptions of photosynthesis and plant cellular respirations and how do they conceptualize the relationships with respect to:

- inter-connectedness between the processes,
- working on multiple ecological levels,
- and being components within "nested systems"?

2. What arguments and explanations do pre-service teachers provide in support of their conceptualizations of how the two plant processes are related?

Significance of the Study:

Current science education reforms advocate a systems level understanding. Thinking about systems allows a learner to be attentive to the components, but also to be aware of the interactions within the system. Systems provide a focus on the relationships, and recognition that full understanding is dependent upon the interactions (AAAS, 1990). Benchmarks suggest that as early as fifth grade, elementary school children should recognize that parts within a system interact and that if one component is disrupted; the entire system is disrupted (AAAS, 1993). An understanding of photosynthesis and respiration opens the learner to an understanding of the ecosystem and the niche plants have within. Ultimately, all humans rely on photosynthesis for their food. A greater understanding of both processes, in the context of the global system should help students recognize a need for the protection of plants as a matter of survival.

Pre-service teachers who focus on the compartmentalization of processes on only one level may misrepresent these important processes to their future students. In a recent study by Ozay and Oztas (2003), when asked why photosynthesis is vital for all living organisms, less than 21% of the high school students had an acceptable scientific conception. Most pre-service teachers are not far from their high school experiences. If pre-service teachers are compartmentalizing photosynthesis from respiration, and do not see the two processes as related; they may pass their perspective to their future students. This project is useful in determining the conceptions of pre-service teachers, and determining if they are attentive to the components within the system while being aware of the interactions. Knowing pre-service teachers conceptions may determine if they compartmentalize the two plant processes, and potentially may assist in the development of instruction to prevent compartmentalization.

Structure of Dissertation:

The dissertation project includes five chapters. The first chapter focuses on the problem statement, as stated above. It describes the need for investigating student conceptions on the two plant processes, as well as provides a brief description of the processes for the non-biologist. The next chapter presents the prior research within the science education community on photosynthesis and plant cellular respiration as well as reviewing research pertinent to the modes of reasoning that pre-service teachers may employ. At the conclusion of this chapter a few significant studies with direct implications for this project are highlighted.

The third chapter details the qualitative study, providing rationale for methods chosen. In the format of qualitative research, this chapter includes brief mention of the background and perspective of the researcher, to allow the reader to determine limitations of the project that are the result of this perspective. Codes used during the analysis phase of the project are provided with a description of the analysis process.

The fourth chapter details the results as filtered through the perspective of the researcher. As is typical with qualitative research, the results emerged through the analysis by the researcher and were determined primarily by the direct expression of conceptions provided by participants.

The final chapter draws conclusions from the entire dissertation project and suggests avenues for future research. This summary is an overview of the entire project.

Chapter 2: Literature Review

This chapter begins with a basic introduction on the topic of misconceptions as an issue in the construction of knowledge. It will briefly differentiate misconceptions from alternate conceptions, preconceptions and alternate frameworks, and defend a position chosen by the researcher for the preference of one term over others. A section on intuitive conceptions follows. The research on misconceptions of photosynthesis and cellular respiration, the characterization of those misconceptions, and attempts at explanations for their origin follows the introduction. The next section considers the pedagogy designed for conceptual change within the topics of photosynthesis and cellular respiration.

The final section of this chapter will address more thoroughly the most recent research on photosynthesis, plant cellular respiration, and complex biological processes. This section will detail the research of Waheed and Lucas (1992), Barak, Sheva and Gorodetsky (1999), Lin and Hu (2003), and Carlsson (2003) with the hope of revealing similar approaches and potential for gathering further information.

Introduction to Conceptual Research:

The basic tenet of constructivism is that students learn through interpretation of events they experience, through the perspective of their prior knowledge. Their interpretation may or may not be in alignment with the generally accepted conception of similar events by recognized experts within scientific disciplines. The potential exists however, to use instruction to move student conceptions closer toward those held by scientists. Students reconstruct their knowledge through new events (including classroom instruction) aligning it with prior knowledge. The process of learning or constant reconstruction of knowledge produces intermediate states of understanding. These intermediate states of understanding are characterized as misconceptions with the idea that these conceptions differ from conceptions held by scientists. Because these conceptions are often significantly different from concepts addressed during instruction in the class, and are interpretations seen through the learner's prior experiences and knowledge, the term misconception is questionable. In past research, these "intermediate states" of understanding that deviate from the accepted scientific conceptions of events were characterized by a number of terms (Smith, diSessa, & Roshelle, 1993) including preconceptions, alternate conceptions, naïve beliefs, alternate beliefs, alternative frameworks and naïve theories. These terms still suggest significant differences between students' conceptions and those conceptions held by experts within the scientific disciplines.

Driver (1983) advanced the term alternate framework. She suggested that students interpret the world as they simultaneously construct their knowledge about the world. Their naïve knowledge is borne directly from their experiences and as such, is "framed" through those events. It is an alternate framework in that individuals within the scientific community do not share the same framework. As an individual has more experiences, some of those experiences will cause the learner to reconstruct their framework. Ideally, with assistance from instruction, the learner reconstructs a framework shared by the scientific community.

Chi and Roscoe (2002) suggest that students are missing information from their initial understanding of concepts but are not a *tabula rasa* or a blank slate upon which instruction can immediately affect conceptual change. Instead, individuals possess naïve knowledge or prior conceptions about specific concepts. Their knowledge is often incorrect when compared to the formal knowledge of scientists. At times, such incorrect knowledge can interfere with the movement towards the more formal knowledge accepted by scientists. Some naïve knowledge is altered through instruction toward the goal conception, and is referred to as preconceptions. Other knowledge seems more highly resistant to such movement toward a goal conception. Even with innovative instructional techniques, some naïve knowledge is more ‘robust” in resistance towards reconstruction. These more robust naïve conceptions are labeled misconceptions (Chi & Roscoe, 2002). This project uses the label misconceptions as prior research suggests that students at multiple academic levels and within different cultural environments are challenged by the concepts of photosynthesis and cellular respiration and do not hold a scientifically accepted conception (Bell, 1985; Wood-Robinson, 1991).

Misconceptions, Alternate Conceptions, or Alternate Frameworks:

Of major concern to researchers and to educators is the restructuring process that promotes movement toward a more acceptable scientific conception. Posner, Strike, Hewson and Gertzog (1982) advanced the idea that there are four conditions necessary in conceptual change. The learner must be dissatisfied with their existing conceptions. When the scientifically acceptable conception is counter-intuitive to the learner, meeting a condition of dissatisfaction is very difficult. It challenges instruction to present a condition in which a learner will abandon an intuitively sound conception for one that seems less probable.

The second condition is that the learner must understand the new conception. They must be able to grasp the new conception in terms of their own experiences.

Instruction is often structured as analogies to enhance the possibility of the students' understanding the new conception in terms of their prior knowledge.

The third condition for conceptual changes is that the new conception must be plausible. It must appear to have the possibility to solve the problems previously addressed by the naïve conception. Plausibility gives credibility to the new conception in terms of consistency with other knowledge.

The fourth condition is that the new conception must suggest to the learner the possibility of using the new conception to open new areas of problem solving. It must appear to be useful.

Under those conditions, a learner may change their original conception towards a conception that is more aligned with the scientific conception. The process of moving from a naïve conception towards a more scientifically accepted conception is called conceptual change.

One avenue of research in conceptual change focuses on the condition of dissatisfaction with naïve conceptions (Basili & Sandford, 1991). Such research promotes the idea that learners need to be presented with tasks, which elicit their misconceptions, and to contrast their misconceptions with the scientific conception. Restructuring of conceptions may be a gradual refinement of ideas, or may include significant changes with strong restructuring (Pearsall, Skipper, & Mintzes, 1997).

Intuitive Conceptions:

The concept of intuitive conceptions offers another restructuring strategy. diSessa (1987) suggests that knowledge about a particular concept is not necessarily highly organized by the learner. He maintains that in the midst of knowledge construction, there are “pieces” which are simple abstractions as to how the world might work based upon the learner’s experiences. These pieces of knowledge (diSessa calls them phenomenological primitives or p-prims) are cued by specific phenomena and are not general or abstract. He suggests that construction of knowledge can be based upon cueing p-prims and considering everyday events to cue these segments of knowledge. Construction of knowledge may be enhanced if p-prims are known, and instruction is based upon using the cues, which elicit their use to move towards a scientific conception.

Regardless of the adjective that precedes the conception, whether it be intuitive, naïve, or alternate, the learner still needs the concept restructured before use within the scientific community. More than twenty years of conceptual change research suggests that students are still challenged in their restructuring of knowledge on photosynthesis and plant cellular respiration.

Misconceptions of Photosynthesis and Cellular Respiration:

Bell (1985) presents a literature review of all the misconceptions investigated within the early 1980s on plant nutrition. Specifically, she reviews two significant papers by Simpson and Arnold (1982a, 1982b), and her own findings with a sample of fourteen and fifteen year old students in London. Within all of these articles, misconceptions regarding both processes are identified. All of the research mentioned in Bell’s review centered on students aged eleven to sixteen. Misconceptions identified centered on the confusion of the terms “food” and “nutrients”; the sources of energy for plants; plants use of light; and gas exchange difficulties with respiration.

Simpson and Arnold (1982a) interviewed Scottish pupils aged fourteen to sixteen regarding the processes of plant nutrition, including photosynthesis, their use of energy and growth. The authors concluded that concepts might be wrong but still hold great meaning to the user. Misconceptions revealed were highly resistant to methods of testing, and replacement by correct information. Conceptual errors were organized into classes, with a suggestion that some errors were prior knowledge and simply were not affected by instruction. Some conceptual errors were actually supported by instruction. The third class of errors arose from inappropriate linkage of correct information presented in instruction.

In their following article, Simpson and Arnold (1982b) suggested that students may be experiencing difficulty conceptualizing plant processes, because pre-requisite information was lacking. In this research, Scottish students age sixteen were interviewed regarding their knowledge of concepts of energy, food, and the source of carbon in forming the carbohydrate glucose. Results suggested to the authors that students at that age may simply be too inexperienced to understand the processes, instructional emphasis may be placed too heavily on the differences of plants rather than the commonalities with other living organisms, and mixed ability classes may simply not be able to fully understand these topics. They cautioned the use of analogies, as suggesting they develop misconceptions. Documented misconceptions are captured in Table 1.

Table 1
Documented Misconceptions

General Category of Misconceptions	Researched Student Conception	Researchers
Photosynthesis- "Food"	Food for plants comes from the soil	Bell (1985); Boyes & Stanisstreet, (1991)
	Plants take in food from the outside environment.	Bell (1985); Anderson et. al. (1990);
	Food for plants includes fertilizer, sun, and water.	Bell (1985); Boyes & Stanisstreet (1991)
	Plant tissues are made from food plant receives from the soil.	Bell (1985); Simpson & Arnold (1982b);
Photosynthesis-Gases	Plants do not use air.	Bell (1985)
	Plants use air in the opposite way animals use air.	Bell (1985); Canal (1999)
Photosynthesis-Light	Plants always need light to grow / photosynthesis doesn't occur continuously.	Bell (1985); Hazel & Prosser (1994).
	Plants need light for health and color.	Bell (1985)

Table 1-Continued
Documented Misconceptions

General Category of Misconceptions	Researched Student Conception	Researchers
Photosynthesis-Light	The role of chlorophyll is to make leaves green, break down starch, or absorb carbon dioxide.	Bell (1985); Simpson & Arnold (1982a);
Respiration	Respiration is gas exchange	Bell (1985); Simpson & Arnold (1982a); Anderson et. al. (1990); Sanders (1993); Canal (1999)
	Plants respire through stomata on leaves.	Sanders (1993): Canal (1999)
Respiration and Photosynthesis as combined processes	Respiration occurs only at night or when photosynthesis is not taking place.	Bell (1985); Sanders (1993)

Table 1-Continued
Documented Misconceptions

General Category of Misconceptions	Researched Student Conception	Researchers

Respiration and Photosynthesis as combined processes	Digestion is the energy releasing process of animals and plants.	**Bell (1985); Simpson and Arnold (1982a); Sanders (1993); Boyes & Stanisstreet, (1991)**
	A source for energy for plants includes water, soil and fertilizer in addition to the sun.	Anderson, et. al. (1990); Boyes & Stanisstreet (1991).
	Students successfully completing high school chemistry could not interpret simple chemical formulas and equations.	Anderson et. al. (1990)
	Plants do not respire. (Photosynthesis is the process that provides plans with the energy they need for life processes)	Sanders (1993); Boyes & Stanisstreet (1991)

Most notable within the context of this project is the idea that students see respiration and photosynthesis as mutually exclusive events. One takes place at night, while the other is not taking place. The suggestion that respiration is gas exchange fits well with the conception that photosynthesis is the only process needed to provide plants with the energy needed for life processes. While none of this early research interpreted their results in terms of systems, the results do suggest that students are not conceptualizing the two processes as connected, and are failing to see interaction of multiple ecological levels or global systems relevance as with “nested systems.”

Stavy, Eisen and Yaakobi, (1987) and Eisen and Stavy, (1988) interviewed children (aged 13-15 years) in Israel, and concluded that it was lack of knowledge in chemistry that prevented them from understanding biological processes. The authors drew this conclusion despite the fact that all of the students interviewed had two prior courses in chemistry. These researchers concluded students failed to recognize their own bodies as being chemical systems, and could not conceive gas as a substance. Student responses to questions on photosynthesis and respiration suggested to these researchers that students conceived of the two processes only in terms of gas exchange, with no relationship to energy. The authors concluded that students failed to see the larger concepts of the two processes, and focused instead on the details, which were not necessarily correct. They reported that 66% of the 8th graders and 60% of the 9th graders thought that photosynthesis was a type of respiration. Many of these students cited evidence that the two processes were opposite, one taking place during the day and the other at night (or seasonal relationships). The remaining 40% of the students interviewed told researchers that plants do not respire at all

If these results had been viewed through the lens of nested systems, the lack of chemistry knowledge in students with two prior chemistry courses is less of an anomaly. The authors’ conclusions strongly suggest that students failed to connect the two processes, and did not attach the appropriate scientific function to many of the multiple ecological levels.

Table 1 summarizes information gained in early research. An effort was made by these researchers to capture the same fervor of identifying misconceptions as had been done within the physical sciences. There were few expressed ideas as to the possible sources of the misconceptions, suggestions for instructional repair, or “conceptual change” within the biological sciences. The two plant processes were rarely investigated as inter-related reactions.

Explanation for Origin of Misconceptions:

A major component of conceptual change research within the biological sciences was a search for an explanation of the origins of misconceptions. Specifically with the topics of photosynthesis and cellular respiration, research focused on potential causes within everyday experiences (Leach, Driver, Scott & Wood-Robinson, 1996; Simpson & Marek, 1983; Stavy & Wax, 1983; Wandersee, 1983;Wood-Robinson, 1991), cognitive levels of the students (Seymour & Longden, 1991) and instructional issues (Barker & Carr, 1989c; Boyes & Stannisstreet, 1991; Anderson, Sheldon & DuBay, 1990). Each of these aspects provided more information regarding conceptions of the two processes.

A major literature review conducted by Wood-Robinson (1991) involved studies from several countries and age groups. Within this review, Wood-Robinson cites three studies with significance for this project: Stavy and Wax (1983), Simpson and Marek (1983), and Wandersee (1983). A brief summary of these three articles from their original source follows.

In 1989, Stavy and Wax published their research on children's conceptions of plants as living things. They asked nearly three hundred children to classify pictures of animals, plants and nonliving things into one of two categories, living or non-living. The sample included Israeli children from six to fifteen years of age. The authors cite prior research that more than 90% of students regarded plants as living objects by age eleven. Stavy and Wax (1989) found only 70-80% of Israel children classified the plant as living, up to age fifteen. They attributed the difference in results to language. In the Hebrew language, the word for animal is similar in phonetics and spelling to the Hebrew word for life. Plant growth and death are verbs that are distinctly different from the terms applied to the growth or death of an animal. A literal interpretation of the Genesis chapter of the Bible also suggests to some children a non-living status for plants with a juxtaposed reference to animals providing life, and plants being for food. It is also interesting that the next largest classification of plants included a third category proposed directly by the participants, that plants were neither living nor nonliving. While evidence within the United States does not suggest more than a small minority of students past the age of eleven do not understand plants to be living, it does question whether plants are viewed as being biological systems with input and outputs into other nested systems.

Research by Simpson and Marek (1983) asserted that being a member of a small high school class or a large high school class did not significantly alter the understanding of photosynthesis. They had hypothesized that students in larger high schools were more intellectually developed, and had greater numbers of experiences. They investigated fifty students in small high schools (defined as having less than one hundred and fifty total students) and fifty students in large high schools. Other biological topics, such as diffusion, homeostasis and classification of plants and animals validated their hypothesis. The topic of food production in plants, however, had a significantly low percentage of conceptual understanding in both types of schools. This was despite the fact that small schools had a more rural environment than the large schools. If plant food production were counter-intuitive, such a result would be expected in both school settings.

Wandersee (1983) used a series of twelve tasks, with a basis in every day experiences to investigate misconceptions of various age students in forty-nine schools and colleges. Some tasks required multiple-choice responses, and others were written. A team of biology instructors rated student-written replies on criteria of clarity, brevity, vocabulary level, scope and content delivery. Wandersee concluded that most students' conceptions on photosynthesis did improve with grade level, except that fifth graders frequently had more accurate conceptions than high school and college students did. Carbon dioxide fixation was not well understood at any level.

The Wood-Robinson (1991) review suggested that almost all interviewed children think plants receive their food from the soil. They conceptualize plant nutrient as a need to take in food from the external environment. The second most predominate misconception was that photosynthesis is the plant's respiration, with carbon dioxide going in, and oxygen going out. This confirms their idea of "opposite reactions", a thought that Canal (1999) updates with more detail. Most of the articles in the Wood-Robinson review focused on photosynthesis and did not include a broader view of the inter-relationships between the two energy reactions.

In research complimentary to Wood-Robinson's findings, Leach, Driver, Scott and Wood-Robinson (1996) showed that children from age five to sixteen moved towards the more scientific conception of plant functions. There was an increased awareness of the plants use of carbon dioxide. However, at age sixteen only 10% of the children stated that plants use carbon dioxide as a raw ingredient in the synthesis of food materials. Although not directly investigating instruction, Leach *et al*. kindly attributes the improvement to teaching. The conclusions drawn suggest that younger students lacked sufficient experiences with plants, and that children could simply not conceptualize that an invisible gas (CO_2) could be responsible for the mass of the plant. It simply seemed more logical to the students that solid substances, such as soil, water and fertilizer must be sources of food for the plant. This research includes evidence that students did not consider the two plant processes as being connected as with nearly 200 students interviewed, not one mentioned plant respiration.

Sanders (1993) also looked for sources of misconceptions, but specifically in respiration. In her study, in-service teachers were assessed for their misconceptions. Some misconceptions were held by more than 75% of the sample, leading Sanders to conclude that teachers were a major source of misconceptions regarding the process of respiration. Instruction given by teachers holding similar misconceptions may be part of the difficulty in understanding these two plant processes. In a more recent study, (Ekborg, 2003) noted that pre-service teachers used "common sense" logic to explain these two processes, particularly when taken out of context in surveys and interviews. Few of these pre-service teachers used arguments from the natural sciences, as their conceptual understanding is too superficial

The work of Seymour and Longden (1991) adds to the misconception identification (see Table 1), but with a strong introduction on the development of schemas according to Piaget, a connection to Ausubel's ideas of prior knowledge and to Gagne's developmental readiness theory. The authors conclude that the misconceptions identified in children aged 13-14, were the same misconceptions expressed by children aged 14-16. Such misconceptions are robust and resistant to change. The concluding paragraphs of Seymour and Longden's article suggest that respiration is above the cognitive level of students this age. They suggest that students within a classroom should be encouraged to "construct" their knowledge by using an instructional approach that forces the child to "re-examine and restructure their beliefs to accommodate new evidence" (p. 183). This research goes beyond the simple listing of misconceptions towards an increasing awareness of pedagogical issues, and importantly, towards a cognitive cause. However, it still fails to address the issue of instruction that focuses on the plant as a system.

According to benchmarks and standards, children as young as 9 or 10 years of age should be able to recognize the basic components of system. If the topics of photosynthesis and plant cellular respiration had been taught as components of a system, students may have been able to construct a function for respiration as within the biological system of the plant, and the global ecosystem.

Even after explicit instruction in which carbon dioxide was emphasized as a source to make carbohydrates, Barker and Carr (1989c) noted that some students still did not link carbon dioxide as a source of growth material for a plant. The authors attribute the students' reluctance to a conceptual belief: CO_2 does not have mass, therefore could not contribute to the growth of the plant. An alternate argument from a systems view is that students failed to see the atmospheric gas as an input component of the plant biological system and therefore could not trace it as output incorporated into the mass of the plant.

. Boyes and Stanisstreet (1991) hinted classroom instruction as being partially at fault for students' misconceptions. They suggested that the types of misconceptions revealed by researchers on the energy relationships are the types that are not easily revealed in a typical classroom. First year college students said plants gain energy from wind and water, and animals gained energy from sleeping. This suggests that students have an alternate conception of energy than the scientific conception. In their research, more than 30% of the college-level students thought energy for plants comes from the soil. The classroom instruction is not detailed in this research, but an approach focusing on biological processes as systems may have revealed energy misconceptions prior to the college-level.

A study by Anderson, Sheldon and DuBay (1990) typifies research that looks for a source of misconception. College non-science majors, most of whom were pursuing degrees in elementary education, were asked to define, in writing, the terms respiration and photosynthesis as well as answer fundamental questions about plant functions. In addition, subsets of the students were interviewed. The methodology used a pre/post test design, with direct explicit instruction as the intervention. Instruction included lectures, laboratory activities and discussions. Misconceptions previously noted with much younger children were confirmed, despite the fact that the majority of the students had several courses (some at the university level) in biology. Within the conclusions, the authors report that while students did significantly better on the posttest than the pre-test, the number of students who fully understood both processes remained very low.

A few other studies suggest methods to assess students' understanding of biological concepts such as photosynthesis and respiration (Kinchin, 2000; Mintzes, Wandersee & Novak, 2001) and these use concept maps or other forms of graphic organizers. Interestingly, among Barker and Carr's (1989a) suggestions for assessment of prior knowledge on the meaning of plants making their own food, they recommend that children not draw analogies between plants and animals. Early association would "merely reinforce the intuitive notion that for plants, eating is absorbing" (p.53). Other researchers (diSessa, 1993) suggest that such intuitive conceptions may be useful in constructing scientific knowledge.

Curriculum, and curricular materials include textbooks, and (Barrass, 1984) investigated student texts as a source of misconceptions. Richard Storey (1989, 1991, 1992) produced a series of articles that cited textbook errors as major sources of confusion for teachers and students. His analyses proved useful in inspiring research on interpretation of textbook graphics (Kearsey & Turner, 1999) and the use of analogy-enhanced texts for complex topics that are exceptionally difficult to understand (Glynn and Takahashi, 1998).

Possible causes identified for student misconceptions were teachers, texts, modes of instruction and lack of motivation. Such prior research cited did not center on the student as an active learner. Nor did research on these two processes suggest that students needed to be aware of their misconceptions, and be willing to alter their conceptions towards a more acceptable scientific conception.

Pearsall, Skipper and Mintzes (1997) typify a shift in awareness towards the learner's own active construction of knowledge. They investigated the knowledge restructuring over the course of a semester in college level students, with progressive concept mapping. These authors concluded that students, who use active methods of processing information, construct more elaborate knowledge structures. Interestingly, Songer and Mintzes (1994) in a previous study concluded that while strategies such as concept mapping and interviewing were able to reveal significant differences between conceptions of students regarding cellular respiration, the students lacked experience in thinking at the microscopic level. Understandings that students had at the freshman level in college were maintained throughout their academic career, despite participation in higher-level courses.

How could the knowledge of photosynthesis and plant respiration that the learners were attempting to construct be so persistently in error? With less emphasis on direct instructional methods, researchers such as Chi (Chi, Slotta & de Leeuw, 1994) ushered in a new perspective for conceptual change, when they considered why some misconceptions are more difficult to change than others. Chi suggests that learners have ontological categories of entities they encounter. If the learner has placed a concept, such as light, into the wrong category, it is more difficult to understand the concept. Light and energy, both physical science concepts on which understanding of photosynthesis and plant respiration are highly dependent, are often cited examples of mislabeled concepts. Students consider light and energy as matter, rather than as a constraint-based interaction.

Learners make a number of errors in their thinking regarding biological systems, and not exclusively at the microscopic level. In a very early article, Jungwirth (1987) suggests that science teachers are ignoring the faulty reasoning of students. Within his study, both teacher and student respondents were unable to determine appropriate variables to control, tended to invent causal intermediates to justify a relationship, and accepted conclusions without regard for statistical differences. He concludes that the education system forces students into blind memorization because many of the teachers have not been trained to reason logically, and textbooks are not written to expound on logical reasoning patterns. He continued to research logical thinking in the biological sciences with similar results (Jungwirth & Dreyfus, 1992).

In a analogous study, Tamir and Zohar (1991) detail the common modes of reasoning within the biological sciences by beginning students, which also are perpetuated by textbooks. They considered the preponderance of teleology, where the result is the explanation of the phenomenon, and anthropomorphism, where human characteristics are applied to nonhuman beings. These authors question whether elimination of this reason is a wise practice. Is it possible to build upon a natural line of reasoning, and alter the framework of what might be intuitive?

diSessa (diSessa, 1981; diSessa, 1998; Smith, diSessa & Roschelle, 1993) considers the same question in his theory of knowledge construction. He suggests that his model of conceptual change does not involve as large a segment of knowledge as a concept, or categories as Chi's does. Those entities are too large. They require language to be formed within the mind. Instead, he asserts that learners see things in the world through connected mechanisms, which integrate into reality, involving explicit strategies and extended reasoning. In his model of concepts, diSessa suggests that learners need both a theoretical base and an empirical base. It must have analytic clarity, allowing the learner to understand its nature. The learner picks features from each experience, relates similar experiences together, and integrates the observations from the experiences into a “coordination class “(diSessa, 1998). Learners form these coordination class structures, which includes information as to when the idea will be useful. These coordination classes provide a systematic way for the learner to get information from the world. A given experience has multiple observations, they are “coordinated” and the strategy for interpretation must also be “coordinated.” The strategies for using knowledge are called the “causal net” by diSessa. Ideally, the “coordination class” and the “causal net” co-evolve allowing the learner to advance in their knowledge.

Learners form their causal net of how the physical world works through their own construction, prior to any instruction. diSessa calls the naïve causal net the “sense of mechanism” which includes a rich system of elements that are only partially organized. The elements of this “sense of mechanism”, derived originally from common experiences, are called phenomenological primitives, or p-prims.

P-prims are much too small to form a coordination class on their own. Multiple p-prims may form the causal net to bring a more formed knowledge structure and the appropriate strategies to form the coordination class. P-prims have been investigated by diSessa in the realm of the physical sciences. Southerland *et al.* (2001) proposed that p-prims also are applicable in the biological sciences. These researchers suggest that a p-prim named “need for change” is an intuitive “snippet” of knowledge that students rely on when considering the processes of evolution.

Within the last few years, emphasis has shifted in the research towards greater understanding of the cognition of the learner. How are students assembling knowledge on photosynthesis and respiration? Are they placing the knowledge into ontological categories? Are they using intuitive conceptions in an attempt to build a more structured coordination class of knowledge that will provide strategies? These types of questions are currently within the literature and go beyond the ideas of listing misconceptions, identifying potential external sources of misconceptions and provide a new focus to the potential of using the naïve conceptions that learners have to build knowledge structures closer in compatibility to scientific constructions.

Influential Research:

There is an extensive amount of information on misconceptions students have regarding photosynthesis and plant respiration (Table 1). Research on specific strategies of instruction (Amir & Tamir, 1994; Eisen & Stavy, 1993,: Hazel & Prosser, 1994; Lumpe & Stavy, 1998) has confirmed the notion that both plant processes are exceptionally challenging to students. Only recently has there been direct attempts to categorize student conceptions on biological topics. There is a need for a better understanding of the reasoning strategies students use to understand photosynthesis and plant cellular respiration. There are five studies with direct influence on this dissertation project. The research done by Waheed and Lucas (1992) is the first to suggest that photosynthesis and plant cellular respiration be viewed from a systems-level perspective. Lin and Hu (2003) used a systems view and regarded the topic as using specific knowledge levels. Barak, *et al.* (1999) recognized the need for a systems-level perspective but suggested that photosynthesis is a simple process in comparison to other inter-relationships in biology. Carlsson (1999) also recognized the systems-level view, but isolated photosynthesis and suggested that learners “experience’ photosynthesis within categories. She draws the conclusion that understanding the significance of photosynthesis does not need the complementary process of respiration. The method that

Carlsson uses, in asking pre-service teachers to assemble a system is useful for its simplicity. Southerland *et. al.* (2001) used a similar method, in asking subjects to use cards and to explain the processes. These authors analyze the results in terms of reasoning modes, and through the perspective of ontological categories and phenomenological primitives, or p-prims.

A Systems-Level View:

In their research, Waheed and Lucas (1992) suggested criteria for understanding the two processes from a multi-system level view. These researchers argued that in understanding a complex living process such as photosynthesis, it is important to set it within the context of its environment, and explore the linking concepts and their interactions. They interviewed students and assessed their understanding of photosynthesis on the following levels: ecological; biochemical; anatomical and physiological; and energy change levels. Student subjects were 14-15 years of age, from London schools, and all had studied photosynthesis. Waheed and Lucas proposed that to understand the process, students must have a knowledge base in all four levels. They analyzed written responses taken from 74 subjects, and assessed their knowledge as into categories of showing “strong”, “weak”, or “no evidence” of a specific ecological level. They found that 93% of the students had understanding at the ecological level, with only 20% overall showing understanding at the energy change level. Physiological level and biochemical levels were 57% and 68% respectively. In their study, only five of the fifty-six students interviewed showed understanding at all four levels. These authors also investigated teaching and textbooks, and concluded that the three texts analyzed did not show inter-relationships between all the levels of the processes.

Waheed and Lucas' research is notable for their systems level approach based on a biological concept. However, the weight is only on four questions and written responses to consider understanding prior to interviewing. There is no explanation provided as to why students had greater understanding at the biochemical level than at the anatomical and physiological level. That result seems counter-intuitive, as it would suggest that students were more aware of biochemical reactions than of plant anatomy. While the authors conclude that students had greater understanding at the ecological level than at any level, there is no context of the instructional approach given to explain this finding. They further conclude that students showed very little understanding of respiration and did not recognize the process as on going and continuous. This suggests that students did not have strong understanding at the biochemical level.

Integrated Systems and Knowledge Categories:

Lin and Hu (2003) also recognized the need to approach both processes as integrated systems. They focused their research on the understanding of energy flow and matter cycling, narrowing that broad topic to food chains, photosynthesis and respiration. Their analysis was based on a hierarchical system of organisms, cells, and molecules. Category frameworks were established and considered as "phenomenal knowledge" or knowledge regarding organisms; "mechanical knowledge" or knowledge regarding cells; and "physical knowledge" or knowledge regarding molecules. These authors assert that understanding is required not only of the concepts within a given entity, but also from the interrelations among the entities that occur at the same time, or at different levels.

They place energy flow and matter cycling on all three-category levels, suggesting that energy depicted in a food chain is energy at the level of the organism, and is within phenomenal knowledge. Energy at the level of cells, or mechanical knowledge is represented by photosynthesis and respiration. An understanding of energy flow and matter cycling represent energy at the molecular level. Lin and Hu (2003) then suggest that understanding energy flow and matter recycling is represented by evidence that a student has representation of the interactions among living systems, at the phenomenal and mechanical knowledge levels. They admit that knowledge is not complete without the physical knowledge, but are careful to point out that knowledge of the physical system without the other two levels is simply not biological knowledge. They recommend that an integrated approach should cover at minimum all three levels of knowledge, and include the inter-relationships between all three levels. Within their literature review is a suggestion that biology is a difficult subject to learn, as it requires three dimensions of thought, macro, micro and symbolic.

These authors used concept mapping to determine if seventh grade students in Taiwan had an understanding at all three levels, phenomenal, mechanical and physical, with attention to relational interactions within and among the levels. Maps were evaluated for the task, a response format, and were scored using an established scoring system. The task was their introduction to concept mapping. Subjects included one hundred and six students from five secondary schools in Taiwan. Students were provided with twelve concepts related to energy flow and matter cycling, and were encouraged to add to the listing, as needed. The scoring system included three categories (phenomenal knowledge, mechanical knowledge and inter-relation knowledge). Inter-relation knowledge considered understanding of the inter-relationships between phenomenal and mechanical; between phenomenal and physical; and between mechanical and physical knowledge.

Four trained biology teachers scored the maps, using a scale of 0-3, and discussions among the teachers provided consistency in scoring. Inter-rater reliability was judged statistically significant based on Kendall's coefficient of concordance, with values ranging from 0.186 to 0.592 for phenomenal, mechanical and the inter-relation knowledge. An average scale score of two was considered to have "strong" understanding, while scores between one and two were judged "moderate" in their understanding, and a score of less than one was evaluated as "weak." The scoring system, with detail of the criteria was provided in the article.

The results suggested that students showed a weak understanding of the concepts of food chains and respiration, with average scores of 0.93 and 0.79 respectively. Understanding of photosynthesis was judged "moderate" with an average score of 1.62. All inter-relation scores between the three levels were below one, showing weak understanding of the integration between systems. The authors expressed surprise at the results, suggesting that all students within the subject had instruction on all the topics. Students often made linear maps, without expressing any inter-relationships. The authors also note students had the weakest understanding of matter and energy in the category of phenomenal knowledge, or knowledge at the level of the organism. They suggest lack of knowledge at this crucial level prevented inter-relational knowledge formation. In a deeper analysis, the authors note that students had a higher level of understanding in connecting relationships between phenomenal and mechanical, a lower level in connecting mechanical and physical, and an even lower level in connecting phenomenal with physical. These authors suggested that students learning biology could not connect knowledge about the physical world to the biological world. Almost 95% of the students had a “weak” understanding in the physical knowledge category.

In the discussion section of this article, the authors conclude a “disconnect” of biology from the physical sciences, suggesting that teachers find examples within “everyday life” to motivate to students and enhance students’ exposure to biology as an integrative science. They also comment briefly on biology textbooks, suggesting some texts are written for student enjoyment, and negate the emphasis on the physical sciences. Curriculum in Taiwan offers biology at the seventh grade level with physics and chemistry at grade eight and nine respectively. The curriculum forces biology teachers to reduce the integration of the physical science within the biology.

The article is interesting in that it does not advocate a systems approach to instruction within the discussion section. Instead, the conclusion and discussion focus on the notion that lack of physical knowledge is the cause of weak inter-relation knowledge.

Concept mapping as an assessment mechanism in this study provides some difficulties in interpretation. The students learned the technique of assessment outside of the context of instruction. According to the article, their experience in concept mapping was limited. Twelve items were provided for mapping, and students may have had other concepts as inter-relation concepts than the provided list. Although the directions specified the potential of including other concepts, neither the scoring nor the discussion mentioned students who added inter-relation concepts to the list.

Biological Processes:

Barak *et al.* (1999) also chose to regard biological processes as inter-relations. Their research is based on Chi's (Chi, Slotta & deLeeuw, 1994) idea that processes are in a distinctly different ontological category from matter. Barak *et al.* argue that learning biology is difficult because the curriculum focuses on matter, not on processes. These authors divide the inter-relationships of processes into the following categories:

- Inter-relations within a biological process (one single process- example given is photosynthesis)
- Inter-relations between processes- (interactions between such as catabolic and anabolic processes)
- Inter-relations between processes and a general biological phenomenon (ex: metabolic processes and thermo-regulation).
- Inter-relations between a general biological phenomenon and scientific theoretical frameworks (ex: cell multiplication and the principles of thermodynamics).

In this research, students' understanding of biological phenomena was assessed after an instructional unit on energy in biological systems. Instruction used a systems approach. Among other biological topics, photosynthesis and cellular respiration were addressed. More than one hundred tenth grade students, with an average age of sixteen responded to questions validated by the authors and a biochemist, independently. The students were asked to "comprehensively justify" their responses on the questionnaire and presented with four open ended questions. One question dealt directly with photosynthesis ("why are the green plants in the basis of the ecological pyramid?") and the remaining three questions dealt with the flow of energy but were not specifically taught within the unit of instruction. (ex: “what are the energy resources for the human body?”).

Student justifications were analyzed qualitatively, with categorization of features within matter or processes ontological categories. Agreement between two independent analyzers was 95%. Overall, the results suggest that a high portion of the students’ responses (60%) regarding inter-relations could not be categorized into either ontological category. Forty percent of the responses regarding photosynthesis did not suggest any relationship between the living and non-living world. Twenty percent of the student responses regarding photosynthesis were assigned to the matter ontology, with forty percent assigned to the process ontology.

The authors conclude that within the four categories of processes, students showed understanding the inter-relationships between metabolic processes and the phenomena of thermo-regulation; and understanding cell multiplication in terms of a general scientific framework was more difficult than understanding photosynthesis and the relationships between catabolic and anabolic processes.

The authors further conclude that matter-based language is indicative of a simplistic understanding of biology. In their experience, such responses were based on specific examples, and unique situations. The answers were all linear. Process-based responses reflected a more meaningful level of understanding, and were more holistic. More linkages represented them. Explanations were more flexible and included both general and formal experiences that went beyond the specifics of the question.

The authors recommend a systems approach to the teaching of biology, suggesting the explicit instruction in the inter-relatedness among systems.

This research is useful for the dissertation project in that it provides another approach to the analysis based upon systems interactions. However, Barak *et al.* place photosynthesis as a single process entity, and conclude that within the entity, learning of the process is simple. It seems difficult to make the argument, with only 40% of the students suggesting an inter-relationship. The "nested system" concept of both photosynthesis and plant cellular respiration is absent here, which the dissertation project hopes to address.

Pre-service Teachers Experience Photosynthesis:

Carlsson 's (1999) research is significant to the dissertation project for the participants and portions of the methodological approach. She argues that pre-service teachers should understand ecological issues from a systems view. Carlsson asserts that teachers teach to their level of understanding. Most students mirror their teacher's level of understanding. Only the rare student can rise towards a more scientific conception than their teacher has. In her study, Carlsson considered photosynthesis as an ecological concept, with connections between living and non-living elements in the natural world. Her focus is justified by citing evidence of the overabundance of science education literature within the physical science (66%) in respect to the biological sciences (20%). She further asserts that neither discipline uses constructivistic or phenomenological research traditions. Her list of ecological studies cite the same research as this project, with the statement 'there is a profound lack of a type of research which aims at describing adults' and college students' ways of thinking, and especially in the field of ecology." (p. 684).

Carlsson (1999) carefully describes phenomenography as an approach appropriate for the study of ecological understanding, as a method of depicting ways people experience various phenomena, and allowing for a combination of different elements, at different levels. She divides biological understanding into two distinct elements: human's relationship to nature, and ecosystem insights. Within ecosystem is the element "ways of thinking about photosynthesis."

The article is specifically on her findings through interviews with pre-service teachers on ways they think about photosynthesis. Carlsson suggests that there are four focuses within this research view:

- Relational-between the individual and the phenomenon
- Experiential (second order perspective) or how the phenomenon appears to people
- Content-oriented which must be understood within some particular context
- Qualitative understanding- the outcome of the research may be a general framework, but not based on strategies of sampling or generalization.

This research is part of a larger project to explore ecological understanding of photosynthesis, recycling and energy from a systems approach. She argues that to dissect the system into isolated parts destroys the system properties. Systems must be approached from a multi-variable interdisciplinary context, rather than reductionistic.

Carlsson used a selected sample approach in choosing her participants, deliberately striving for diversity of ideas. She conducted two interviews, and used two different settings. One interview asked the participant to construct an "eco bowl' from available components. The participants were presented with an empty bowl without a lid, and allowed to use materials such as sand, soil, stones, water, green plants, earth worms, dry leaves, and wood-lice, as requested by the participants. This interview generally lasted 1-1 ½ hours. Two weeks later, the participants were asked to comment on a hypothetical spaceship trip. The trip was to last 6000 years, and the participants were asked to plan for the survival of no more than 100 humans aboard the ship.

Carlsson concluded that student responses regarding photosynthesis fell into four distinct categories:

- Category 1: Plants take in and use some components and produce others, independent of this intake. This category is mechanistic rather than dynamic, and suggests very little understanding of photosynthesis.
- Category 2: The ecosystem is seen as a functional whole, in which plants are basic. This category suggests a view of the conservation of matter, and recognizes the role of plants in the ecosystem.
- Category 3: Plants have respiration and can, therefore, be regarded as more or less, "self-sufficient" organisms. Carlsson focuses this category in a deeper understanding of energy transformations, but it could also be viewed as a deeper connection between systems with the plant being viewed as an intact biological system.
- Category 4: Photosynthesis creates order and resources. Again, Carlsson focuses on the awareness of energy transformations, with the recognition that energy becomes available within the reactions for other processes within the global system.

Carlsson suggests that these categories are inclusive, hierarchical and provides a graphic representation suggesting that only category one has ever been described in the literature previously.

Her research is interesting for this dissertation topic in view of the methodology used, as this project will attempt to categorize pre-service teacher conceptions. It differs in a number of ways. Carlsson concludes recognizing respiration as a plant process is not crucial to understanding the plant as a system, as participants in category four understood order and resources. This questions her categories. A systems view of the plant would suggest that both processes create order and resources. Carlsson limits her conclusions to placement of student views into categories without considering expressed misconceptions, modes of reasoning, or intuitive conceptions.

Ontological Categories or Phenomenological Primitives:

Southerland, Abrams, Cummins and Anzelmo (2001) characterize student conceptions on biological phenomena by considering conceptual frameworks or p-prims. In their research, students were selected from four grade levels and three different regions in the United States and interviewed using cards depicting various biological processes. The interviews were set in the context of instruction by a field observation of the science classroom one week prior. However, the science instruction did not necessarily correspond to the biological phenomena on which the interview was constructed.

Classroom teachers were asked to categorize students into ability groups of high, average, and low, based on prior science achievement. Students volunteered to be part of the research. Each interview was conducted individually, with semi-structured questions using the students’ responses as follow-up questions for clarifying. Students were specifically asked "how" a biological phenomenon could occur. Their responses were coded and analyzed.

Categories of responses included:

- Anthropomorphic- when the response used human attributes in their explanation.
- Teleological- when response used end result as the agent of cause.
- Mechanistic proximate- when response identified a specific biological causal agent.
- Mechanistic ultimate- when response used a long-term (genetically based) agent.
- Predetermined – when the causal agent is identified as god or nature, or is not clearly identified.
- Don't know – when the response was "don't know" cause.
- Blended – when the response fell into more than one category.

The authors then used a quantitative approach to their data analysis, and were able to suggest that twelfth graders used more mechanistic proximal responses than other grade levels; results were similar across the United States; and explanations were both tentative and shifted across the various interview prompts. These authors then discuss the results through the perspective of conceptual framework and p-prims.

They speculate that tentative explanations indicate intuitive conceptions and offer a biological p-prim of "need as a rationale for change." They conclude their study with a recommendation that further descriptive work be done on students' understanding of biological phenomena, and that such work include the recognition of proximate and ultimate causality.

Southerland's research has potential for categorizing student conceptions on photosynthesis and respiration within the context of instruction, and through the lens of reasoning modes, ontological categories and intuitive conceptions.

Conclusion:

The dissertation project considered prior research, and brings more focus towards pre-service teachers' conceptions of photosynthesis and plant cellular respiration. Early misconception research, while useful in identifying alternative frameworks did not set their findings in the context of instruction. This project included field observations set within the context of instruction on the plant processes investigated. Methods used in revealing misconceptions were primarily written, through surveys and questionnaires. These methods allow for easy revision by the participant and may not reveal intuitive conceptions. Later research used similar methods, relying heavily on written responses or exclusively on one to one interviews with a researcher. This project did not rely on written responses by participants and may have revealed more intuitive conception than previous research. Much of the prior research focused on the understanding of elementary or middle school children, with only a few involving pre-service teachers. Investigation of pre-service teachers' conceptions is important in considering their future as educators. The potential for moving conceptions towards more scientifically accurate conceptions is strongest in the population of pre-service teachers. Implications for long-term improvement of science education are directly tied to pre-service teachers. Only recently, has there been research that investigates the inter-connections of the photosynthesis and plant cellular respiration and systems. The method of investigating has been to use traditional interviewing techniques. The categories suggested within the Carlsson (1999) research are not set in the context of conceptual frameworks, or intuitive conceptions, but instead on “experiences” of photosynthesis. In this project, categorization includes the context of intuitive conceptions, and is set in the context of the instruction. Southerland *et al.* (2001) addresses conceptual understanding longitudinally, removing the context of instruction, and uses a traditional interview method. This project addresses conceptual understanding, is set in the context of instruction, and used traditional interviews combined with participants’ discourse. The literature review suggested that strong methods of revealing pre-service teachers conceptions needed to be combined with an analysis that includes instructional context, reasoning modes, and potential intuitive conceptions.

Chapter 3: Method

This dissertation project investigated pre-service elementary teachers' conceptions of photosynthesis and plant cellular respiration using standard qualitative methods of field observations and interviews. These methods allow the researcher to share in the understanding and perceptions of others within natural settings (Berg, 1998). Methodology in this project moved beyond prior research on the topics. Field observations placed the study directly in the context of instruction. Participants were asked to respond orally to scenarios and cognitive questions, in dyads and individually. Conceptions revealed in this project were likely more intuitive than prior researchers due to the combination of data collection methods used.

The project was qualitative, using information gathered directly from participants. Information from pre-service teachers was gathered from "explaining sets", cognitive interviews and clarifying interviews. Each is described, including a rationale for the collection methods selected.

Research Questions:

This project was guided by the following research questions:

1. What are pre-service teachers' conceptions of photosynthesis and plant cellular respirations and how do they conceptualize the relationships with respect to:

- inter-connectedness between the processes,
- working on multiple ecological levels,
- and being components within "nested systems"?

2. What arguments and explanations do pre-service teachers provide in support of their conceptualizations of how the two plant processes are related?

Data Sources:

This project explored pre-service teachers' conceptions using explaining sets, cognitive and clarifying interviews as data sources, with the intent of triangulating, and providing a convergent validation (Berg, 1998) of the conceptions. Triangulation in this project was achieved through application of multiple sources, including cognitive and clarifying interviews. The researcher also served as passive observer during field observations and explaining sets. The instructor interview verified the instructional approach, and serving as validation of the instructional materials presented.

The instruction and context is described providing additional information regarding conception construction. This approach was unique in that published research on the topic has not either included the context of instruction, or asked participants the source of their conceptions. Figure 4 provides a summary of the data collection instruments, the research design and the analyses of the data.

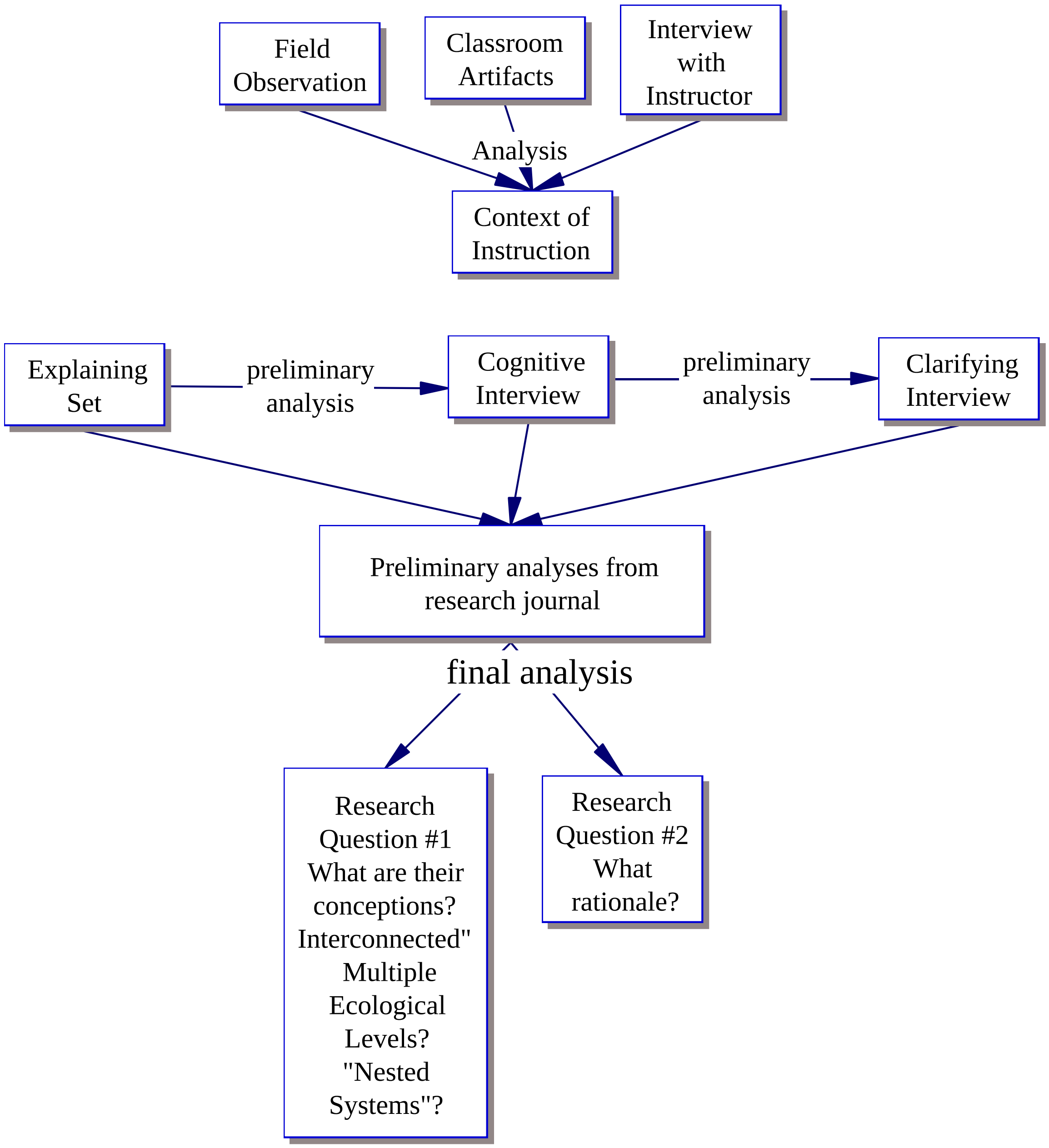

Figure 4: Research Design

Design and Data Collection:

The project was situated within the context of a biology content course designed for elementary education majors at a midwestern university. The participants included recent high schools graduates just entering college to non-traditional college-aged who were seeking second careers. There were eighteen students enrolled in the biology course, and all participated in the project, although not with all instruments. Components of the project included field observations, “explaining sets”, cognitive interviews, clarifying interviews, and an instructor interview. A research journal was maintained throughout the duration of the data collection phase.

The project description, including consent letters are provided for review in the appendices. The project description is included in Appendix A, modified as originally approved by HSIRB, from a middle-school pilot population. Consent documents for pre-service teachers are provided in Appendix B.

Design of the research offered the potential for multi-levels of investigation. The researcher had the perspective of the pre-service teacher while attending class sessions devoted to the topics of photosynthesis and plant cellular respiration. Another level was represented when the researcher observed participants explain the two processes to each other. The pictorial recordings taken during meta-representation provide a perspective independent from language constraints. The perspective evolved when the researcher interviewed participants regarding their shared experience. The combination of all the artifacts gathered within the project provided sufficient data on pre-service teachers’ conceptions of the two plants processes.

Data Collection Instruments:

Data were collected from pre-service teachers in an “explaining set”, a cognitive interview and a clarifying interview. Field observations were made during the instruction. The instructor of the course was interviewed. A researcher’s journal was maintained throughout the process. Each data collection instrument, its rationale and procedure is described.

Explaining Sets:

Explaining set were originally designed with the idea that participants would have a greater comfort level discussing complex processes with a classmate rather than with a researcher. The design was chosen based on personal experience. The researcher previously observed college aged students working collaboratively converse differently about scientific topics among themselves than when responding to questions posed by their instructor. The language employed is generally less formal when discussing a topic with a peer. Resulting explanations might be less formal and more revealing of intuitive conceptions in a situation of paired peers.

Participants were placed into “high achieving” and “low achieving” dyads. “High achieving” and “low achieving” designation was assigned in consultation with the instructor, who provided information regarding the participant’s relative exam scores, and their class attendance. Pairing criteria, unknown by the participants, was based on their first exam scores, upon questions asked and answered successfully in class, and class attendance. The exam scores fell within a narrow range and designation of low and high was arbitrary at best. The course enrollment was only eighteen students, and the explaining set was conducted within week four of the nine-week course. Sixteen of the eighteen pre-service teachers participated in this portion of data collection. (See Appendix D).The purpose for this arrangement was that students being aware of the capabilities of other students within their class might be more hesitant in their own turn at responses. Being hesitant and uncertain may reveal intuitive conceptions (Southerland, *et al.*, 2001).

The explaining set was designed to alternate questions among the participants within the tasks, thereby reducing anxiety among the low achieving student. The script for the explaining set is in Appendix C. The purpose was to set a conversational tone.

The four tasks within the explaining set are described below:

- Task 1: The "warm-up" task. This task was designed to establish both a talk-aloud protocol and a procedure of alternating explanations. Participants were asked to assemble an Escher tessellation puzzle that was challenging in the placement of the pieces. The puzzle promoted the idea of inter-connectedness as the individual pieces were combined to make one product.
- Task 2: The "plant comparison" task. This task asked for an explanation of plant growth. Props included two of the same species of plant but of differing size. The task was designed to determine if students could conceptualize plant growth as a function of a global atmospheric system. It was also designed to reveal if students connect plant growth and other metabolic processes with plant cellular respiration. The scenario was designed to promote the plant as a biological system with global connections.
- Task 3: The "ecosystem in a jar" task. In this task, participants were presented with a clear plastic jar containing plastic plants and two figurines of people. They were asked to imagine the objects as living and life sized, and to explain their vision of the future for the organisms within the jar. This task was designed to determine if pre-service teachers could

explain the products and processes of photosynthesis and respiration, and if they viewed them as inter-connected and independent of human activities. Accompanying questions asked for a reflection on how they have conceptualized the two processes. This task set the plants on multiple ecological levels, as biological systems within a global system.

- Task 4: The meta-representation. Participants were asked to draw a representation of a "plants' role in the natural world." The design for this task is based on diSessa's (diSessa & Sherin, 2000) suggestions for meta-representation of intuitive knowledge. Each participant verbally explained the meta-representation individually and in turn. Their explanation served as a validity check, reducing the potential for an interpretation based solely on artistic ability.

The explaining set was introduced by the researcher, with a few brief statements and an opportunity for clarification of directions. The researcher explained the procedure to both participants, acknowledged the need to alternate the order of explanations within the dyad and the need for longer duration explanations. Such statements discouraged participants from simply repeating their partner's explanation. Participants often cited the other's response, but also frequently "piggybacked" by adding their own conceptions.

During the explaining set, the researcher was a passive observer in the room, taking notes in a journal. The notes captured detailed descriptions of the interactions between participants, but also included speculations as to their conceptual understanding. Journal entries taken during the explaining were consulted during construction of probing questions for the cognitive interviews.

The researcher only presented the questions, the props and instructions. Participants were asked to make their explanations at least thirty seconds in length, and to define any scientific terms used. In addition, the researcher reminded participants of the need for privacy within the research to prevent revealing tasks and responses to other participants prior to their session with the researcher.

Participants were asked to explain both processes of photosynthesis and cellular respiration. One may have known the processes well (“high achieving”) while the other may have been more hesitant (“low achieving”). This protocol encouraged explanations in common everyday language and in some dyads, provided in-depth conceptions on systems, including reasoning modes and intuitive conceptions. The explaining set was both video and audio taped and later transcribed. The transcription was checked against a digital voice recording, an audio voice recording and the video voice recording for accuracy.

The order of the prescribed tasks within the explaining set represented an increasing level of abstraction as well as a progression from the ecological level of the organism through the ecosystem towards the global level. Participants were asked to focus on the plant as an organism first and relate cellular and biochemical levels to the organism level. All ecological levels are represented in the ecosystem jar task. Meta-representation allowed for a summation at all levels, and a representation of systems and their components. This explaining set has not been used in prior research.

In this project, the participants were asked to be involved in the explaining set as part of a course assignment. Laboratory time designated by the instructor facilitated this arrangement, and only four participants were scheduled other then class time set aside for the project. In the explaining set, participants were paired in dyads. They were asked to provide an auditory explanation of the four tasks described above.

Participants were all enrolled in the same class, but for nearly all, the explaining set was their first formal introduction to a classmate. See Appendix D for a list of the participants. There was little interaction within the lecture setting among classmates, and only four laboratory sessions of two and a half hours each prior to the explaining sets. The original intent of a greater benefit in revealing intuitive conceptions may have been more dramatic in a course setting that encouraged student participant and collaborative grouping.

Cognitive Interviews:

The cognitive interview was an opportunity to question conceptions provided during the explaining sets and to allow participants to verify and provide further evidence. The plan was to select a range of perspectives on photosynthesis and cellular respiration. The instructor in this project asked that participants consider the cognitive interview an extra-credit option.

Timed as it was immediately following the release of the second exam, fourteen of the seventeen students (one student withdrew from the course after the second exam) were involved in cognitive interviews. Both high achieving students (those who were doing well in the course, asking and answering questions and attending) and low achieving students were represented in the cognitive interview sample. The three students who did not participate were students who had scheduling, transportation or childcare difficulties. The cognitive interview did represent a range of understanding of the processes. Conceptions were noted which represent the least sophisticated level of understanding regarding systems. Participants also expressed understanding of interconnectedness, multiple ecological levels, and nested systems.

The interview focused on the two plant processes, using two different sizes of the same species green plants. They were the same plants used in the explaining sets. Questions in the cognitive interview focused on the plant as a biological system, specifically on plant growth. In addition, questions focused more on plant interactions and systems. Participants were asked to define both processes and consider a situation where both plant processes were disrupted. The participants were also asked how they had come to understand photosynthesis and cellular respiration. The interview was semi-structured, but beginning questions are provided within Appendix E. Probing questions for each participant came from three sources. One source was the entries of impressions recorded in the researcher's journal. A review of the transcription of the explaining set provided another source. Some questions were spontaneously formed to clarify responses the participant provided. For example, the following question was spontaneously formed in response to a pre-service teacher's description of a plant as healthy: "When you say healthy, what do you mean by healthy?"

The researcher's journal was consulted prior to conducting cognitive interview to review explaining set conceptions and plan questions for cognitive interviews.

The cognitive interview was taped and transcribed. Transcriptions were checked against the digital record, an audio record and a video record for accuracy. The researcher took both descriptive and reflective notes of each cognitive interview immediately upon completion, entering these notes into the research journal.

Clarifying Interviews:

Preliminary analysis of participants' discourse was completed between both explaining sets and cognitive interviews. These interviews took place within week seven of the nine-week course. Seven of the remaining seventeen pre-service teachers elected to participate. Efforts were made to involve more participants but placement of the project within the short course session made scheduling difficult.

The clarifying interview intended participants clarify their conceptions in a third experience. This third conversation would then provide an opportunity to correct any misunderstanding on the part of the researcher and to clarify participants' conception on the two plant processes. During the cognitive interviews, the researcher noted a pattern of participants referring to images that had been presented in the course lecture or were in the course text. Participants expressed frustration at "seeing" a mental image associated with their classroom instruction, but being unable to explain their conceptions without the image in front of them. A similar pattern emerged with their vocabulary. Participants articulated a "tip of the tongue" phenomenon when they wanted to use a term from the vocabulary of the unit, but could not recall the term. To offset this phenomenon in the clarifying interview, the researcher provided copies of many of the images found in the text (which were also in the lecture presentations) and vocabulary words that participants had mentioned during the cognitive interviews or explaining sets.

The questions for these participants were derived from five sources. The research journal was consulted for impressions and reflections on both the explaining set and the cognitive interview. Transcripts were re-visited for potential questions. The fifth source was the responses of the participants during the clarifying interview, as some questions were formed spontaneously. For example, the following question was asked when a pre-service teacher described a cycle as processes: “Why do you think a cycle is a series of processes?”

Questions in the clarifying interview often began with a phrase such as “do you remember when you said this….” , followed by “can you give me more detail on….?”, or “Can you tell me what you meant when you said …….”?. In addition two questions were asked of all participants of the clarifying interview: “What do you think a life cycle or a cycle is?” and “What do you think a biological system is?” The researcher had earlier noted interesting concepts regarding cycle and systems applied to plant processes.

Clarifying interviews were audio taped and video taped for later transcription. Transcriptions were checked for accuracy by listening to a digital recording, the audio recording and the video sound record. Descriptive and reflective notes were recorded within the research journal.

These three instruments (the explaining set, the cognitive interview, and the clarifying interview) served as data collection instruments to answer both research questions.

Field Observations:

Field observations were conducted to set the interviews in the context of instruction. Field notes focused on the instructors’ pedagogical approach, and discourse between student and instructor. The intent was to achieve a greater understanding of student conceptions from a shared experiences and referents. Field observations began one class period prior to the instruction on the two processes to reduce the potential of the Hawthorne effect, and to make the researcher less visible (Berg, 1998) during the instruction. Field observations were conducted in the third and fourth week of a nine-week session. Field observations totaled ten hours.

Field observation of the instructional content established a point of reference for a shared experience between participants and researcher. It also allowed for analysis of instructional materials presented to the participants. Instructional materials, including texts and course handouts, were studied to determine the extent to which the approach considers "nested systems." The materials were analyzed after the field observation, and analysis following guidelines established for biology text evaluation (AAAS, 2004). Those guidelines include seven categories for evaluation. Category I is a sense of purpose within the unit, the lesson and the lesson sequence. Category II takes into account students' ideas, including recognition of prerequisite knowledge and skills, and the prior assessment of student ideas. Category III includes engaging students with a wide variety of phenomena, and vivid experiences. Category IV includes the development and application of scientific ideas. Category V includes promoting student thinking about the phenomena by encouraging self-explanation. Category VI involves assessing the progress of students, and Category VII involves providing support for the teacher. Although this project evaluated high school textbooks, many of the issues seem applicable to first year college texts.

Observations were recorded on audio and videotape with later transcription. Due to space and safety constraints, observations in the laboratory were only audio taped. In addition, the researcher took notes during all observations. These notes were both descriptive and reflective (Creswell, 1994).

Instructor Interview:

A day prior to the optional final exam, and a full week after student conceptions had been analyzed; the instructor was interviewed. This interview was more than one week after the last pre-service teacher interview. The instructor's interpretation of the participants' conceptions of the processes was not considered in the analysis, as the instructor interview was conducted after preliminary analysis of explaining sets, cognitive and clarifying interviews of the participants. The instructor interview was designed to determine the instructor's conception of plant processes, her awareness of current reform efforts within science education and her instructional approach. The instructor was asked to explain her sense of the students' conceptions of the two topics. Questions are included in Appendix F. The interview was semi-structured, with questions formed from the instructor's responses. Due to time pressures and schedules, the instructor's interview took place on the phone, and was only recorded digitally. It was transcribed and checked three times against the original digital recording. Descriptive and reflective notes were recorded in the research journal.

Researcher's Journal:

A research journal was maintained throughout the period of data collection. It contains researcher impressions of progress throughout the collection process, notes for analysis, and potential questions for clarifying interviews. All significant contacts with participants were recorded in the journal. Entries to the journal were made during the "explaining sets" while the researcher was actively listening to the participants, but not interviewing. The journal was particularly helpful in determining potential questions for participants for both the cognitive and clarifying interviews. The researcher's journal captured decisions made at all junctures within the data collection process. Previous sessions notes were read prior to each data collection session. Notes were recorded during, or immediately after a session, to provide a frame of reference for the researcher and to provide continuity and consistency to the project.

Figure 5 below illustrates the relationship between the field observations and the data collection. It also indicates the number of participants from the original eighteen members of the class who participated in each session of data collection.

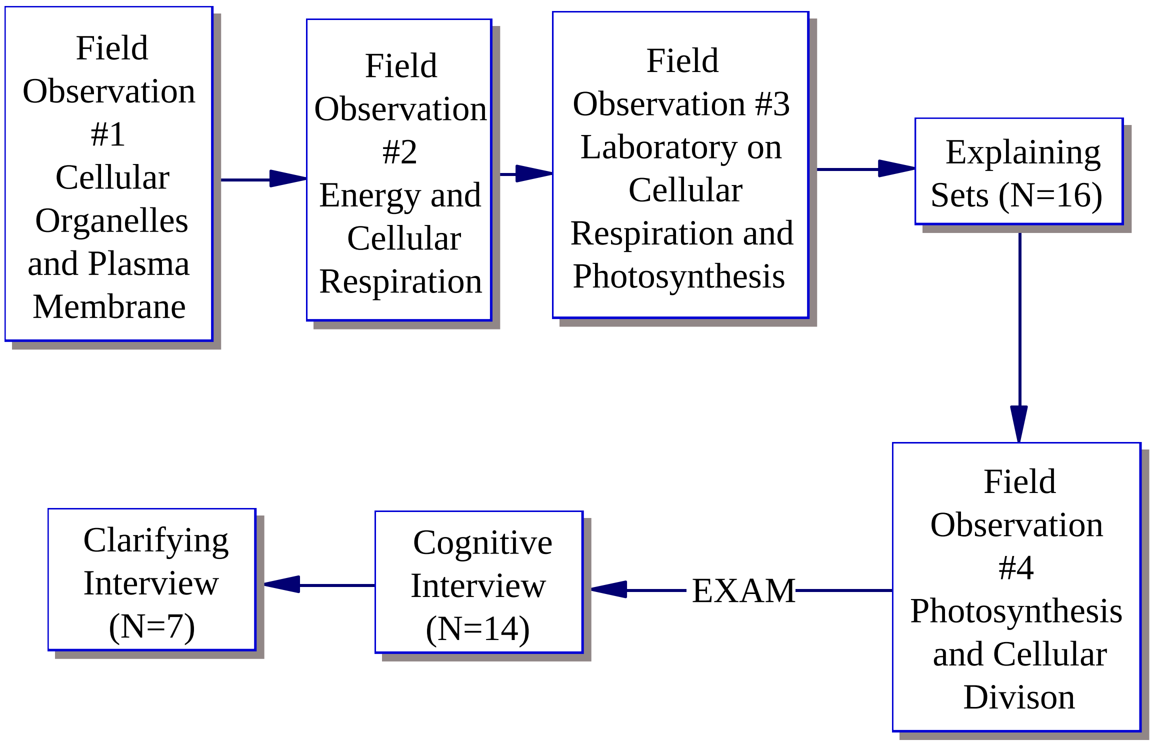

Figure 5: Time Line of Design

Data Analysis:

Analysis in qualitative research is set in the context of the purpose, and is thus guided by the research questions posed. In this project, informal data analysis was conducted simultaneously with the data collection, in the form of narrative writings in a research journal (Creswell, 1994). The simultaneous activities engaged the researcher in sorting, categorizing and formatting information representative of the participants' conceptions. Data analysis included both a reduction ("de-contextualization") and interpretation ("re-conceptualization") with the result being a larger constructed image of pre-service teachers' conceptualization of plant processes.

Analysis followed the process of data reduction, data display and conclusion drawing. Data reduction included the collection process and the research questions themselves.. It also included coding and sorting of data. It is important to recognize that within qualitative research data "unfolds, cascades, rolls and emerges" (Lincoln & Guba, 1985 as cited by Berg, 1998, p. 27) Subsequently a "spiraling" approach develops which never leaves any one stage behind (Berg, 1998).

Codes surfaced as the data were collected. The data itself provided categories of student conceptions and information on the extent to which the processes were seen as being inter-connected, occurring both on multiple ecological levels, and within "nested systems." The data revealed modes of reasoning that students used when forming conceptions. It may have also revealed intuitive conceptions suggesting a less formalized knowledge structure. Detailed passages expressed directly by the pre-service teachers serve as substantiation of the researcher's interpretation.

Answering of the Research Questions:

Data collected from explaining tasks, cognitive interviews and clarifying interviews were analyzed to answer the following research questions:

1. What are pre-service teachers' conceptions of photosynthesis and plant cellular respirations and how do they conceptualize the relationships with respect to:

- inter-connectedness between the processes,

- working on multiple ecological levels,
- and being components within “nested systems”?

2. What arguments and explanations do pre-service teachers provide in support of their conceptualizations of how the two plant processes are related?

Question one of the research questions was answered from the pre-service teachers’ conceptions recorded during the explaining sets. During the cognitive interviews, participants verified original responses and explained discrepancies in the clarifying interviews. Pre-service teachers provided conceptual understanding of plant growth, and conditions needed. The first seven questions of the cognitive interview elicited information regarding plant growth. Questions eight and nine probed conceptions of multiple levels. Responses to questions ten through twelve revealed the pre-service teachers conceptions of both processes as components of a nested system. Participants provided further detail in responding to questions thirteen through nineteen regarding the connections between the two plant processes.

Responses to question number six in the first task (“explain how you came to know about plants?”) and question number fourteen of the cognitive interview (“How did you come to know about plants and what they do?” and “How do you come to accept these ideas?”) were used to answer the second research question. Responses to the questions within the explaining set, cognitive and clarifying interviews revealed misconceptions, many which had already been documented by researchers. Analysis included noting misconceptions previously documented. In addition, conceptions were described which were not scientifically accurate, and not previously documented.

Specifics of the research questions and the sources for information are provided in the accompanying tables.

Table 2
Sources for Answering the Research Questions
Note: T1 represents Task 1 the plant comparison in the explaining set
T2 represents Task 2 the ecosystem jar in the explaining set
T3 represents Task 3 the meta-representation in the explaining set
Ex: T1#1 is the first question in Task 1 of the explaining set.

Research Question	**#1 What are they?**	**#1 are they interconnected? ***	**#1 are they at multiple levels?****	**#1 are they within "nested systems"? *****	**#2 What rationale?**
Explaining Set	T1#1, T1#2 *all of T2 & T3	T1, T2, T1#3; T1#4;T2#1; T2#2;T2#3-5; T3	T1#3;T1 #4; T2#1, T2#2; T2#3-5;T3	T1#3; T1#4; T1#5, T2#1; T2#2;T2#3-5;T3	T1#6
Cognitive Interview	#1-#20	#1-#7; #15; #18	#8; #9; 15; #16; #19	#10-#12	#20

***Interconnections: evidence that photosynthesis and plant cellular respiration are both plant processes, within one single system, and that both processes are necessary for energy flow.**

****Multiple levels: evidence that photosynthesis and plant cellular respiration take place at different ecological levels of interaction, i.e. biochemical, cellular, organism, and global.**

*****Nested systems: evidence that the two plant processes operate within multiple systems interdependently**.

Table 3

Summary of Questions Posed to Pre-service Teachers

Task 1 (Compare plants)	Task 2 (Ecosystem)	Task 3 (Meta-representation)	Cognitive Interview #1-#7	Cognitive Interview #8-#14	Cognitive Interview #15-#21	Clarifying Interview
T1#1 Explain any differences you see in these plants.	T2#1 Possible for person to survive?	Explain how you think plants are part of the natural world.	#1 Differences between two plants.	#8 What are plants currently doing?	#15 Are the processes connected? How?	What is a life cycle? What is a cycle?
T1#2 Explain how the two plants became different from each other.	T2#2 Possible for green plants to survive?		#2 How did differences occur?	#9 How do various parts help in functioning?	#16 What role do cellular organelles play in the processes?	What is a biological system?
T1#3 Explain any special conditions or requirements needed.	T2#3 What will happen to the person as time passes?		#3 Detail how plants became different. Any needs?	#10 What role does plant have in world?	#17 What role do the processes play in the ecosystem?	

Table 3-Continued
Summary of Questions Posed to Pre-service Teachers

Task 1 (Compare plants)	Task 2 (Ecosystem)	Task 3 (Meta-representation)	Cognitive Interview #1-#7	Cognitive Interview #8-#14	Cognitive Interview #15-#21
T1#4 Differences between plants and other organisms.	T2#4 What will happen to the plants as time passes?		#4 Elaborate on conditions needed.	#11 Do you think plants are different and how are they?	#18 If the processes where disrupted what effect would that have?
T1#5 Similarities between plants and other organisms.	T2#5 Explain the relationships in the enclosure.		#5 Elaborate on details of needs.	#12 Do plants interact with other living things?	#19 How do the components work together?
T1#6 How do you know?			#6 Explain difference in leaf size.	#13 What do you think photosynthesis is?	#20 Are some ideas confusing? If so what is?
			#7 How did plants use the materials?	#14 What do you think cellular respiration is?	#21 How do you know?

Table 3 includes the explaining set and interview questions as a cross-reference to Table 2. Many of the questions in Table 3 have been abbreviated for a quick reference. The exact wording of each question is provided in Appendices A and E.

After the explaining set and the cognitive interviews, transcriptions were made from video and audio recordings. The transcriptions were read for a broader sense of all the conceptions. The resulting information was large in quantity. The researcher took notes during the reading, just to capture ideas as they come to mind. Codes arose through the listing, and original start codes were reviewed and changed appropriately to align with the data. The data were organized into patterns through the coding and analysis process. Conceptions described by the participants were consistent overall, but some questions revealed more information from some participants, and less from others. At times participants added to their previously described conceptions, and at other times throughout the project, their responses were less concise. In categorizing the conceptions, the researcher worked primarily from the transcripts, audio and video recordings of individuals prior to considering the entire sample of conceptions described. In the few instances of participant contradictions, or unclearly described conceptions, the researcher interpreted such conceptions as being incompletely formed, and therefore included those conceptions into categories that reflected their formative nature. The final result of data analysis was the emergence of a larger consolidated view of pre-service teachers' conceptions on photosynthesis and plant cellular respiration.

Start Codes:

Transcriptions from each interview and explaining set were coded to reveal pre-service teachers' conceptions of the processes in terms of interconnectedness, multiple ecological systems, and nested systems. In addition to the interviews and explaining sets, field observations were analyzed. Field observations revealed the instructors' classroom approach, provided a source of shared contextual examples and experiences, and enhanced the interpretation of pre-service teacher and instructor interviews. Transcriptions of field observations were coded. Coding initially focused on conceived connections between the two processes, both by instructor and pre-service teachers, the multiple ecological levels, and evidence of the understanding of nested systems.

As participants provided their conceptions on the processes, modes of reasoning were coded. Modes of reasoning included justifications that pre-service teachers provided for their responses and were used to answer research question two. For example, a response that suggested the participant has formed the majority of their conceptions from a direct reading of the course text was coded as "authoritarian" if the participant cited the text as a source for their reasoning. The coding table (Appendix G) was modified from those used by Southerland, *et. al.* (2001) and Amir and Tamir (1994). It reflects data gathered from these participants in this project. The value of qualitative research is to find patterns within the data itself.

The Researcher:

Qualitative analysis is always unique to the researcher. In that frame, it is important to set the project into the context of the researcher's own experiences and perspectives (McMillan, 2000).

The perspective brought to this project includes more than twenty-five years of instruction at a community college level, in a variety of introductory science courses, representing all of the science disciplines. Work with college-aged students has been augmented with outreach projects in local school districts. Since 1999, the major teaching assignment has been with elementary education majors, in a series of courses emphasizing integration of the science disciplines. Benchmarks and national standards were used in design of the original course series. Formal education includes a teaching certification at the secondary level, an advanced degree in biology, with a cognitive in psychology, and work towards an advanced degree in animal behavior. Fifteen years of work experience includes the design, implementation and instruction of a developmental science course with an emphasis on reasoning skills and science as process.

The researcher's perspective is provided to recognize the level of comfort with "nested systems" as an instructional approach and subject for analysis; the experience of listening to varying levels of student discourse, and awareness of national reform efforts.

Selection of the Classroom:

The researcher determined classroom selection, using two criteria. It was important to set participants' conceptions into the context of instruction. Therefore, the availability of a biology content course provided exclusively for pre-service elementary teachers was one criterion. During the time available to the researcher, and within convenient geographic location, there were only a few choices. The second criterion was the instruction of photosynthesis and plant cellular respiration, and the connection of the two processes within the same unit of instruction.

Permission for entry into the university setting was originally requested through the Dean of the college from which the course was offered. The Dean contacted the Department Chair, who then contacted the instructor, and provided the researcher with logistics for introduction. A discussion with the instructor of the course being offered, and her expressed perceived difficulties that students had with the two topics was important to the selection. The instructor suggested that cellular respiration was the more difficult of the two processes for students to understand, needed more time for instruction, and within her course structure, was timed to provide laboratory investigations to complement classroom lectures. The instructor offered a laboratory period to be set aside for this project.

All eighteen students enrolled in the course were asked to participate, and all did participate, although not within all aspects of the data collection (Appendix D and Figure 5). The project was very similar to standard educational practices of formative assessment, in that all students within the course were asked their conceptions. Information was also gathered from the instructor involved, and from the materials of instruction, including classroom presentations, experiments and textbooks. These were analyzed as potential sources for conceptions.

Description of the Community and University:

The university is located in a rural community in northern Michigan, sixty miles from a major metropolitan area. The community has an estimated population of 12,000 people, exclusive of students. The university is the major employer in the region, and students enrolled number nearly 10,000 each year. The university is a career-oriented public institution, offering more than 150 degrees. The elementary education degree is one of its most recent degree offerings, but the institution has achieved national recognition for other science-related professions. The degree is such a recent offering that the upcoming academic year is the first for graduates from the program. All elementary education majors are required to enroll in the course selected for this research project.

In summary, this project investigated pre-service teachers' conceptions regarding two plant processes, photosynthesis and plant cellular respiration, specifically with respect to understanding the two processes as interconnected, as occurring on multiple-levels and as "nested systems." Misconceptions were also noted, as well as reasoning modes. Analysis included the context of instruction, as a source for conceptions, but also included meta-cognitive interview responses. Set in the context of their instruction and within the perspective of ontological categories, reasoning modes and phenomenological primitives, this project captured the conceptions of pre-service elementary teachers on photosynthesis and plant cellular respiration.

Chapter 4: Results

Introduction:

In this chapter, the resulting analysis of data is presented. The pre-service teachers' conceptions are categorized in response to both research questions. Quotations directly from the participants provide evidence for conceptions revealed.

Chapter four also includes analysis of the text and other curricular materials made available to the pre-service teachers. The instructional context is also characterized to provide reference for their conceptions.

Answers to Research Question One:

1. What are pre-service teachers' conceptions of photosynthesis and plant cellular respiration, and how do they conceptualize the relationships with respect to:

- inter-connectedness between the processes,
- working on multiple ecological levels,
- and being components within "nested systems"?

This question is answered in general, first considering both processes together, and then separately. The question is answered with consideration to interconnectedness, multiple ecological levels and "nested systems." Participants varied widely in their conceptions of the two processes. The variance was idiosyncratic in that while individuals' conceptions did not vary over the duration of the project, they tended to focus on individually relevant facets of the processes. Generally, these pre-service teachers had more scientifically acceptable conceptions regarding photosynthesis than cellular respiration. For that reason, even though general categories of their conceptions are advanced, any single individual's responses could be sorted into more than one category. One individual may have had nominal knowledge of cellular respiration, and admitted reluctance at providing information regarding processes at the cellular level. However, the same individual may have also admitted a purpose for the process, which was beyond their current level of understanding. The same individual might in a later interview articulate the purpose as growth for the organism, again telling the researcher that they are unable to provide more detail. When questioned about photosynthesis, the same individual might have provided a description of the process as an energy reaction that releases O_2, in conjunction with cellular respiration.

Conceptions varied between the two processes, so that an individual participant could have fallen into the nominal processes category regarding cellular respiration, yet be categorized as purpose processes when considering photosynthesis. The idiosyncratic responses made categorizing challenging for the researcher, but facilitated the decision to consider both processes first, then photosynthesis and cellular respiration separately. Joy provides an example of the idiosyncratic nature of their responses. In response to a question on the role of plants in the ecosystem she said:

> …. when you look at the food chain, it always starts with the plant, because they are the ones making food for us. When we consume the plant, we get the energy and if there weren't any plants, then we would have to find a way to photosynthesize, so we could get our own direct energy from the light. So, we have to have plants, and they produce oxygen too. Or, you know, there is oxygen, they can photosynthesize, but now there is more plants around, there is more free oxygen, so that we can breathe whenever, wherever.

Joy suggests that photosynthesis is an energy process, which she mentions first in relationship to their ecosystem role. However, she views photosynthesis as an oxygen process too. When asked later in the interview how disrupting photosynthesis would affect the ecosystem, Joy places oxygen production as a priority:

> Eventually, I don't think there would be as many people, because we wouldn't be able to breathe as well as we do. There wouldn't be as much oxygen in our atmosphere, so there would be less organisms, that could breathe in our population, and not just humans, but other things too, other living things.

Due to the variance in responses from individual participants, the decision was made by the researcher to combine data collected and consider all conceptions voiced by participants within the project.

Participants described their conceptions in response to questions that were then interpreted and analyzed by the researcher. Responses, which focused on the biochemical level, used phrases such as "the hydrogen ion gradient" and "it needs energy in the form of ATP." Responses describing conceptions at the cellular level included phrases such as "this process happens in the mitochondria." Participants who focused their responses on the organism level described the plant, often times pointing directly to the plants, or used phrases that included structural components of the plant, such as leaves and roots. Responses typical of the ecosystem level used phrases that implied interactions of plants, as being part of the food chain, or as affecting the community surrounding the plant. Global level conceptions included phrases in their descriptions such as "adds oxygen to the whole atmosphere" and "it balances the environment."

Answers to research question number one are summarized in table 4. The table shows categories when the two processes are combined, and when they are separated. It also summarizes the system relationships expressed by participants.

Table 4
Summary Table of Conception Categories

Both Processes	Photosynthesis	Cellular Respiration	Relationships
Nominal Processes Photosynthesis: (5/18) Cellular Respiration (16/18)	Don't Know (5/18)	Don't Know (16/18)	Connected (18/18)
Purpose Processes (17/18)	As Energy Process (10/18)	CO_2 to O_2 (5/18)	Multiple Levels – Varied from participant to participant. See Table 5.
Organism to Global (5/18)	As Food/Growth Process (5/18)	Releasing CO_2 (3/18)	Nested Systems – (2/18)
Biochemical to Organism (4/18)	As Oxygen Process (2/18)	As Energy Process (2/18)	

When considering all facets of the two processes, the participants' conceptions fell into four major categories:

- Nominal Processes
- Purpose Processes
- Organism to Global Processes
- Biochemical to Organism Processes

Each of these categories includes the term "processes." All the pre-services teachers referred to both photosynthesis and cellular respiration as processes. There is some evidence to suggest that while the term was applied, there may not have been a universal understanding of its definition. Participants incorrectly applied concepts such as "cycle" and "by product" leading to questions about their understanding of the term "process."

Pre-service teachers in this project used the word cycle to refer to food chains as well as biochemical processes where the product of one chemical reaction becomes the reactant of the next. They also used the term "life cycle" to refer to the decomposition process, as well as the time from birth to death.

Nominal Processes Category:

In this category, participants used the terminology appropriate to their unit of instruction, but did so unconvincingly. They were not unable to respond to questions regarding their use of terminology, nor were they able to elaborate on subsequent questions related to the same topic. Responses of this group were characterized by the use of repetitive phrases such as "going hand and hand", referring to the connection between photosynthesis and cellular respiration. Conceptions in this category were superficial. Phrases were seemingly "plucked" from the classroom lecture, with little or no substantive understanding, but recognition that the instructor had used the phrase in class. Nominal knowledge about the topic was prevalent at multiple levels, and involved most facets of the topics.

For example, in this exchange, Natalie (designated as N) suggests to the researcher (designated as R) that she knows about light:

> R: Tell me a little bit more about their relationship with the light. Can you tell me more detail about that?
> N: Well, they need the light to grow, to photosynthesize. I know they don't use the green light, but there is ultra-violet and red light that they use. But, they don't use the green light. Um, how do they grow? Um, I know they get their water from the roots; they get their branches from the leaves and stuff.

Natalie is only able to provide phrases pertaining to light, that were emphasized by her instructor. Despite instruction on photosystem I and photosystem II, and how light energy is transformed within the system, Natalie can only offer the phrase “they don’t use green light.” She quickly refocuses the question to the need for water at the organism level.

Nearly all the pre-service teachers had nominal process knowledge regarding cellular respiration. See table 4. Only two participants recognized cellular respiration as an energy reaction. Most participants had only nominal process knowledge on specific ecological levels. Only two pre-service teachers had some scientifically accurate conceptions on all ecological levels. Two other participants had conceptions on all ecological levels, but the majority of their conceptions were not scientifically accurate.

Purpose Processes:

In this category, participants presented a conception of either or both processes having distinct purposes. In general, the purpose expressed was in service to humankind. Most pre-service teachers conceptualized plants as service organisms to the ecosystem, or specifically to humans. The concept is illustrated in Anita’s description of her meta-representation:

> I said the plants are a major part of the world, you know, because if there were no plants, then there wouldn’t be anything to breathe CO_2, carbon dioxide, or oxygen for people to breathe, um, if there were no plants, the bugs wouldn’t be able to pollinate anything, meaning they wouldn’t probably be able to eat. And, the bugs would die, and the bugs are eaten by other consumers, and if there were no bugs, the consumers wouldn’t be able to eat, and then we wouldn’t be able to eat. So, there would probably be no life if there weren’t any plants, because plants are like the basis of everything. If there were no plants, there probably wouldn’t be any life.

Anita considers plants removal of CO_2 from the environment as beneficial for other organisms, as is the production of oxygen beneficial. Pollination seems to primarily benefit insects (“bugs”). The food chain is portrayed as if plants initiate a chain of events, as a service to life on the planet.

Nearly all of the participants provided a purpose to both photosynthesis and cellular respiration that was external to the plant as a system. Their view suggested plants have an altruistic nature. Only Bob suggested that perhaps humans have a bias for our own perspective.

> Yeah, the human, well, see that’s kind of bias because we are humans you know, I mean like, if the plant could talk it probably would say the greatest thing is the, you know, that I have another plant with me, it’s a different genetic makeup.

Bob’s comment within the explaining set was in response to one proposed by Nan’s regarding the presence of two humans within the ecosystem jar. His comment illustrates a concept which will be addressed later, a potential intuitive comparison of plants to humans.

Organism to Global Processes:

Included in this category are conceptions at the organism level, progressing toward the global. Five participants could identify both photosynthesis and cellular respiration as happening within an organism with interactions in the ecosystem and at the global level. See table 4. Sam’s response to the potential disruption of photosynthesis illustrates this category:

> Probably a big huge, probably a global effect on the whole world. Without plants, probably wouldn’t be able to exist, and without the energy, the consumers wouldn’t be able to consume the energy. And, depending on what consumers consume the energy, we might consume from those consumers. So, they not only have an effect on the plants, but their consumers maybe, even animals, there

> would be a lot less animals and even, the animals, there would be a lot more effect on the human population as well, a large effect.

Sam's response moves from the plant as an organism, immediately to the global environment. He is able to draw back and consider regional effects, telescoping outward again towards a more global perspective. Despite an instructional emphasis at both biochemical and cellular levels, Sam is not able to discuss the plant processes at either the cellular or the biochemical level. Sam responds "both having oxygen involved" when asked about biochemical equations of photosynthesis and cellular respiration.

Biochemical to Organism Processes:

In this category, four participants described plant processes at the biochemical ecological level (table 4). Their conceptions at the biochemical ecological level were not always accurate, but these participants were able to conceptualize ATP, embedded enzymes, and hydrogen gradients. They were able to place the biochemical level within the organism. However, they were not always able to present complete and accurate conceptions at all levels. Ann responded to the meta-cognition questions of how she knows about plants:

> …if I know what happens on a molecular level, then I can understand better what happens at further stages, because I know, the basis of what.

She clarifies her response further continuing with the same concept:

> I don't know, the chemical, the chemical things, the components always stay the same, so like all plant cells have a cell wall, and things are very structured it seems, so it's easy for me to learn things like that because they are very structured things to learn. So, it's easy to learn like chemical stuff.

She continues later with:

> So, science is always the same, every cell has a cell wall, there is no, every plant has a cell wall, there is no exception to that rule, that a plant cell does not have a

> cell wall. So, it’s very easy to learn the basics of things, because in science, they are the same, they don’t have exceptions, they never change.

Ann was able to discuss ATP, and hydrogen gradients. When asked how ATP is made by the plant, Ann describes her conception, not completely accurate, but one which recognizes ATP at the biochemical level as being related to energy at the organism ecological level.

> …you have chlorophyll, like this, <refers to an image on the card> and then light comes on one of these little sacs, and it bounces an electron up, and it falls, and then light bounces it up again. And then, once, ah, it comes back down, it gets, that, ah, when it fall, it’s letting off, you know, what’s that. It’s letting off energy, because you have potential energy, and then kinetic energy.

Ann provides a view of her conception of the predictability of science. She expresses comfort with the predictability of the biochemical and cellular levels. To Ann, these two ecological levels are less abstract than the ecosystem and global levels of understanding.

Participants who could move from the biochemical level to the organism level matched the instructional approach. Four participants could describe their conceptions at the biochemical level and move through the cellular level to the organism level. Two additional participants could not articulate any conceptions at the cellular level, but could describe their biochemical conceptions and organism conceptions. Within this group of six participants, all but two of them earned the highest scores on the photosynthesis and cellular respiration exam, based on information provided by their instructor.

Photosynthesis:

Participants knew more about photosynthesis than cellular respiration, despite cellular respiration being their first introduction to the processes with emphasis on the connection between the two. This phenomenon could be attributed to the use of plants employed during explaining sets and cognitive interviews. While this may be considered to be a design flaw, an attempt was made to offset the effect during the clarifying interviews when biochemical and cellular levels were emphasized. Pre-service teachers may have just been able to better articulate conceptions on photosynthesis with the plant organism directly visible. Their laboratory experience involved the plant and its role in photosynthesis. Participants focused on the leaves of the plant when checking for photosynthetic activity. Their laboratory validation of cellular respiration involved corn seedlings. The plants used as a prop in the explaining set and cognitive interviews were not the same species as their laboratory plants. These plants however, were much closer in size than the seedlings used in the laboratory to validate cellular respiration. Even though the participants were explicitly told that plants use cellular respiration as a means of energy attainment, the majority of the participants described photosynthesis as the energy reaction in plants (table 4). All participants used physical characteristics of the plant to provide information regarding photosynthesis to the researcher and to their peers in the explaining set. Although understanding of the organism at the ecological level was not always accurate, all participants used their understanding of the organism to focus their descriptions. Four major conceptual categories emerged from the data and are represented in table 4:

- Don’t Know Photosynthesis
- Photosynthesis is Energy Process
- Photosynthesis is a Food/Growth Process
- Photosynthesis is an Oxygen Process

On the few occasions where participants were inconsistent with their descriptions, their conceptions were aligned into more than one category. Specific questions provided more information regarding their level of understanding, so often conceptions were confirmed through cognitive and clarifying interviews. When pressed for more detail, a participant occasionally responded, “I don’t know”, raising questions about their understanding of earlier conceptions. A few participants had responses that fell into more than one category. For example, Kay describes photosynthesis as:

> When the plants take the sunlight and they create oxygen for the plant to grow, it’s their energy.

Kay’s conception includes energy, growth and oxygen, although with little detail. Energy and growth within this context would relate to the organism ecological level, while oxygen suggests a biochemical ecological level. Kay’s concept of photosynthesis could not be interpreted through her response to this one question. Only after considering all of her responses was it possible to determine that Kay has a superficial understanding of photosynthesis.

Don’t Know Photosynthesis:

Five of the eighteen participants admitted they found photosynthesis confusing, or knew nothing about it. See table 4. Betty’s exchange (comments preceded by B) with the researcher (designed R) serves as an example:

> R: What about plants do you find confusing?
> B: I guess just exactly how photosynthesis occurs.
> R: How it occurs?
> B: Right, exactly how it occurs. I know how it occurs in a book, or on a piece of paper, I can understand that, but just exactly how the cells work. I know that, it’s just….I don’t see how they can do that.

Betty’s response suggests that she does know the book version of photosynthesis, which she perceives as being separate from the physical process. She can’t describe the process at the cellular level. Earlier in the interview, Betty suggests that food for plants is from “decaying matter in the soil.” She tells the researcher “I can’t even begin to go through all the processes.”

Photosynthesis as Energy Process:

Conceptions within this category suggest an understanding that photosynthesis is an energy process. Participants provide evidence from food chains and light energy. For example, Anita suggests that the sun ultimately determines photosynthesis.

> I mean the sun, is basically, I don't know, a big factor in life, because without the sun, a lot of things wouldn't be able to produce, like corn, and stuff that we eat, vegetables, and the grass that cows eat, which we eat the cows, so a lot of things wouldn’t be able to be produced, and we would have to use what we have left and after that, we wouldn't be able to live.

In her description Anita suggests the sun is the source of energy for the plant, but immediately removes the plant to a producer role within the food chain.

Participants often expressed the concept that energy comes directly from the sun, but did not mention the biochemical photosystem reactions as they had been instructed. No participant mentioned electrons being excited or moving from a ground state. Typical of the conceptions in this category is Joy’s:

> um, it (photosynthesis) is a combination of reactions that create energy for um, like every other living thing. Basically, coming from the sun, we’ll say.

Joy describes the reaction as a service reaction supporting other organisms. Photosynthesis is simply the mechanism by which energy from the sun is directly exploited by other organisms. Joy says the plant “creates energy.”

Even though participants conceptualized photosynthesis as an energy process, their descriptions were not necessarily scientifically accurate. Vera provides an example of nominal knowledge:

> (Photosynthesis is….) A certain amount of energy out of the light, which is called ATP, into taking the light, and turning it into energy, and the energy that plants use is glucose.

When comparing photosynthesis to cellular respiration, many participants chose photosynthesis as the energy reaction, and cellular respiration as the gas exchange reaction. More about the connection of these two processes is described later.

Photosynthesis as Food/Growth Process:

Conceptions within this category included the knowledge of plant growth, but linked the food produced to a service for other organisms. There was no evidence of a conception of plants as independent organisms. Each participant who defined photosynthesis as a food/growth production process also suggested that plants make their food from nutrients obtained from the soil. Participants could not distinguish between "food" and "nutrients." Responses during the cognitive interview provided evidence of their inability to separate the two. When asked how the plant used photosynthesis to grow, one half of the pre-service teachers indicated that they did not know. These pre-service teachers did not connect growth of a plant to the process of photosynthesis.

That carbon dioxide is a necessary component of photosynthesis was seldom noted (mentioned only by three of the pre-service teachers), and it was never associated directly with cellular growth. Of the three participants who mentioned carbon dioxide as a necessary component of photosynthesis, Anita provides this evidence of her concept of its role in photosynthesis. Although she was unable to verbalize the connections between CO_2 and plant growth, she identified carbon dioxide as a source of oxygen to the plant.

> Well, with the oxygen, plants give off O_2, like, you know while they are going through their phase of photosynthesis. They give off oxygen, in order for them to have carbon dioxide, in order to give off oxygen, and they go through certain cycles to do all of this.

Photosynthesis as an Oxygen Process:

Participants identified photosynthesis as a process for producing oxygen. This role was seen as a purposeful event, i.e. "they give off oxygen, which we need to survive." Despite conceptions regarding oxygen and carbon dioxide exchange as being cellular respiration instead of photosynthesis, all participants knew photosynthesis-released oxygen. There was no consideration of the two conceptions as incommensurate, that cellular respiration and photosynthesis both release oxygen. Participants did not recognize their own inconsistent statements of oxygen being released by photosynthesis, and cellular respiration being the gas exchange reaction, taking in carbon dioxide and releasing oxygen.

Only one participant temporarily questioned the idea of photosynthesis releasing oxygen. In the explaining set, he questioned survivability with the ecosystem jar, saying:

> They have no source of oxygen or anything like that; they are going to suffocate in there.

Later, in the same task, he discovered his error, and immediately noticed the benefits to the humans, despite the question's focus on the plants.

> Well, they would produce the oxygen, so I guess they would be fine. But, I mean, they have light, they have soil, and everything else, so I guess it would survive, and maybe like green plants would give off oxygen for the little people.

Oxygen production was described as a process beneficial to humans, and other oxygen- using organisms. It was viewed as a by-product of photosynthesis and a major contribution by plants within the global atmospheric system. Only one participant stated that plants also use oxygen for energy transformation.

Plants were conceptualized as being dependent on humans for their source of carbon dioxide.

> I would say that um, the plants are providing oxygen for the people, and the people are providing the carbon dioxide for the plants, that they need for photosynthesis.

This conception may mentally justify a high human production of CO_2, if plants are direct beneficiaries. Only one participant addressed this potential. Bob in his explaining set described an experiment in which a higher level of CO_2 was provided to plants.

> ….where they got an acre of land and they sprayed CO_2 into it, and the plants actually ended up growing faster than ones outside of it, in the control, you know, in the normal atmosphere.

Cellular Respiration:

Despite the fact that cellular respiration instruction preceded instruction in photosynthesis, and immediately followed a chapter on energy, the pre-service teachers conceived the reaction as one of gas exchange. The participants suggested that cellular respiration is a secondary, but complementary process to photosynthesis. Just as photosynthesis provides the energy for a plant, cellular respiration can remove the "by products" of cellular metabolism. Four themes were evident in their understanding of cellular respiration and shown in table 4:

- Don't Know Cellular Respiration
- CO_2 to O_2
- Releasing of CO_2
- Energy Process

Don't Know Cellular Respiration:

Two participants readily admitted they did not know enough about cellular respiration to have formed a concept of the process. Natalie tells the researcher:

> If you could remind me of that term, I would be more than happy to tell you, but I can't remember that term.

This comment was recorded immediately after the exam on the topic and within the cognitive interview. Pre-service teachers who only participated in the explaining set never mentioned cellular respiration at all. Carl and Ruby never provided any evidence of understanding cellular respiration. Only two pre-service teachers suggested cellular respiration when asked what the plants were doing. One of those responded, "breathing." Unfortunately she was unable to clarify further exactly what the term "breathing" meant. She apparently, as Natalie illustrates above, lacked a formed conception of cellular respiration, but did have an idea that, as with other organisms, the plant must "breathe."

CO_2 to O_2:

Five participants described a reaction in which the carbon was simply removed from carbon dioxide and changed into free oxygen. This idea was the most common conception of cellular respiration within the sample of pre-service teachers. Natalie expressed her view as follows:

> Isn't that when the by product is oxygen? It takes the CO_2, gives it to ATP, and then comes out of the oxygen and gives it to the Calvin cycle?

Vera responds to the direct question of "what is cellular respiration?" concisely by saying:

> The transfer, the transformation of CO_2 into oxygen. They respire oxygen.

Releasing CO_2:

Three pre-service teachers held a conception of cellular respiration as a mechanism for releasing carbon dioxide. Among them, the mechanism of release varied. Nan suggested photosynthesis and cellular respiration are opposites, with one producing oxygen and the other producing carbon dioxide “just like breaking down your food, the glucose and putting it into CO_2.” She stops short of suggesting an energy reaction.

Betty discovers during the cognitive interview that she conceptualizes plants as both using and releasing carbon dioxide. Betty is designated in the following exchange as B, the researcher as R.

B: They (plants) produce oxygen.
R:They produce oxygen.
B: And, they use both oxygen and carbon dioxide.
R: Ah, they use both oxygen and carbon dioxide. Can you explain that to me? How do they use both?”
B: They need the oxygen to respire.
R: Okay.
B: I’m not sure how they use the carbon dioxide they produce. I think they produce some too. A little bit.
R: But, you’re not sure how they use it?
B: I’m not sure about the CO_2. I’m not sure how they use it. They use carbon dioxide.
R: You said they both use it and they also release it?
B: Um, I think a little bit. I think. That’s what Dr. Smith said.

Betty’s response suggests confusion over cellular respiration. She has accepted the instructor’s word that carbon dioxide is released, but cannot explain how the plant could both respire CO_2 and use CO_2. She correctly attributes the need of O_2 to respire. She cannot assign CO_2 to photosynthesis. Her reference to the instructor references the laboratory activity where CO_2 was measured as a product of respiration.

Bob suggests that plants and animals must just need the “opposite” gases for cellular processes.

> Cellular respiration is the, the respiring of a cell. In order to have that you need to have carbon dioxide, because, well, in these types of cell, yes, because that's the, in order to respire they need to use that (CO_2) in their cells….
>
> Followed quickly by:
>
> Plants are different, because they actually use CO_2, and respire oxygen. It's the exact opposite. It's a perfect combination to have them with animals, because they are in equilibrium.

Cellular Respiration as Energy Process:

Three participants conceptualize cellular respiration as an energy process. See table 4. Sam provides this example:

> Cellular respiration is…basically taking the energy out of the food molecules and food itself and that is being converted into um, ah…I don't know what kind of energy it is being converted to….chemical energy?

Although these participants suggested that cellular respiration is an energy process, they may not conceptualize the reactions as serving a purpose in the same way photosynthesis seemed purposeful. In fact, they struggled with the relationship between energy and carbon dioxide. Ann's exchange with the researcher highlights her confusion.

> R: What do you think cellular respiration is?
> A: Okay, cellular respiration is ah, when ah, they make oxygen.
> R: Okay, go on ahead
> A: The cellular respiration, we did this thing in lab where we had like corn seeds and we had dead ones and live ones and we just had regular water, and we put a pH thing in there and we found that, ah, the corn left off CO_2.
> R: Right.
> A: Well in plants, they usually give off oxygen.
> R: Okay
> A: So this is…Dr. Smith said that was called cellular respiration, but I think ah, she said plants do both, and I can see how they give off oxygen, but I don't really know why they give off CO_2, and I don't know if they do it just like seedlings, and that's cause …..cause they give off CO_2 because they are using like an apple has the seeds in the middle and it uses the apple, the rest of the apple as food to grow into a tree, so I don't know if the seeds respire too. I don't know if they give off CO_2 like we do, because they are kind of like eating maybe, so they are breaking that stuff down.

It may appear in this exchange as if Ann conceptualizes cellular respiration as a confusing gas exchange reaction. She questions if cellular respiration exists in the plant beyond the seedling stage. Her conception of cellular respiration is that it is an energy reaction, which provides energy in the form of "food" to the plant, much as the fruit of the apple provide food for the developing seeds. Ann conceptualizes both photosynthesis and cellular respiration as energy reactions, evidenced by her earlier response to photosynthesis. ("It's a way to make um, food and energy for the plant.") She questions the need for both processes in the plant.

Later in the interview however, Ann clarifies her conception of photosynthesis and cellular respiration and reveals how she thinks of the two processes being related.

> Well, this is what I understand of it, photosynthesis breaks down, like, um, carbons and makes energy and stuff, and um, to get the product back into the glucose, the six carbon sugar, then they use cellular respiration. So, then, yes, the big plant would… I'm trying to think…You know the glucose in the thing, like the energy in food, for photosynthesis, and then you have like the products, which is energy, and then you needed that to make food, so cellular respiration is taking that energy back into making food, and that's the cellular respiration.

In the previous exchange Ann is responding to a question about how the two processes are connected. Notice that she describes them as two different processes. Photosynthesis is responsible for breaking down carbons, making energy and "stuff" and cellular respiration "is taking the energy back into the food." She conceives the two processes as energy processes, yet with opposite purposes.

Connected:

All participants responded in the affirmative when asked if photosynthesis and cellular respiration were connected processes in the plant (table 4). This is not surprising as the instructor explicitly told the class that plants do both processes. The laboratory activity they preformed asked participants to test for both products, CO_2 from cellular respiration and O_2 from photosynthesis.

Even though all pre-service teachers knew the two processes were connected, only two had a partially accurate conception of how photosynthesis and cellular respiration are connected. Ann connects both processes to energy reactions, but struggles as to why the plant would need both. Her confusion may lie within her concept of food. She defines photosynthesis as a way to “make, um, food and energy for the plant.” When asked by the researchers if those are two separate items, food and energy, Ann has this response:

> Well, I guess, cause, energy…food is something they use, I guess to grow. I don’t know how to explain food and energy. It’s just we eat for energy, and then there is like energy of ATP, and it makes like food, so. And, then food is used to make energy, so. Hmmm, that is very complex there.

Asked later in the interview what she still finds confusing, Ann offers this response:

> Um, why they have energy, like I said the food, gives them energy, and yet they have to have energy. They have to have food for energy, and energy for food. That still is kind of confusing to me.

As noted earlier, Ann describes photosynthesis as the necessary reaction to “get the product back into the glucose, the six carbon sugar” which she follows immediately with the statement of “then they use cellular respiration.” Evidence for her confusion with food and energy is provided in her following statement.

> You know, the glucose in the thing, like the energy in food, for photosynthesis, and then you have like the products, which is energy, and then you need that to make food.

Ann was present for all three data collection opportunities and confirmed her conceptions regarding connection between processes over the duration of the project. There were four participants, including Ann, who over the course of three interviews were very articulate. These individuals provided a great deal of information in their explanations. During the clarifying interview, they readily moved components (cards with cellular illustrations or biochemical labels) provided to locations, and explained their conceptions. Their explanations were so consistent that combined with the researcher's interpretation of the cognitive and explaining set, a visual representation of biochemical relationships emerged. More detail concerning these four participants conceptions follows.

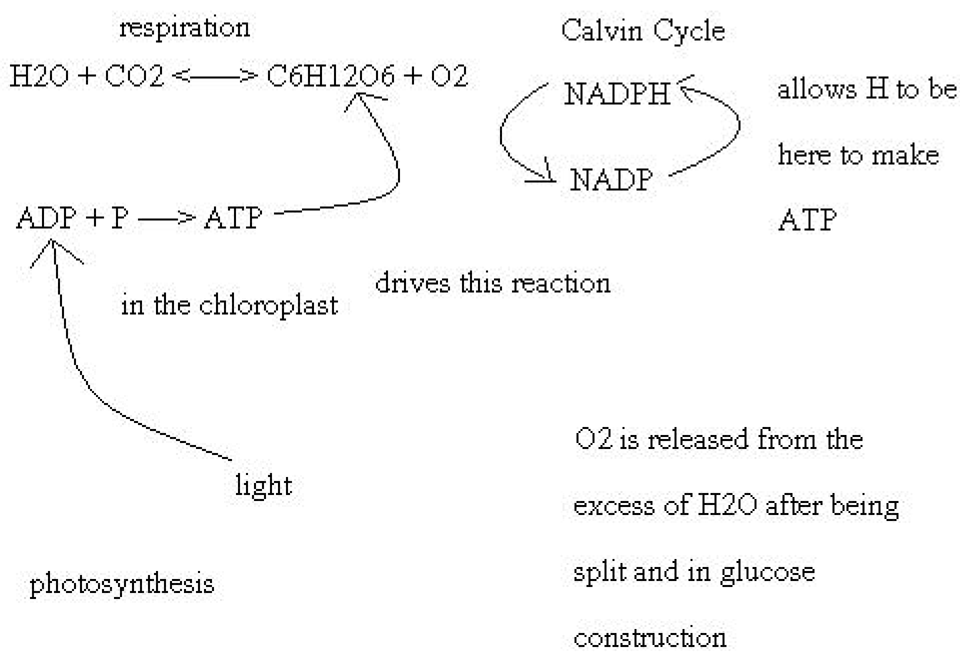

Figure 6: Ann's Model of Connection

Ann's connection of photosynthesis and cellular respiration is illustrated in figure 6. Ann was the only pre-service teacher who actively puzzled over the connection between the two plant processes.

The other participant (Sam) who connected cellular respiration and photosynthesis through the mutual use of oxygen had less conviction to his conception.

> Both being, both have oxygen involved, I believe. Both of them creating energy or energy being converted into something else, something other, for something else to survive.

Sam's statement is confirmed later when asked if plants do both process. He takes evidence directly from the laboratory experience.

> I believe it (the plant) does. We did the…the cellular respiration we did the labs on the leaves, and we were converting those, using all the starch and the glucose, so. Yes, I believe they do. So, I'll just go with yes, that's my final answer. I'll go with yes. <laughs>.

Later in the same interview, he hesitates when both processes are viewed at the organism ecological level.

> I can't really see it. I mean the main things I can explain, they both photosynthesis and cellular respiration, and they both have to do with oxygen. I can see that. I mean, if they have to do without, and I can see that they need CO_2 to live still, you know plants, um, I can't really explain. I really can't explain that much why. You know, I can't.

Sam's conception has oxygen as the primary shared component between the two processes. He is able to connect the two processes together, but is unable to verbalize their connection with energy. His response lacks detail and conviction. Ann's connection with energy is stronger. She provides more biochemical level evidence. Her description involves more than one ecological level. Yet, she puzzles over why plants would need two sources of energy since her conception of photosynthesis is that of an energy reaction for the plant.

Since participants conceptualized cellular respiration as a gas exchange, and photosynthesis as the attending energy reaction, these were the connections used to tie the two processes together. Photosynthesis was viewed as the energy reaction, and cellular respiration the gas exchange reaction allowing the energy reaction to occur.

Jay has the two processes connected through one equation. Jay defines photosynthesis and cellular respiration for the researcher.

> Basically, I think its (photosynthesis) taking energy from the sun's light and transferring it to energy to be used by the plant which can be done through glucose and all that.
>
> I'm going to say right now, I think it's (cellular respiration) taking carbon dioxide using it for the photosynthesis process and in the end comes oxygen, which is given off, and used by others, such as humans.

Jay's summary was interpreted by the researcher after the cognitive interview, and verified during the clarifying interview. While not a direct quotation by Jay this interpretation is verified through all three data collection instruments.

In the presence of light energy CO_2 (of cellular respiration) and H_2O (of photosynthesis) yields O_2 (of cellular respiration) and carbohydrate (of photosynthesis). One equation involves both processes, with the gas portions being the respiration, and the water and carbon portion (carbohydrate manufacturing) being the photosynthesis segment.

At least two other participants within this sample share Jay's conception of the connection between photosynthesis and cellular respiration.

Nan provides evidence of nominal knowledge of processes. Like other participants, Nan knew from the laboratory experience and the instructor's comments in class that the two processes were connected. She cannot articulate how they are connected, nor why. Cellular respiration is not clear to Nan. She cannot provide a system purpose for the process. She knows that cellular respiration is the opposite of photosynthesis, but she uses the wrong ecological level in this first statement of their connections.

> Um I believe that breaks down the food, it (cellular respiration) starts to break down the food, and it goes to um, oxygen. But, I know its' completely like the opposite in photosynthesis, it takes in the oxygen and produces the sugar.

A second opportunity for connecting the two processes arises later in the interview, and Nan repeats her idea of cellular respiration and photosynthesis as being opposite.

> R: Okay, what do you think cellular respiration is?
> N: Um, like kind of the exact opposite, just like breaking down your food, the glucose and putting it into CO_2.

Later in the same interview, when asked how the two processes are connected, she replies "they both need oxygen" and when asked how both use oxygen she replies:

> Oh, I believe they need oxygen for energy, to just go through the process, they need energy to do that. I believe. I'm not sure. I'm still confused on how the whole process works.

As with other pre-service teachers Nan knew the definition, but did not link the process to energy within the food, nor has she linked the two processes together, as interconnected. During the clarifying interview, Nan selected glycolysis, Kreb's cycle and the electron transport chain as the connections between the two processes. She described the connections as involving CO_2 and O_2. Her equation, with interpretation by the researcher from her other interviews, is shown in Figure 7.

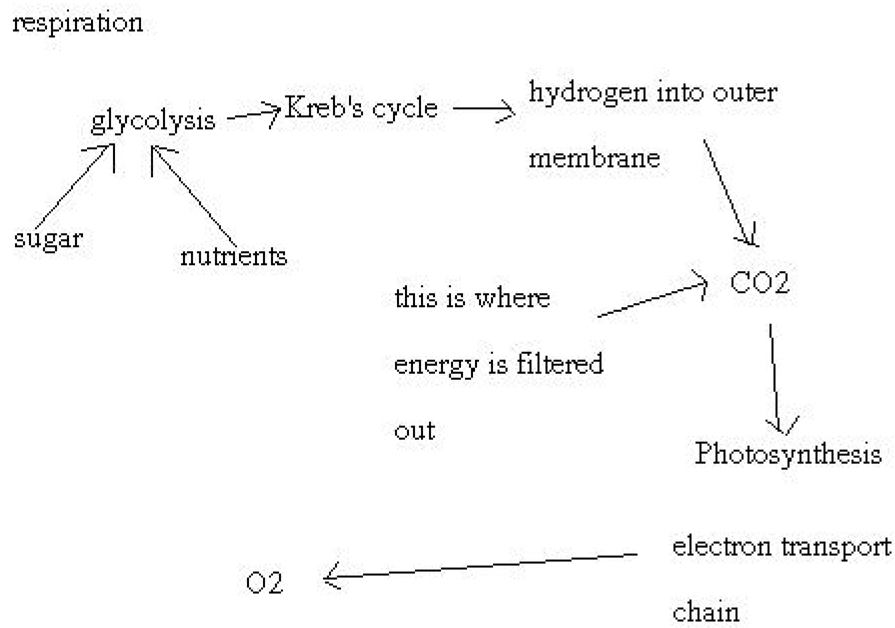

Figure 7: Nan's Model of Connection

Even though connections between the two processes were not obvious to the pre-service teachers, over the course of three data collection sessions, four participants eventually provided explanations of their connections. The researcher analyzed the explanations made by Ann, Jay, Nan and Bob, and interpreted the respective cognitive interview and explaining sets. The visual representations (figures 6, 7 & 8) are the result of data analysis. None of these conceptions neared scientific accuracy.

Bob connects the two processes in the clarifying interview by providing this model of his understanding. Squares and rectangles represent the connections at the biochemical level of photosynthesis and cellular respiration. Circles represent chemicals only within photosynthesis.

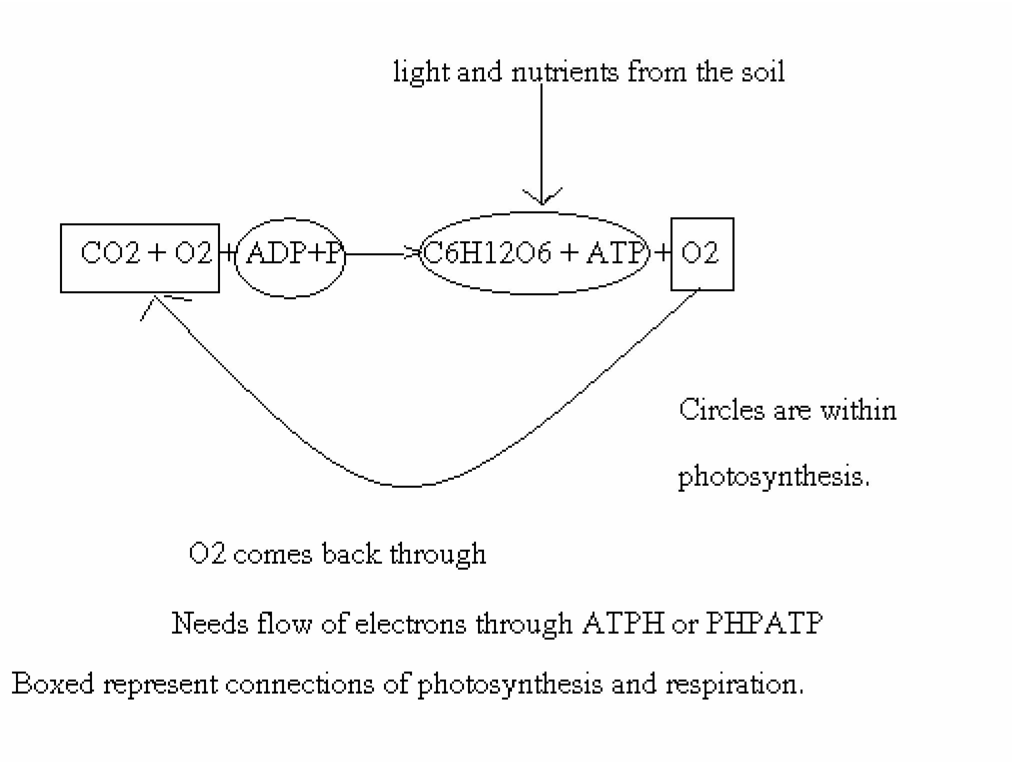

Figure 8: Bob's Model of Connection

Bob's model has photosynthesis as the energy reaction, and cellular respiration as a gas exchange reaction. Bob can't recall the initials of the energy carrier, and so it becomes ATPH or PHPATP. He sees O_2 as being used again by the plant, within the same equation.

Multiple Levels:

Participant's conceptions of ecological levels can be measured by the extent to which they focused their responses in the explaining set and interviews. It is important to recall that only seven participants were present for all three data collection instruments. It might be argued that participants who were only present for one data collection instrument did not have the opportunity to discuss the processes at more than one level. However, there is evidence that this was not the case. Betty was present at half of the cognitive interview, but was unavailable for the explaining set and the clarifying interview. Betty could describe her conceptions of the two processes at both the organism and biochemical levels. Natalie, who was present for all three data collection instruments, focused all conceptions at the organism level.

The researcher journal and all three data collection instruments, when analyzed, allowed the researcher to place participants' descriptions on specific ecological levels. Placement was not indicative of accurate scientific conceptions, but rather the ability of a participant to respond to a probing question involving a specific ecological level. Specific questions aiding placement included question twenty in the cognitive interview. This question asks what ideas were still confusing. For example, when Jay responded to the question regarding his confusion, he stated:

> I'm not sure exactly where it (photosynthesis and cellular respiration) goes. I kind of have an understanding of the process, but I'm not sure of the steps of the each process exactly.

His reference to "steps" suggested to the researcher that he was unsure of his understanding at the biochemical level. If a response to question twenty suggested confusion at a specific ecological level, then participants were considered to be less firm in the concept at the level suggested. Only two pre-service teachers suggested no confusion at any level. It may be useful when considering table 4 to also view Appendix D which details the extent to which pre-service teachers participated in the data collection instruments. For example, Betty only participated at the cognitive interview. While participation at the other two opportunities for data collection may have yielded more information, it was determined that all three data collections were not necessary to obtain valid information concerning their level of knowledge. For example, Natalie participated in all three data collection opportunities and could only provide information at the organism level.

Table 5

Participants on Multiple Levels

(Shaded areas represent participant focus on a specific level)

Participants	**Global Level**	**Ecosystem Level**	**Organism Level**	**Cellular Level**	**Biochemical Level**
Ann	■	■	■	■	■
Bob	■	■	■	■	■
Charles	■	■	■	■	■
Nan	■	■	■	■	■
Betty		■	■		■
Jay	■	■	■		
Ken	■	■	■		
Amy	■		■		
Anita	■		■		
Carl		■	■		■
Joy			■		■
Ruby		■	■		
Shirley	■		■		
Vera	■		■		

Table 5

Participants on Multiple Levels-Continued

(Shaded areas represent participant focus on a specific level)

Participants	**Global Level**	**Ecosystem Level**	**Organism Level**	**Cellular Level**	**Biochemical Level**
Kay					
Suzy					
Totals	10/18 or 55.5%	10/18 or 55.5%	15/18 or 83.3%	4/18 or 22.2%	7/18 or 38.8%

Two participants (Suzy and Kay) did not provide enough evidence to place on any level. Kay conceptualized both processes as too abstract to consider. She expresses her view:

R: What kind of things does it need to be able to grow? Is it doing those things?
K: I don't know, you probably can't see what it does.
R: Are there things that take place that you don't see?
K: When they absorb the light, you can't really see when they do that, but they do.

Kay's conceptions at the organism level suggest that she hasn't completely formed ideas about plants as organisms.

K: The roots is what sucks up some of the water, and take it to the leaf. And the sunlight, usually goes in there, and does its thing in there.
R: Does the stem do anything?
K: Um, it's obviously where the leaves grow, but um.
R: Anything else for the stem?
K: Not that I can think of.

Suzy's interview is similar to Kay's, and is punctuated with many "I don't know" comments. Suzy also conceptualizes the processes as too abstract to comprehend.

> They are possibly growing. A little bit. They could grow a little bit each day, and that would be hard for us to see, you know. Growing by, you know, just looking at it by our eyes, but it's growing. It's giving off energy as well.

Suzy provides further explanation of the statement "giving off energy" with the familiar theme of a service purpose to plants.

> Um, hmm, ah, well, it gives off energy, like through, if another animal or something eats it too. That's like giving energy to that.

Other participants may not have been scientifically accurate in their discussions of multiple ecological levels, but had more ecological levels represented by their explanations. They were able to respond to specific questions regarding their conceptions of the two processes at different ecological levels. Bob, for example, describes his idea of the connections between the two processes. Only towards the end of his explanation does he suggest any hesitancy.

> ah, I have here, the world, the ecosystem, the leaves, the cell, a more definitive cell, the cell wall, I think <looking at cross section of the leaf>, the cell wall, this is light energy harnessed to boost light energy to a higher level of energy. I have a sun here, the chloroplasts, here, this is where the energy is harnessed, carbon dioxide and minerals go in, boost it into higher levels of energy, sugar molecules and the food molecules come out. This is the mitochondria, and energy, glucose, which is glucose, will call that like that. Oxygen, um, are shipped here, and NADH, in the process of the electronic transport
> chain, right here, it's how the energy is produced the most, it's about ATP, are produced in the electronic transfer chain, about four are produced in the Kreb's cycle, and a couple in glycolysis. That's the molecule entering the mitochondria, and ah. I don't know, that was just kind of, putting them in, I really, a lot of those things I didn't know.

In his description, Bob presents a superficial global view ("I have here the world"). He briefly refers to the ecosystem. He uses the cell as the location for the biochemical reactions described. His description is not entirely accurate, but he is able to link together coherent phrases regarding ecological levels, and he simultaneously provides an explanation within one or two ecological levels within one explanation. His explanation does suggest that he sees minerals as a component in the photosynthesis process, and that energy, sugar, and food molecules are not necessarily different.

“Nested Systems:”

Only two pre-service teachers provided evidence that they may be close to a scientifically accurate conception of nested systems. Question fifteen asked participants how the components of the processes worked together. Three pre-service teachers admitted that they did not know. Considering cellular respiration was conceptualized as a gas exchange reaction, and photosynthesis as an energy reaction, a logical response matching these conceptions would be oxygen production as the purpose of both reactions. The purpose of photosynthesis is to take energy from the sun to use in the production of oxygen of cellular respiration. This idea connected with human’s need for oxygen.

> It (photosynthesis) gives off all of its energy for the plants to use, to make food for themselves, and with the cellular respiration, it gives off oxygen to humans, for without plants, I think humans would not be able to survive, we would just be breathing pollution and all that stuff that we don’t need to breathe.

Ann was one pre-service teacher who did provide clear evidence of her conceptualization of nested systems. Her meta-representation is included in Appendix H.

> …and the littlest part has to work for the biggest part to work. The biggest part has to work for the littlest part to work. I could even break this down further, with one little organelle and show all the parts, but I’m not that talented.

Contrast Ann with Bob’s reliance on terminology that suggests nominal process knowledge. His conception of nested systems includes a misconception of energy being “reproduced” by the plant, instead of transformed.

> They reproduce energy from using the sun. Whereas we reproduce energy, well, we can. I guess in some point, because we get energy from the sun, as we get heat, we use the heat, but they actually produce a physical thing, by harnessing the energy….

He may have conceptualized plants and animals as having similar energy needs, a view unique among his classmates.

> We can store it and use it from potential energy to kinetic energy. Essentially, they (plants) can do the same thing, because once they produce that potential energy, which is this leaf right here, I eat that leaf, and then it turns it into kinetic energy within my cells, so they are the root of all energy, in most, in a lot of systems.

Even though both Ann and Bob view photosynthesis and cellular respiration as “nested systems”, Bob did not have the same recognition of cellular respiration as an energy reaction that Ann did. Bob was able to place the global energy source with the organism level, and the interaction of the plant in the ecosystem to the cellular level but, as evidenced by other responses, he attributes energy to photosynthesis and cellular respiration to gas exchange.

Those pre-service teachers who participated in the clarifying interview were asked to define a biological system.. Their responses confirmed their conceptions of nested systems. Jay hesitates and stammers over the question:

> <Laughs> um, basically, I don’t know how to put it…uh, I guess it’s everything within like biology and stuff, going hand-in-hand. ….like basically, how everything works and interacts with one another.

However, Jay is one of three pre-service teachers to suggest that systems involve interaction.

The pre-service teachers conceptions are summarized in table 4, presented earlier in this section.

Misconceptions:

Overall, the pre-service teachers expressed many of the same misconceptions documented previously including that 1) the majority of plant material comes from the soil, 2) that cellular respiration is breathing, 3) the relationships within the food chain is one of size, with the largest organisms being the top carnivores, 4) decomposition is simply the mechanical breakdown of organic material, 5) carbon dioxide was not considered when listing the conditions necessary for plant growth, 6) plant focus was nearly exclusively on oxygen production, and 7) an inability to distinguish the various terms for food, such as glucose, carbohydrates, and sugar.

Table 6 summarizes the prevalence of misconceptions observed during this research. The table lists a phrase describing the misconception, and the number of participants who held the misconception. It should be noted that participant's misconceptions were coded during the analysis phase. Fourteen participants were involved in the cognitive interviews, and if the misconception was identified during an explaining interview, the participant had an opportunity to correct the researcher's impression. If, however, the participant first expressed a misconception at the cognitive interview, and the participant was not present at the clarifying interview, the misconception was recorded, but not necessarily confirmed. The number of participants holding specific misconceptions may appear to be inflated due to design for the research topic that emphasized system related conceptions.

Table 6
Misconceptions Noted within Project

Misconception	Number of Participants	% of participants
Plant Matter from Soil	18	100%
Respiration is Breathing	11	61%
Food Chain is Size Related	4	22.2%

Table 6
Misconceptions Noted within Project-Continued

Misconception	Number of Participants	% of participants
Decomposition Process is Physical	7	38.8%
Plant Food	7	38.8%
Life Cycle	10	55.5%
Leaf Function	7	38.8%
Oxygen and Energy	3	16.6%

Plant Matter Comes from Soil:

This misconception is well documented in research (Bell, 1985; Boyes & Stanisstreet, 1991). Carbon dioxide provides the carbon necessary for the production of glucose, which ultimately forms the structural matter of a plant. The misconception suggests however that the source of plant matter is from the soil. The plant uses roots to draw matter from the soil, which ultimately composes the plant matter. Despite being able to provide the equation for photosynthesis, all eighteen participants in this project explained that the major source for the plant matter was from nutrients (or food) that the plants took from in through their roots.

Evidence for the misconception that the majority of plant material comes from the soil is provided in Charles' description of how nutrients help plants:

> They're like a food source, they're sucked up through the soil, if you had some plant food in there, you know it would be taken up from the roots, up into the stems, and then the plant would make food out of it, using the light that it gathered in the chlorophyll and it would photosynthesize, and ah, basically be able to make some food. And, there are also some respiration aspects, and stuff like that.

His response indicates confusion regarding differences between food and nutrients. He may consider the word nutrient as being synonymous with food. This misconception is described later.

Respiration is Breathing:

The conception of respiration as breathing is another well-documented misconception (Anderson *et al.*, 1990; Bell, 1985; Canal, 1999; Sanders, 1993; Simpson & Arnold, 1982a). Cellular respiration is actually an energy transformation process, which utilizes oxygen. The misconception is that cellular respiration is primarily a gas exchange reaction, or “breathing” which takes place at the cellular level. Eleven of the participants expressed a belief in these misconceptions.

Bob provides evidence of the misconception that respiration is breathing in his description of cellular respiration in plants and the idea that the processes of photosynthesis and cellular respiration are opposites. He may have generalized the idea of opposite processes to reach that conclusion.

> We take in oxygen and respire carbon dioxide. Um, we, and it's opposite for plants, they, and obviously ours is more physical, I mean, ah, it's hard to say, because we're a lot bigger than most ah, well, no we're not. I don't really know, as far as bringing in the air physically, I don't see plants, opening and closing their lungs, you know they don't have um, lungs, but they do use carbon dioxide in the process of photosynthesis. Um, I think that's about it.

Food Chain is Size Related:

More recently documented has been a misconception regarding the size relationships within food chains (Lin & Hu, 2003). In the natural world, consumers come in all sizes. Four of the participants expressed a simplistic view of the food chain as being a linear progression of size, from smallest to largest organism.

In her description of a food chain, Ann describes the order of the chain as follows:

> Like a food chain is like the sunlight hits the plant, then the plant is eaten by a little organism, and that organism is eaten by a little organism and then a food web is a lot of the different things together, and then um, the food web, usually ends, like they say it ends with a big carnivore or something, but then the life cycle is like when, that carnivore dies and is decomposed.

In her explanation, Ann touches briefly on another possible misconception, her idea of the life cycle. Other participants had similar ideas regarding the phrase “life cycle” which will be addressed later.

Decomposition Process:

Another misconception is that decomposition process is mainly a physical process. That understanding fails to account for the biological processes of decomposition (Driver, Squires, Rushworth, & Wood-Robinson, 2001). Seven participants in this project discussed decomposition as an important component of a food chain, or as being important in the flow of energy, but failed to address organisms involved in the decomposition process. Typical is Betty’s description suggesting a very fast clean process:

> Well again, they (plants) provide food, and nutrients, and when they decay, they put those nutrients back into the soil, so that other plants and organisms can use them. And, they create the sun's energy into a more useable form of energy for their organisms.

It isn’t clear from Betty’s description that any other organisms are involved in the process. In her explanation, the plant is presented as a service organism that even in death continues providing for other organisms.

Plant Food:

Misconceptions regarding plant food (Anderson *et al.*, 1990) were also evident in this project. The pre-service teachers in this research described food and nutrients as being synonymous, failed to recognize the potential for chemical energy within the bonds of food molecules. Seven participants interchanged the concepts of food, nutrients, glucose, and carbohydrates. Jay in his explanation of how plants grow demonstrates his confusion over the terms carbohydrates, glucose and nutrients.

> R: ….when you say fertilized, what do you think it's taking up from the soil?"
> J: Well, it's got to be some type of nutrient… Um, I'm trying to think…. Cause I thought, if I remember correctly, is it something that they use carbohydrates, and they transfer it into glucose?

Other Misconceptions:

Previously undocumented misconceptions were also noted. Careful instruction may actually advance these conceptions toward a more scientifically acceptable conception. These conceptions may not be as robust as research has suggested for misconceptions previously documented Pre-service teachers in this project confused the endoplasmic reticulum with the mitochondria, respiration with reproduction, and carbon dioxide with oxygen. Hesitation to consider these as a misconception arises from the possibility the pre-service teacher may have simply misspoken or may have been momentarily disengaged from details.

There were other misconceptions (or perhaps alternative conceptions) described that may warrant further research. Although articulated in this research sample, these conceptions may or may not be advanced to the level of a more scientific conception through careful instruction. At this time, that is unknown.

Life Cycle:

Ten of the pre-service teachers in this sample had a broad view of the concept of life cycle. Anita explained her conception of a cycle that she calls a “life cycle” which blurs the distinction between a biochemical process and the concept of life span as applied to the organism level.

> Well, a cycle is the process of which an organism, or whatever it is goes though, to either reproduce certain chemicals, or um, just to go through anything, basically, like a life cycle or any, something.

In the clarifying interview, only three of the seven participants presented a scientifically accurate conception of a cycle. The others use the term “life cycle” / “cycle” interchangeably applying them to describe biochemical processes as well as food chains. When referring to the decomposition of plants, participants used the phrase “life cycle.”

Leaf Function:

Another misconceptions observed concerned the function of leaf in plant processes. Seven of the participants in this project failed to provide a scientifically accurate function for the leaf of a plant. Anita suggested that the leaf only grows once it is shed during the fall of the year.

> ….it basically makes it own food to grow. And, I guess the, you could say like the leaves shed, and get bigger, and the stem, it would also do the same. ….Like in the winter, all the leaves fall off, and in the spring, the leaves grow, and as they grow, they might grow a little bigger than what they were last year.

When asked about the function of a leaf in photosynthesis and cellular respiration Nan provided this explanation:

> Um, the leaves, I think the leaves they basically, um, help retain the water. A lot of the leaves have a lot of waxy coating on it. So, it helps, um, absorbs the water, and it helps retain in the plant, so it doesn’t ah, like fall off or whatever.

During her three interviews, Nan was unable to identify the leaf as a location for important plant processes. Her lack of understanding came despite lab work she had conducted involving leaves, and her comments about the leaves spreading to maximize exposure to sunlight. According to Nan, she had successfully completed a botany class prior to her enrollment in the pre-service teacher's biology course.

Oxygen and Energy:

Three pre-service teachers used the terms "oxygen" and "energy" interchangeably making it difficult to determine if they thought they were the same. This exchange with Kay illustrates the confusion and suggests that the participants had a non-scientific conception of energy.

> R: Can you tell me, what do you think photosynthesis is?
> K: Um, when the plants take the sunlight, and create oxygen for-
> R: Okay, so the plants take the sunlight and they create oxygen for?
> K: the plant to grow, it's their energy.
> R: Which is their energy, the oxygen is their energy?
> K: Um, kind of. Yeah. I think.

Summary of Misconceptions:

In general, misconceptions already documented by other researchers were observed in this sample of pre-service teacher. In addition other possible misconceptions concerning cycles were also identified. Participants demonstrated misconceptions regarding the function of a leaf, and the relationships between oxygen and energy.

Major Themes Emerged from Responses to Question One:

The conceptions presented by these pre-service teachers can be categorized into three main themes: egocentrism, interdependency, and sociological. These three ideas were a central focus in nearly all the conceptions offered. Descriptions and examples follow.

Egocentrism:

The pre-service teachers repeatedly referred to the plants as organisms providing service to humans. This utility viewpoint could be considered a form of egocentrism. The interdependency theme explained directly below also is a form of egocentrism. Participants were not able to envision plants as independent from humans. Plants were seen as intended to provide a service to humans by their production of oxygen and as producers within the food chain. Anita provides an egocentric example as she explains the biochemical level:

> The carbon is taken away, and the plants use it for something else and in the end, oxygen comes out, and they are now giving off oxygen, which we breathe.

Anita suggests that plants use carbon "for something else" failing to see the connection between glucose and the carbon molecule. The important part of the reaction appears to be the oxygen "which we breathe." She clarifies that position later, when questioned about the role of plants, to which she replies "Well, the major thing is to give off oxygen to us human beings."

Stated purposes for photosynthesis were directly tied to human survival. Among pre-service teachers attributing gas exchange to cellular respiration, the egocentric purpose was maintained. Anita describes the purpose of cellular respiration:

> Cellular respiration it gives off oxygen to humans for without plants, I think humans would not be able to survive, we would just be breathing pollution and all the stuff that we don't need to breathe. And, that is what it (the plant) does for the ecosystem.

Anita implies that the need of humans to breathe oxygen may be significant to the entire ecosystem. An egocentric view of a plant's role in the ecosystem was a theme in all interviews, although not always as obvious as these examples. Even Ann, a pre-service teacher who could conceptualize the processes on multiple ecological levels, and as nested systems, held an egocentric view.

> Plants produce oxygen, which helps us breathe, and then they um, that helps, like the ozone, to keep our temperature, the right temperature, right, so that we're not overheated, and some plants give us food to eat, vegetation, and that feeds lots of animals.

Ann clarifies her position further in the interview, tying it directly to an ecosystem issue.

> ….. and with them (plants) giving off oxygen and that, um, that (process) helps our ozone layer, with us giving off CO_2, they can use that and give us back oxygen, cause that's what we need to live, so with us, given off so much CO_2 and stuff, we need a lot of plants to help balance our ecosystem, so that we don't end up with no ozone layer and all die.

Notice in this statement that Ann attaches a direct service purpose to the plant processes. She also suggests that since we give off CO_2, plants are needed to help balance "our" ecosystem. The "balance" assisted by plants justifies releasing of CO_2 by humans.

Meta-representations were also drawn of plants providing shade, food, and oxygen, directly for people.

Interdependency:

The pre-service teachers repeatedly stated that plants needed humans for their survival. They expressed an "interdependency" that was viewed as the "balance of nature." Humans provide CO_2 for plants, and plants provide oxygen for humans. The need for human intervention in the life of plants was frequently expressed. Humans care for plants by providing water, nutrients in the form of food. We provide soil, and the carbon dioxide. Anita provides her conception of the dependency of plants on humans, when responding to a question on how plants differ from other organisms.

> Um, well, plants are very different from other organisms, they need to photosynthesize, to sit out in the sun, need to be watered, compared to humans,

> who don't sit out in the sun, and don't need to be watered. They make their own food. Which humans don't have to make their own food. They go out and cook it or catch it or whatever.

In her explanation of the differences, Anita suggests that plants need to be watered, but provides another glimpse of egocentrism with her hint of superiority of humans: "humans don't have to make their own food."

When considering the relationships within the ecosystem jar presented in the explaining set, Charles at first is confused as to where the people would get oxygen.

> And that so, they have no source of oxygen or anything like that. They're kind of going to suffocate in there. But, if it was open, it would be the perfect place, so…

As he re-think the contribution of the plant once more, he recognizes the source of oxygen for the people, and suggests the interdependency:

> ……but ah, okay, once again, for a plant to survive in such an environment, it would have to have, well, they would produce the oxygen, so I guess they would be fine, but I mean, they have light, they have soil, ah, and everything else, so I guess it could survive, and maybe like green plants would give off oxygen for the little people, organisms, the life of them too. So, they'd all depend on each other. They have to keep everything in balance.

These pre-service teachers suggested that plants were useful in their own preservation. When they die and decompose in soil, they serve as their own food source. It "helps other plants and helps the soil." Some dyads referred to this idea as the "life cycle" of plants.

Participants also suggested that pollinators would determine long-term survivability. Others suggested that human consumption would be the determining factor, as humans require a lot of energy, would over eat their resources. In their scenario, plants would have limited potential for long-term survival. Charles typifies this conception of interdependence:

> Okay, you're definitely going to have the life cycle and stuff like that, ah, everything inside is pretty much interdependent on each other, so basically like if

> the plant dies, so if the plants inside the little enclosure dies, then the people are going to die, because they won't have a source of oxygen. Um, but if the people die, then plants don't really have a source of taking in CO_2 or taking up oxygen or something like that, so they're all really dependent on each other. It's almost like, in that little environment, it's like a fragile sort of system that takes place.

Later:

> ……the people are consuming that energy and giving back to the plant by their activities and producing like carbon dioxide for photosynthesis.

Amy and Shirley, during their explaining set, were in such agreement concerning this dependency that they sometimes complete each other's sentences. Their comments reflect both dependency and the utility of plants for use by people.

> Amy: They've (plants) got carbon dioxide….
> Shirley: from the people…
> Amy: ….to transfer to oxygen.

Shirley provides more evidence of her conception when explaining her meta-representation, which conveys both her view of dependence and usefulness.

> Okay, I drew this hideous picture, of a plant, like a household pot, that because, a plant, you know, people have plants in their homes to make it look nice, and calming, and also, the plants, also help, you know in breathing. And, I drew the people, helping the plant by giving off the CO_2 and the cat helping. So.

All pre-service teachers interviewed for this project conceptualized plants as being dependent on humans for water, care or carbon dioxide.

Sociological view:

Explanations provided by participants suggested a societal need for caring about plants. Plants provide a service to individuals, but also benefit human society as a whole. Plant interactions within the ecosystem were viewed as necessary for human society, including pollination, for the purpose of forming fruits that humans use for food. Plants were mentioned as being necessary for the mental stability of the humans, to prevent boredom and give "beauty" to the natural world. When speculating about problems, such as over-abundance or a lack of plants, the participants conceptualized societal needs first. Plants could "over populate the people" within the ecosystem, and "suck the ground dry from water." People "need self discipline" to care for their habitat or a more "primitive society" would emerge which would ignore civil laws. The pre-service teachers described conceptions of an ecosystem that only could meet the needs of society with careful manipulation. Kurt had this comment on the potential of surviving in the ecosystem:

> We don't have unlimited supplies of food and water now, and we have countries that lack those, you know, basic necessities of life.

When responding to the question of long-term effects of an ecosystem, Kurt and his dyad partner Kay provided this perspective:

> Kay: As time passes, they are going to have to limit, maybe learn to limit a little, not go excessive in what they are eating, but, and they also are going to have to maybe restrict to just um, like, a vegetable and plant kind of diet.
> Kurt: …Like from the aspect as far as they having some self discipline, it's kind of like human nature has a tendency to kind of want when it's unlimited we kind of want to indulge in it, and then it's like you have to know when to say no, and when to say yes.

This conception of there being a societal need for plants was a less common theme than egocentrism or interdependency, but was promoted by a majority of pre-service teachers in this sample.

Answers to Research Question Two:

The pre-service teachers provided a variety of examples for their reasoning. During the interviews, participants used authoritarian, anthropomorphism, teleology, and tautology rationale to justify their explanation. Rarer were instances of mechanistic proximate and mechanistic ultimate. Reasoning modes were not easily discerned in many instances. Participants attempted to use the vocabulary of the topic instruction, and were challenged by their limited knowledge of the processes. At times, it was difficult to determine if the reasoning was tautological, or if the explanation provided was simply a failed attempt to use recently acquired vocabulary. Bob provides an example in his description of the mechanism of ATP formation:

> …and the hydrogen goes one way, or no the hydrogen goes back in, and the oxygen is breathed out. That's how it is done. So, oxygen is the by product.

In his reasoning, Bob is clearly confused as to the direction of the movement of hydrogen across a membrane. He ties the hydrogen and oxygen together, ending with a statement that oxygen is a by-product. Is this an example of faulty reasoning, the circular argument typical of tautology? Or is his nominal knowledge regarding the formation of ATP and its relationship to oxygen being expressed? Bob doesn’t really understand the relationship here. Oxygen is a by-product in the process of photosynthesis, and a reactant during cellular respiration. While an attempt was made to quantify reasons provided by participants reflecting how the two processes work; it must be stated that the majority of participants had nominal knowledge of either photosynthesis or cellular respiration.

Authoritarian:

When asked how they knew specific details about the two processes, a commonly cited source was classroom instruction. Those suggesting authoritarian justification cited their instructor, a text, or similar sources. Anita tells the researcher her faith in the instruction she is receiving:

> Well, I don't think the teacher is going to get up and just lie about something. So, I mean like right now, I can go by what a teacher tells me until someone else tells me different. So, I just go by what I read and by what I'm taught, before I learn something differently.

Some participants suggested an “order within the universe”, or an “assignment” for the plant to fulfill a particular role. Anita expresses this during her discussion on plant pigmentation, after acknowledging the source of her knowledge:

> She [Dr. Smith] was telling us that with regular plants, they use the colors red and blue, to get their green color. But, they can't use green because it reflects off of the plant. With algae, algae uses green among the other colors because algae is brown. So, they are allowed to use green and yellow and whatever, all the other colors, you know go with that. With the light using the regular plant, they are only allowed to use two certain kinds of colors, like algae or what other kind of plant, they are allowed to use the green and the yellow and whatever other colors.

Natalie provides her view of this order with the following exchange regarding plant functions:

> N: Plants from each other have different things that they do.
> R: So different plants have different things they do?
> N: Right, like radishes don’t grow corn, and corn don’t grow radishes. Oak trees deliver acorns, and flower for nectar. So, I think they all have their own different thing.

Natalie suggests in her comments an authority that dictates to plants their particular function.

There were less than twenty total citations of authoritarian sources. Authoritarian sources were more distinct than other reasoning modes, not being so easily confused with nominal knowledge issues. Besides their instruction, participants also cited experiences they shared with relatives. Gardens tended with grandparents were mentioned, as were personal experiences with houseplants.

One pre-service teacher relied entirely on experiential information when justifying her responses. This pattern began in the explaining set and was observed again through to the clarifying interviews. She cited examples of plants that she moved from the kitchen window due to steam, and the growth of corn and radishes. Natalie provides this explanation for her knowledge:

> I would say (knowledge about plants) from my Mom, and high school, what little biology, and I did not so good in those classes either. Um, my own experience, such as African violet steam, not a good idea. Things like that.

When asked about how they knew about plants, the majority of participants mentioned some physical activity they had been engaged in which provided information. Specific labs and experiments were mentioned. For example, Ann cites the laboratory experience with the corn seedlings as justification of her ideas of cellular respiration:

> The cellular respiration, we did this thing in lab where we had like corn seeds and we had dead ones and live ones, and we just had regular water, and we put a pH thing in there and we found that ah, the corn left off CO_2.

Jay also used a laboratory activity to justify his conception of cellular respiration as gas exchange:

> I'm just thinking that because when we talked about the plants, uh with their wax coating and the pores allowing them to exchange gases and everything.

While the pre-service teachers readily mentioned these experiences as the sources of their conceptions about plants, classroom instruction never focused on prior experiential knowledge.

Anthropomorphism:

The pre-service teachers also tended to attribute human characteristics to plants. This reasoning mode was characterized as quite distinct with minimal confusion with nominal knowledge, as noted in teleology and tautology. There were more than fifty instances during all the interviews when participants assigned human characteristics to the plants. Some of these incidents however, were minor, such as granting a gender designation to a plant. Other incidents of anthropomorphism were more involved, suggesting knowledge or purposeful action by the plant. During her clarifying interview, Ann provided this brief anthropomorphic statement regarding glycolysis:

> R: It can do either one? It can go into glycolysis or it can go through all three?
> A: <nods head affirmative>
> R: What makes it stop, do you think, if it doesn't do all three?
> A: Um, well, glycolysis can, if they don't have…um, I guess some, this is all they know how to do. It's programmed in their DNA. That is all they know how to do.

Note here that Ann also describes a mechanistic ultimate reason, in that genetic information determines what the plant can do. However, but her first and last responses give plants the human characteristic of "knowing."

Teleology:

Some of the justifications expressed for differences in sizes of plants revealed a teleological rationale. As was true for tautologies, it was more difficult to distinguish teleology and simply getting lost within the vocabulary. Subsequently, there is less confidence in more the fifty coded incidents of teleology. It may be that instead of using a result as the explanation, the participant simply had limited depth in their response, reflecting superficial knowledge of the topic. In one of the more distinctive examples of teleology, Joy explains one plant's fuller shape with this comment:

> It obviously is more full. Like, maybe the light source, is coming from all around it or something. So, the plant kind of grew out towards the light. This one has more brown on it, it's kind of wilted maybe. It just looks kind of droopy, more so than the other one does.

In her comment, she is suggesting that light produces growth; therefore, if the light were all around the plant, it would grow fuller. She also compares flaccidness of the plants and their coloration, giving no rationale for how they may have become different.

Tautology:

At times, the justifications offered were so circular that the argument was difficult to follow. An example is Bob’s explanation of his laboratory experience. Lab participants had used a Benedict’s test to indicate the presence of glucose and an iodine test for starch.

> We had a starch test, a Benedict's test, and that, it had less starch or glucose; it would stop producing energy, and energy source, glucose. In turn, that would slow down all the energy that the mitochondria can, you know, use, and the ATP production would slow down. And once the ATTP production would slow down, the PHP ATP production would slow down, and um, you just wouldn't be able to reproduce cells, and it wouldn't grow.

In Bob’s explanation, he reveals confusion between starch, glucose, and energy. At the end of his discussion, his confusion is further elaborated as he links ATTP (a vocabulary error) with PHP ATP (another vocabulary error) and cell reproduction.

The pre-service teachers frequently gave one-word responses for their explanations, suggesting growth was caused by “photosynthesis”, and photosynthesis was explained by the presence or absence of “light.”

Mechanistic:

Participants did provide explanations suggesting a mechanistic understanding of the two processes, focused primarily at the ecological level of the organism. The pre-service teachers rationalized plant appearance by attributing their appearance to lack of water, nutrients, and sun. Those mechanistic proximal responses accounted for the majority of incidents recorded. Less common were explanations involving genetic variability that were recorded as mechanistic ultimate.

Quantification:

Table 7 quantifies explanations participants provided in their responses. Caution should be taken in interpretation. Participants' justifications of their responses were not always distinguishable from attempts to apply unfamiliar vocabulary. Circular reasoning (tautology) and using a result to explain a process (teleology) were not easily discernable from nominative knowledge. The quantified values expressed here may be over inflated and more reflective of their nominal knowledge of the topics.

Table 7
Quantification of Reasoning Modes

Mode	Number of Coded Instances
Anthropomorphism	55
Authoritarian	18
Mechanistic	Proximate (23) Ultimate (9)
Tautology	92
Teleology	51

Intuitive Conceptions:

The explaining set provided an opportunity for participants to explain the two processes to their peers. In this project, for the majority of the pre-service teachers (12/16), the explaining set took place a week after their laboratory experiences with photosynthesis and cellular respiration, but before the completion of the chapter in lecture. After reviewing the data, it was apparent that even with the four participants remaining and though they all had taken their exam, and had completed the unit of instruction, the explaining sets provided insight into preconceived notions about the two processes. One possible explanation was that the exam focused primarily on the biochemical level, and the explaining set questions focused primarily on the organism, ecosystem and global levels. Conceptions expressed held more examples of potential intuitive thinking regarding the two processes. Although there were comparisons of plants to humans in the other interviews, the majority of conceptions expressed that plants were either like or unlike humans occurred in the explaining set. This was true even for the four participants who participated in the explaining set after taking the exam on the topic. The same set of questions was used during the cognitive interview, asking participants to compare plants to other organisms. Yet the comparisons with humans were more prevalent in the explaining sets.

Ann provides a view of her conception of how plants are similar to other organisms:

> They do give off CO_2, which is carbon dioxide, and they need water, and food, which is, ah, they make glucose, just like us, we need that for energy. And when we eat them, we get some of their energy. Their energy is neither created nor destroyed, so they have to pass it to the plant from the sunlight, and then to us. So. We all have energy, so they are similar in that too.

Later on in the same explaining set, Ann shares a similar conception:

> ….and ah, my Grandma would always say, you don't put water on in the middle of the day, because they are hot, and they're hot, and if you dump water on them, it's just like us, if you're hot and you jump in the cold water, you just go "ah" and they'll shrivel up, and they'll get cold, and it's best to put water on them in the morning, when they are cool, and they'll just soak it up and drink it.

When considering the ecosystem jar and its potential long-term effects, Ann has this comment:

> But, the plants, I'm sure will be just fine as time passes, like people get old and their cells start to die and stuff. Plants, they go forever, they'll live.

Kurt compares plants to humans at more than one ecological level.

> Um, well, I mean, I know one main difference is that um, like, humans for instance, we don't have a cell wall, and I think plants have, um, you know cell walls. We have pigmentation for our color, and they use like chloroplasts, so.

In his next comment regarding similarities, Kurt has another comparison:

> They need sufficient light and water to survive, well, I believe all other life's organisms need our light source as well, like human beings, we need an ample amount of food, water, and rest, in order to survive and really function.

Notice Kurt's possessive use of "our" light source while suggesting that, similar to humans, plants may need "rest."

Carl starts his conception of similarities by comparing plants and humans, but broadens the scope to include other organisms. He then completes the conception by refocusing on humans.

> Basically, plants are made up of the same building blocks as everybody else, of molecules, cells, it takes all the same things to build a plant as it does to build a person, cat, dog, bird, we're just about all the same things, with just a few minor differences between each of us. A different little cell here, a little cell here and you're a plant, and you're green.

The pre-service teachers may have spontaneously used themselves or other humans as a point of reference for the plant processes, evidenced by the following:

> Ruby: How do plants differ from other organisms? Ah ha ha! How do they differ from? Hmm, they have sugar. We have sugar, right?
>
> Ann: They need water and food, which is, ah, they make glucose, just like us, we need that for energy.
>
> Bob: Obviously, their atmosphere, their conditions to grow, so, ah, they can't think. Really, I mean, plants are, they don't have a brain, so they don't necessarily know. But, they are like a, they are like a… the parents of a plant have to have to care for them in order for them to thrive, and that is similar to others…
>
> Jay: We don't, we can't make our own energy from sunlight, or anything like that, so we have to eat the plants that make the energy from the sunlight.
>
> Kurt: Um, well, I mean I know one main difference is that um, like, humans for instance, we don't have a cell wall, and I think plants have um, you know, cell walls; we have pigmentation for our color, and they use like chloroplasts, so.

> Anita: …need to be watered. They make their own food. Which humans don't have to make their own food, they go out and cook it or catch it….

> Joy: …plants need water, and we all have to have the same kind of energy, even though it comes, we make it in different ways….

Their focal point in all of these exchanges is a human. The potential for consideration of these statements as pre-conceptions is discussed in chapter five.

Major Themes Emerged from Responses to Question Two:

Justifications provided by the pre-service teachers in this study can be divided into three major themes: nominal knowledge of the processes (which may have interrupted their reasoning); experiential authoritarian reasoning; and anthropomorphism (a clear preference to attach human characteristics). These themes are given further explanation below, with examples for clarification.

Nominal Knowledge:

The researcher had difficulty determining if the pre-service teachers did not understand the terminology they were using, or were using teleology or tautology for their explanations. This was particularly true at the biochemical level, with participants unable to distinguish between carbon and carbon dioxide at times, and at the cellular level with confusion between chloroplasts and chlorophyll. Even at the organism level, when trying to explain how the plant might change if it could not photosynthesize, Anita was unable to explain the process well enough to respond fully to the question. Is this tautology, or nominal knowledge?

> Well….the plants would probably use what stored energy it has left. And, try to give off as much oxygen as it could. But, after awhile, it wouldn't, it wouldn't any plant wouldn't be able to survive, without light. And, it would kill; it would kill a lot of things.

Anita's explanation strongly suggests confusion between energy and oxygen. Anita apparently sees photosynthesis as an energy reaction for the plant. Her response also suggests a sociological view, in that other items beside the plant would be ultimately affected. She elaborates later to include humans in her response. The circle that she has drawn in her logic suggests even more strongly that she doesn't understand how energy and oxygen are related to photosynthesis. It was difficult for all the pre-service teachers to provide justification for their responses because their knowledge about the topics was too superficial. This explanation is also evidenced by the brief one-word responses frequently given. The plant uses sunlight to "photosynthesize" and for "food."

Experiential Authoritarian:

Participants used their prior experiences to build responses to questions. They even reached back into experiences from their elementary years. Those experiences, in some cases, held more weight than their current instruction. Even Ann, who verbalized confusion over cellular respiration and the expelling of carbon dioxide by plants, used elementary experiences to justify her responses. During classroom instruction, prior knowledge was never considered. Nor did the instructor ask her students to reflect on any common experiences. The pre-service teachers in this study apparently naturally did so when searching for justifications for their responses. Ann provides an example here of relying on both her classroom instruction, and her elementary experiences. It is interesting to note that she separates detail about photosynthesis from knowledge at the organism level. Ann was a participant who had knowledge at multiple ecological levels, and was aware of "nested systems."

> Ah, well a lot of the in depth photosynthesis stuff I learned from Dr. Smith, but like the stem and the leaves I learned when I was really little, doing little biology

> things. You'd have a flower, and you brought home to your mom, and to make it part of the class, they'd teach you about stems and leaves.

Ann also referred to her home environment in this exchange, another common aspect in their explanations. Seven of the participants used examples directly from experiences with relatives. In Ann’s comment, she attributes her elementary teacher’s intent as bringing the flower “home to your mom” first, and secondarily as “about stems and leaves.” This provides further evidence of the sociological view noted earlier.

Anthropomorphism:

Participants in this study attributed human characteristics to plants in their explanations. They identified parenting skills, intelligence, intent to their actions, and other human attributes when discussing the two processes. An example is Ann’s comments regarding the use of ATP. Ann was one of the few participants to discuss ATP, so when she considers why plants need ATP, it is surprising to hear her anthropomorphize the plant with a “mouth.”

> I think it uses it for everything, that’s um, why it needs a lot of ATP. It uses is to um, grow, and it goes through the food, and it uses it to make the food, cause it doesn't have a mouth to eat it. <laughs>

Even though Ann laughs at her own comment, she inadvertently compares the human need for a mouth and food associated with that form of ingestion, with a different form of food to satisfy the physical limitations of a plant. The intuitive conceptions provide further evidence to the anthropomorphic theme. If participants use “self as first referent” when they consider the processes of plants, a logical next step may be to anthropomorphize the plant with human characteristics. The combination of anthropomorphic reasoning and intuitive conceptions give evidence to the egocentric theme explained previously. Apparently, participants viewed plants from their own perspective, applied a limited number of human characteristics, and judged them to be useful to humans within the ecosystem.

Context:

Field observations were made during a summer session of nine-week duration. Pre-service teachers met with their instructor for ninety-five minutes each lecture period on Monday, Wednesday and Friday. Attendance (see Appendix D) was documented. The lecture began at 9:15 am in an amphitheater style classroom with a capacity for more than one hundred students. The facility included a lecture podium and a demonstration table, and was technology enhanced with an overhead projection system and networked computer. The lecture was in the science building of the university and the classroom included a sink and other laboratory needs. Pre-service teachers sat at solid tables in permanently attached chairs. They used the tables for books and other items, and for taking notes while the instructor lectured. They were provided with printed copies of the PowerPoint presentation used during each class period. The handout included diagrams and illustrations presented on the screen. The instructor often referred to both illustrations and text during the lecture presentation. Each handout represented a chapter from the required text. The handouts for these two chapters included six pages (36 slides) for cellular respiration and five pages (30 slides) for photosynthesis.

On Tuesdays and Thursdays, the pre-service teachers attended a laboratory. This facility was a traditional science lab with tables and equipment. It contained a large demonstration table placed between two sets of student tables. The laboratory assistant placed all needed supplies on the central table, and pre-service teachers worked in groups of four on activities from their lab manual. Laboratory attendance was mandatory, with a caution on the syllabus that "missing more than two labs will result in a failing grade in the course."

In addition to handouts, there was a required textbook for the course. Few pre-service teachers brought their texts to the lecture sessions. The text was the second edition of *Biology: A Guide to the Natural World* (Krogh, 2002), and during the nine-week session, all but six of the thirty-one chapters were covered. Appendix I provides a list of topics covered by the title of the chapters and the order in which they were covered during the nine-week session. The pre-service teachers read more than five hundred pages of their text, averaging over sixty pages per week.

Analysis of the text and laboratory manual, handouts and other support material , and of evaluation materials used in the course, are described below.

Text:

The AAAS Project 2061 Biology textbook evaluation recommends seven categories for evaluation of a text. These categories and a brief definition appear in Table 8, which includes results of categories applied to the text used in this project. Only the two of the twenty-five chapters covered during the instructional period were germane to this research. Chapters 7 and 8 were analyzed, though the text had a consistent format throughout.

Table 8
Textbook Analysis

Categories:	Ideas:	Biology: A Guide to the Natural World
Category I: Providing a Sense of Purpose	Material should convey a sense of purpose at all levels of instruction and should present materials in a logical sequence.	Each chapter begins with narrative; some set a purpose better than others.
Category II: Taking Account of Student Ideas	Material should specify prerequisite skills that are necessary for learning, should alert the teacher to commonly held student ideas, and should address commonly held ideas.	There is no mention of prerequisite skills required. There is brief mention of commonly held ideas. No mention of how to address commonly held ideas.
Category III: Engaging Students with Relevant Phenomena	Material should provide multiple and varied phenomena in support of key ideas.	Chapter provides multiple examples, ask students to conceptualize through analogies that supports key ideas.

Table 8

Textbook Analysis –Continued

Categories:	**Ideas:**	**Biology: A Guide to the Natural World**
Category IV: Developing and Using Scientific Ideas	Materials should develop an evidence-based argument for key ideas, introduce terms meaningfully connected with ideas. Ideas should be effectively represented, synthesized and connected. Practice should be provided.	Photosynthesis chapter provides an historical perspective of Calvin's research into light independent reactions. The respiration chapter does not provide an historical perspective. There are practice web investigations.
Category V: Promoting Student Thinking about Phenomena, Experiences and Knowledge	Materials should encourage students to explain their own ideas, asking for their reasoning and interpretation.	Chapter reviews include summary statements of sections; key terms; multiple choice questions; brief answer questions and applying your knowledge.
Category VI: Assessing Progress	Assessment should be aligned to goals, and should be used to inform instruction. Testing should be for understanding.	Materials for assessment are self-assessment only. They are listed in Category V:

Table 8

Textbook Analysis –Continued

Categories:	**Ideas:**	**Biology: A Guide to the Natural World**
Category VII: Enhancing the Science Learning Environment	Materials should provide teacher content support, encourage questioning, and support all students.	There is no evidence of teacher support in this text. There is no mention of accommodations for all students.

Chapter 7 in the text addressed cellular respiration, immediately preceding Chapter 8, which covered photosynthesis. When considering Category I (setting a purpose) the two chapters begin with an engaging narrative. Chapter 7 had a brief story of the 1996 expedition of Mt. Everest, which resulted in the death of a guide by oxygen deprivation. The narrative transitioned to the concept of cellular respiration with the following two paragraphs:

> The tragedy of the 1996 Everest expedition drives home a point and raises a paradox. No one needs to be reminded that we need to breathe in order to live, and most people are aware that oxygen is the most important thing that comes in with breath. That said, of the next 100 people you meet, how many could tell you what oxygen is doing to sustain life? Put another way, why do we need to breathe?
>
> The short answer is that breathing and oxygen are in the energy transfer business. They are part of the system that allows us to extract, from food, energy that is then used to put together the "energy currency" molecule, ATP. (Krogh, 2002, p. 132)

Chapter 8 had an opening narrative as well. The chapter opened with the setting of the sun on a pond.

> Silently, something else is changing as the last light fades. The green world is shutting down. Microscopic pores on the leaves of bushes and trees are closing

> up, ceasing to be openings for the carbon dioxide that flows in and the water vapor that flows out during the day. The green world is alive at night, but the activities it carries out are not so much different from those a human listener might be undertaking while relaxing at the water's edge.(Krogh, 2002, p. 153).

Both chapters provided a step-by-step view of the two processes, moving through the three stages of glycolysis first, and then the two stages of photosynthesis. Section headings of both chapters are provided in Appendix I. It is interesting to note that both chapters start at the organism level of understanding but move quickly to the biochemical.

Both continually oscillate between levels throughout the chapter, providing sectioned illustrations with cellular level information set in the context of the organism level. An example is the transition paragraph in 7.1, which moves from "energizing ATP" to the "electrons fall down the energy hill":

> Where does the energy come from? For animals, such as ourselves, it comes from food: energy that is extracted from food powers the phosphate group up the energy hill, and literally onto ATP.
> In tracking the extraction of energy from food, we will use as an example one particular molecule, glucose, to see how energy is harvested from it. Though the details here are complex, the essential story is simple. Electrons derived from glucose, which is high in energy will be running downhill, they will be channeled off, a few at a time, and their downhill drop will power the uphill push needed to attach a phosphate group onto ATP. (Krogh, 2002, pages 132-133).

Both chapters conclude with summary paragraphs. Chapter 7 ends with this comment on photosynthesis:

> This long walk through cellular respiration has illustrated how living things harvest energy from food. Recall, however, that this chapter began with the observation that we ultimately have one source to thank for this food: the sun's energy, trapped by plants in the chemical bonds of carbohydrates. This energy conversion takes place through a process that has beautiful symmetry with the respiration you have just looked at. That process is called photosynthesis.(Krogh, 2002, p.147)

This paragraph, with its direct reference to photosynthesis and plants, implicitly sets an idea of interconnectedness, working on multiple ecological levels within nested systems. The concluding paragraphs of Chapter 8 have more evidence of a systems approach.

> It (photosynthesis) is the foundation of plant growth, and upon plant growth hinges nothing less than the survival of all animals- including human beings. Without an understanding of this linkage, it's easy to see plants as a set of mute fixtures whose main contribution to human life is aesthetic. But, with this knowledge, you can begin to see the central position that plants occupy in the interconnected web of life.(Krogh, 2002, p. 163)

Later on the page, in the same section, the author writes:

> Cycle has been a reoccurring word in this long discussion, because the only one-way trip you've encountered has been the relentless "spillage" of energy from the Sun down into heat. Looked at in a cynical way, Earth and its inhabitants constitute a kind of leaky holding tank for energy that comes from the Sun. Looked at another way, however; the living world has been able, through photosynthesis to take the Sun's energy and build a remarkable edifice with it. (Krogh, 2002, p. 163)

These two paragraphs from Chapter 8 show the connection between photosynthesis and cellular respiration, the global ecological level through the organism level, and suggest a view of nested systems. There is no explicit explanation of the concept of systems. Nor is an introduction to multiple ecological levels as components within a biological system presented.

Analysis of the textbook under Category V involved evidence of materials encouraging students to explain their own ideas. In both chapters, there are summaries tied directly to tutorials. For example, at the conclusion of chapter 7, the following entry is provided for section 7.1:

> The molecule adenosine triphosphate (ATP) supplies energy for nearly all the activities of living things. For ATP to be produced, a third phosphate group must

> be added to adenosine diphosphate (ADP) a process that requires energy. Tutorial 7.1.2 Oxidation-reduction reactions. (Krogh, 2002, p. 147).

In the same section of the text is a set of multiple-choice questions that focus primarily on the knowledge level. An example is provided here:

> In the first step of glycolysis, glucose enters the cell and immediately has a phosphate group from ATP attached to it. This process is called:
> a. phosphorylation
> b. oxidation
> c. photosynthesis
> d. electron transport
> e. the citric acid cycle. (Krogh, 2002, p. 149)

Also included is a section entitled “Brief Review”, containing a set of questions focusing more on organism and ecological levels than on the biochemical or cellular levels. Although the instructor mentioned these questions in her directions for exam preparation, participants did not mention their use to the researcher. Two of these questions within the set provide an example the focus on multiple ecological levels:

> 2. Explain why you should expect to have more mitochondria in your muscle cells than in your skin cells.
> 3. Since ATP is used for our cellular needs, why don’t we just eat ATP? (Krogh, 2002, p. 149)

Another set of questions in this section are subtitled “Applying your knowledge”, and included the question,

> 2. Why do you think that we use the same word-*respiration*- for breathing as we do for breaking down food to extract its energy? (Krogh, 2002, p. 149)

There was no mention within the course syllabus nor did the instructor mention specifically these self-assessment items.

Category VI is a category analyzing curriculum alignment. The researcher was not aware of an instructor’s version of the text. Questions from the evaluations appeared to align well with the instruction in the lecture and the text, but only the self-assessment items listed in Category V were available to the researcher and the pre-service teachers. Their instructor gave the participants self-assessments, but these aids were not mentioned during research interviews.

Laboratory Manual:

Materials pertinent to the course included a laboratory manual, authored and illustrated by the course instructor with a single laboratory activity combining cellular respiration and photosynthesis. The activity begins by introducing the chemical equations for both processes. It reviews the concept of pH, and provides a simple diagram of the relationship of H+ concentration and the pH scale. Finally, it introduces the idea of a pH indicator, using as an example of the equation actually tested in the activity that of adding CO_2 to water.

The laboratory procedure was presented in clear precise steps. Tables for recording data and illustrations of the procedure aided procedural descriptions. The activity was divided into four parts. Part A asked the pre-service teachers to observe a color change when CO_2 is blown into water prepared with phenol red and one drop of NaOH. The color change from pink to yellow signaled the change from a more basic solution to one more acidic, and was used to detect the presence of CO_2.

Part B begins with the statement “Plants, like animals, have cellular respiration.” In this activity, pre-service teachers prepared three different test tubes, each containing phenol red. One test tube contained corn seedlings, which had been heat killed. Another test tube contained viable corn seedlings. The third test tube contained only the phenol red. The pre-service teachers then compared the three test tubes for changes in color after forty-five minutes. This activity showed the presence of CO_2 in the test tube of the live corn seedlings and allowed comparison with the non-living seedlings and the indicator's original color.

Part C compared the leaves of two plants. One plant had been kept in a dark cabinet for more than two days prior to the activity. The other plant came from the university's greenhouse. The pre-service teachers performed two experiments on leaves from each plant. One test was an iodine test for the presence of starch, a storage form of glucose. The other used Benedict's solution as an indicator of the presence of glucose. Details of both procedures were clearly articulated with numbered steps and illustrations.

Part D emphasized the role chlorophyll plays in photosynthesis. The pre-service teachers repeated the procedure outlined in Part C, but with leaves from variegated plants. They cut the leaves to separate green-pigmented areas from white. The white non-chlorophyll pigmented sections were tested for the presence of starch and glucose. Green chlorophyll pigmented sections were also tested for the presence of these substances.

The last section of the laboratory activity was a series of probing questions directly related to the laboratory experiences. Questions were divided into A, B, C, and D, corresponding to the sub-activities in the session. The questions were open-ended and asked for explanations with responses. The questions as they appeared in the laboratory manual are listed in Appendix K.

Handouts:

The pre-service teachers also received printed PowerPoint slide handouts for each chapter. The handouts coincided with the lecture presentation. The majority of illustrations also coincided with the textbook. However, a few were only available on the handout, and on their WebCT site. The instructor interspersed illustrations with text material in the presentation. Most text material was brief and summarized details the instructor had verbalized.

The pre-service teachers were also provided with a set of study questions for each chapter, prepared by their instructor. The study questions for both Chapter 7 and Chapter 8 appear in Appendix K. These questions were open-ended, and formatted to encourage a complex often-lengthy response. Although their instructor referred to them in her interview and during one class period as a source for potential exam questions, there was no evidence that the pre-service teachers actually completed these questions. Two questions in particular were relevant to this research. Question #12 asked, "Is photosynthesis an endergonic or an exergonic reaction? Where does the energy come from?" It potentially provided a clue to the interconnection between the two plant processes. Question #13 addressed a common misconception: "Where does the carbon come from that is used to make sugar?" There was no evidence that the instructor discussed these questions with the pre-service teachers and these questions did not appear on any evaluations.

Other Support Materials:

Pre-service teachers had other support materials available for their use throughout the nine-week session. The textbook included a CD-rom, which provided summaries of each chapter. There were web-based activities that the pre-service teachers could complete. These were provided by the textbook publisher and available through their WebCT site. Participants were often invited by their instructor to ask questions or visit her during office hours. Only one pre-service teacher referred to the CD-rom during any of the interviews, also referring to a session with the instructor. Because the WebCT site was not available to the researcher, the support material will not be analyzed in this paper. A comment made during a conversation with the instructor suggested that few of the pre-service teachers used any of the support materials.

Field Observations:

Four field observations were made during the project. Three of these were conducted during the lecture period, and one during a laboratory. The first observation occurred one lecture period prior to instruction on photosynthesis and cellular respiration. Lecture topics for that field observation were cell structure, the plasma membrane and energy. At that time in the nine-week session, the class had been together for nearly two weeks, and had completed one unit of instruction (ecology).

The lectures were typical science content presentations. Lectures were delivered by the instructor and focused entirely on content, emphasizing knowledge attainment. The instructor remained at the front of the classroom, while the pre-service teachers sat in their chairs in the amphitheater. Lectures on chapters 7 and 8 combined accounted for 146 minutes of class time. During this period, there were 79 direct interactions between students and the instructor. Included in this category were instances when the instructor would direct a question to the pre-service teachers or vice versa. There were more instructor directed questions (more than 45) than pre-service teacher initiated inquiries. Only Ann, Bob and Betty initiated questions during field observations. The majority of the instructor-initiated questions could be classified within the knowledge category of Bloom’s taxonomy (Bloom & Krathwoh, 1984). A representative question from the instructor and the resulting exchange with the pre-service teacher is provided below as an example.

> I: We would call these, not the light reactions, but the…what? What is the other name for this, that?
> S: Light dependent
> I: light dependent reactions. That is what is in your textbook. Not the dark reactions but the…
> S: Light independent
> I: Light independent. Okay?

Connected:

Lecture instruction on connection between the two plant processes was very explicit. The instructor told the pre-service teachers that plants do both processes:

> Now, plants also need oxygen. Plants also respire. Remember from lab. Plants respire. Plants also need a source of oxygen. They also have respiration. It's just that plants can also do this (referring to photosynthesis). Okay. We can't. They can do this also. But, they do the same thing we do, but they also do this. Okay.

This statement was made in direct response to a question about the use of oxygen by plants. Note that while the instructor explicitly told the pre-service teachers that the two processes were connected, she only implicitly provided information about how they were related. The pre-service teachers in the class were expected to determine the connections for themselves.

Opposites:

The two reactions were frequently discussed as being opposites of each other. Three pre-service teachers stated the processes were opposites during their cognitive and clarifying interviews. This may be a partial explanation for their conception of photosynthesis as being the "energy" reaction and cellular respiration as being a "breathing" reaction. Such a conception is further validation of the processes as "opposites". They may have generalized the phrase "opposites" to extend beyond the confines of the biochemical equations.

Multiple Ecological Levels:

Lecture instruction on multiple ecological levels was less explicit than the connection between the processes. The instructor mentioned multiple ecological levels in several instances. Seldom was there an explicit reference to a function found at one level that served another level. Topics were shifted rapidly from one ecological level to the next in most lectures. Here is an example of a switch through multiple levels that takes place within a few seconds:

> Basically, those big protein pigments, chlorophylls are going to be embedded, in these membranes. That is where the green is. You look at a leaf and it looks green, but not really, it's just the chloroplasts. Oh wow. It's actually in the little sacs inside the chloroplasts, that's where all the green is, because that is where all the pigment is. So, this where photosynthesis is going to occur. Okay, I've already said this, but these are some things when we are reviewing to think about. Right. Reverses the electron flow. Respiration, takes what comes from glucose and makes ATP, and gives the oxygen to make water. Okay. In photosynthesis, we're going to split water and form oxygen. We're going to grab those electrons and eventually give them, they are going to end up in, so exactly swapping the order of the electrons in their flow.

In one of her summary statements immediately after the instructor had moved quickly through each of the three metabolic processes, she uses multiple ecological levels throughout.

> These are the three processes. This right here is our mitochondria. Right? Originally came from a bacterium that was an endosymbiote. Now it lives in eukaryotic cells, and is what is responsible for the allowing us to have cellular respiration, for allowing us to use oxygen, to make ATP for the process. So, here we're going to have our process. The first one. This process occurs in every single cell on the planet, glycolysis. It's sort of the oldest form around. It likely evolved first before these other processes evolved. This occurs just in the cytoplasm. And, we're going to have a little ATP made, and then some parts of glycolysis are going to move into the mitochondrion, where we're going to enter this other

> cycle, called the Kreb's cycle. Okay, a little ATP is going to be made,. But, the main thing to keep in mind is going on, is both in glycolysis and the Kreb's cycle, we're grabbing electrons, we're harvesting electrons.

Within her summary, the instructor has mentioned:

- the global level ("occurs in every single cell on the planet"),
- the ecosystem level ("came from a bacteria that was an endosymbiote"),
- the cellular level ("in eukaryotic cells", "mitochondrion")
- and the biochemical level ("ATP", "oxygen" , "glycolysis", "Kreb's cycle")

with the implied idea that all of these levels are working together for a joint purpose ("grabbing electrons" and to "make ATP"). She has implicitly provided the concept of "nested systems."

"Nested Systems:"

The concept of nested systems was even more implicit. For example the discourse provided here implies that biochemical reactions work together to assist the organism, but doesn't actually state the concept of nested systems, with potential emergent properties.

> We start with glucose, and then we go here, and then we go here, and then we go here, but I want you to keep in mind is that this series of chemical reactions, that we're talking about glycolysis, the Kreb's cycle, and the electron transport chain, this process, it's just part of your metabolism. Okay? There are hundred and thousands of chemical reactions that are occurring all the time. And, sometimes the molecules can enter this process at different points. We don't always have to start at the top, start at glycolysis.

It is doubtful that a pre-service teacher without direct instruction in systems would view processes affecting cell respiration as part of the overall cell metabolism. They would not likely make the same connections as the instructor, who already understood as being part of the organism, as well as a component in the ecosystem, which contributes to the global environment. The instruction was too implicit to adequately convey such connections.

In the lecture on cellular respiration, the instructor responded to a question from a pre-service teacher on the movement of hydrogen ions across the membrane. “Does it use energy less? Energy that falls makes ATP? Why not out of the cell?”

The instructor clarifies the question and tries to understand if Bob is referring to the mitochondrion. Bob persists however, and clarifies his question to a completely different level from the discussion:

How does this affect the energy of the organism, on the outside?

The instructor (designated in the exchange as I) recognized that Bob (designated B) had changed levels and responded with the only explicit instruction of a biological system observed during the field observations.

> I: No, no, you can’t destroy energy, but an organism can take energy in. We’re what is called an open system. Energy comes in energy goes out. Okay, so in general, ah, we get our energy, our energy input into the cells of in our body is glucose, to get them into our cells, we have to expend a little energy, to bring it in. But, once we have the glucose in our cells we can, have cellular respiration, use all that energy, from the glucose to make lots of ATP, take that ATP and use it to take more glucose in, but you know, it involves the other things within the cell. Okay, a lot of energy that we take from glucose, ah, is used to make ATP, have ATP doing all the things that we can do for the cell, lost as heat, but we constantly have energy coming in as food, energy going out as heat, we’re an open system. Okay? Now, in the universe, we can’t destroy energy, but energy is transformed from one form to another, potential to kinetic, potential to kinetic.”
> B: it’s pretty much a circle?
> I: Well?
> B: some what?
> I: sort of not, more one way, energy coming in, energy from the sun, going through organism and out as heat. It’s more, more of a one directional thing. Kind of like we talked about with ecosystems. Okay, other questions?

In this exchange note that the instructor again switches rapidly between multiple ecological levels, talking of input into the cells, input from the universe, and giving the perspective of multiple levels nested within the universe. Bob questions if the relationship is cyclic, to which the instructor suggests that it is not cyclic, comparing it to discussions undertaken during instruction about ecosystems.

The researcher noted that during the lecture on cellular respiration, pre-service teachers asked questions seeking to clarify the multiple ecological levels as the instructor focused on the biochemical. Typical questions included:

> Ann: That's all in the mitochondria right?
> Bob: Where does the water go? Into the cell?
> Bob: This happens in the mitochondria? Where does the energy go while getting there?
> Bob: Citric Acid? CO_2? Kreb's Cycle? How do these relate to one another?
> Betty: Are we still in the mitochondria?

It is interesting to note that Ann and Bob were two participants who had an understanding of systems and were able to converse on multiple ecological levels. The majority of the other participants did not willingly venture beyond one or two ecological levels. During the lectures, it appeared that Ann and Bob answered the majority of questions posed by the instructor. Although a relatively high number of interactions occurred, the majority of responses were brief. Several minutes sometimes elapsed without any interaction by the pre-service teachers.

The lectures differed from the lab experience by their level of interactions. While the researcher sat in the middle of the laboratory classroom, the instructor moved freely about the room. Interactions that took place were too numerous to count without sophisticated equipment. The instructor concluded the laboratory by having each individual check responses to the questions prior to leaving the room.

Evaluation:

The pre-service teachers were evaluated on course content through four exams over the course of the nine-week session. Each exam represented two weeks worth of instruction. The exam including photosynthesis and cellular respiration also included topics covered in two other chapters, membranes and energy. Exams were multiple-choice and scored electronically. The researcher was not offered the privilege of viewing the exams, but was assured by the instructor that they bore a strong resemblance to the three bonus quizzes given during the field observations.

The question below, taken from a bonus quiz offered to the pre-service teachers on the last field observation day, is typical of the style, depth and level of the questions asked on other bonus quizzes.

> Which of the following best explains how the energy from the electrons is used to make ATP in aerobic cellular respiration?
>
> f. electrons are given directly to ADP to make ATP at the bottom of the electron transport chain
> g. light energy is used to add electrons to ADP to make ATP.
> h. the energy of the electrons is used to create a H+ gradient, ATP is made as the H+ diffuses back through the membrane.

None of the bonus questions assessed knowledge of systems. There were no questions on connections between photosynthesis and cellular respiration. There were no questions involving multiple ecological levels. All questions centered on one level, generally biochemical or cellular. There were no questions that implied nested systems.

The course had a traditional grading scale, with gradations between 59.6% and >94% representing letter grades from F to A, including pluses and minuses. Final grades were calculated from multiple sources: four exams, lab participation, lab quizzes, bonus quizzes, and an optional final that could replace an exam score. There was no quiz on the photosynthesis and cellular respiration lab.

The context of instruction on the two plant processes was traditional, focused primarily on biochemical and cellular ecological levels. There was only occasional mention of the other ecological levels. The instructor primarily lectured. Collaborative groups were reserved for laboratory activities, but each pre-service teacher was evaluated individually on their laboratory activity. Labs were scheduled independently of the lecture, although in close time sequence to the current topic.

Instructor View:

The instructor of the class had been teaching at the university for five years. Her credentials include a doctoral degree in a biological science field. She admitted during a conversation with the researcher that she had never taken a formal education course and was instead teaching by listening to student concerns and making adjustments accordingly. She describes her lecture approach on these two challenging processes as: "Just try to repeat things again and again, until I feel like they are with me."

During her interview, which took place after preliminary analysis of the pre-service teachers' conceptions, the instructor reiterates her approach of using student feedback to adjust her teaching methods:

> …and looking at student evaluations, you know you have to take a look at that sort of thing. And every once in a while, you kind of get a trend, you know. Students seemed to comment that they liked the lab more. I had more comments that they could totally understand it. I think for a lot of them, it may not be the main portion where they get their info, but it seems to sort of bring together things for a lot of them, especially when it doesn't well, it doesn't always work out with the timing.

In her comment, the instructor focuses on a difficulty often faced by many college-level science courses: that of scheduling labs independently from the lecture. Coordinating the lab with the lecture topic is challenging when institution administrators view the two independently. In this project, the timing of the laboratory experience was synchronized with the lecture.

When was asked her ideas regarding the “perfect approach” which specified no time constraints, no financial constraints, with a goal of having students better understand the two processes, her response is as interesting for what it doesn’t say as what it reveals about her approach:

> Um, gosh, I think probably in terms of time, a lot more time. Um, would probably be a good thing. You know if I had half a semester, to talk about respiration and photosynthesis, I think that would be a lot better in terms of, you know, having them get the finer, the finer points of it.

In a later question, another idea occurs to the instructor to complete her response to this same question:

> …so, in terms of going back to your earlier question, if time and money were limitless, and all of that, if I could have a perfect sequence of lab and lecture activities that is probably the way I would chose to do it. Just in terms of their ability to get the concepts, I think that would be, if I could just have lab meet whenever I wanted, to be perfect with in the lecture, everything. I think that would be great.

The instructor focused on motivation, level of detail, and the science background of the students in making her decisions regarding course content for these two plant processes. She explains her approach:

> …it is not a class that, well, some of them will be using this information for further science classes, but most of them, just kind of, you know, it’s sort of a stopping point for a lot of them. I just wanted to sort of have them see the basics about photosynthesis and that, you know, how it works, how it relates, you know, to factors that might effect their lives, in terms of everything from global

> warming, to hey, this is what wave lengths of light are important, so that maybe they can make some connections in that way, and have some appreciation of it in that way, but not, um, drive in every little detail.

In the interview, the instructor noted that she started with ecology for the beginning of the nine-week course because:

> It's kind of nice to start with the ecological things, because it kind of hooks them a little bit. Um, you can kind of relate it to things that they have seen on television, or you know documentaries, or even movies like "Finding Nemo" and things like that. You kind of get them a little interested. And, we had already discussed some of the ecological, um, you know, food webs, you know, things along that line, it's a kind of place for them to put a lot of things into perspective.

She also noted that the beginning of their text is a chemistry introduction, which is not particularly motivating.

Lack of motivation on the part of her students is one major concern for this instructor. Of the twelve questions posed to her within the interview, motivation is a reoccurring theme in nearly half of her responses, either directly or indirectly. In this response, she answers the question regarding the challenges the students might have:

> Unfortunately for them, they kind of feel like they know what is going on during lecture, some of them do, some of them don't. It would be nice to go over things that evening after class, try to do the study questions, go over this before that gets away from you. But, I think unfortunately, schedules, etc..you know a lot of them, don't end up doing that. I think, you know, repetition is probably my first strategy, um, in lecture.

She elaborates further on her perspective of a strategy for learning content material within the course:

> Um, in terms of things that they have available to them, you know I always say textbook is something, etc…but I really preach to them to read the chapter before they walk into lecture. Lecture goes pretty fast. A lot of students think they will go to lecture and they, and they will try to read it all before the exam, and think that's going to help them. That's the first thing, read the chapter before you come….

Considering how students may actually study for the exams, using the materials provided, the instructor made this statement:

> …. I want them to not, just be reading their notes, but to ask themselves, do I actually understand this. And, so, my study questions are sort of a way, to hopefully test themselves. Um, before you know, they come back to lecture, did I really understand this? Now, unfortunately, the way some of the students do it, they probably, ah, look at a study question, look it up in the notes, and that is as far as they go…I also try to encourage them, to you know, check their answers, but I don't post the answers, because I think that, if I did that, then they would do even less, in terms of work. I think they would probably just study the answers, and would never try to work on it on their own.

The instructor chose an approach to content based upon motivation with attention to the diversity of their pre-college science backgrounds. She was aware of the multiple ecological levels of detail within the topics, and makes this comment on balancing interest with understanding:

> …. I try to explain one thing at a time. Sometimes there are diagrams that has everything in there, but I mean a lot of times, I try to, you know, I show a big picture and then zero in on one area, and then go back to the big picture and, so they know we're here and then summarize it again for them, at the end.

She also explains this approach by suggesting that it matches her learning style;

> I guess that is sort of the way, um, if I had a question, you know, this would lay it out, and plus I try to figure if it's laid out that way, you know, when they are looking at afterwards, it will make a little more sense to them, when they take a second look.

The instructor included more one-on-one instruction in the laboratory, and the pre-service teachers mentioned the labs as sources for their conception of plant processes. She had designed and written the laboratory activity herself, and had this to say about the approach to instruction used:

> …I kind of like starting out with the pH exercises, we just had started talking about pH in lecture, so they should already kind of know what it is, but they kind of need a little reminder, and by sort of doing that beginning exercise, it doesn't seem to change color, it sort of sets them up to see, well, CO_2 that did this in the

> cup, so that happens to the corn CO_2, sometimes that worked for them. I know, our corn seedling experiment didn't work all that well this semester, but sometimes it has worked pretty well, and I notice a light bulb, "oh, this plant did the same thing when we breathed in, so the plant is doing the same thing."

The reference is to the laboratory activity with the corn seedlings. Ann had used that experience during her cognitive interview to justify her ideas about plant cellular respiration. Ann questioned if cellular respiration in plants was restricted to the seedling phase. She used these ideas as the basis of "research" with her instructor regarding cellular respiration. The instructor did seem to have an intuitive ability to perceive student challenges within the laboratory.

The instructor also recognized the potential of "too much information" within the lab context as evidenced by this comment:

> …sometimes I think I have too much going on in that lab, there are things I need to cut out a little bit, for some of them to get the, to get the, message.

When asked twice about the challenges and difficulties that the pre-service teachers faced during the instruction on photosynthesis and cellular respiration, the instructor hedged the question, at one point saying:

> You probably have a better impression of that, after all of your interviews, than I do.

However, she was able to articulate her goal for pre-service teachers to have a broad view of the two processes upon completion of the course:

> I would hope, you know, they get the big, the big take home messages, that I try to drive home, in terms of where do you breathe in oxygen, what does photosynthesis mean in terms of the whole ecosystem, and why do they have to learn about electrons, you know, some of these bigger issues.

When asked if she thought the pre-service teachers viewed the processes as being part of an ecosystem or a biological system in general, her response was:

> I hope so, I mean that I hope they see that. That this is an entrance point for energy within the ecosystem. I've said it enough…, um, but you never know if this is something that they ever really take home. In terms of respiration, I think I try to take in terms of this is everything all cells do, you know, to live. This is how you get your energy. You try to relate it to why will you die if your cells die, have no oxygen. Well, sort of why, and you'll know the answer if you try to think about some other parts of this.

The instructor related to the researcher in her interview that she hoped the pre-service teachers would view the plant processes as being set in the context of the ecosystem. The pre-service teachers were able to articulate a purpose for the photosynthesis at the ecosystem level, but the purpose was corrupted by a view of plant dependency on humans. The pre-service teachers did not conceptualize the plant as an independent biological system.

In general, the instructor provided an exceptional laboratory experience for the pre-service teachers in terms of connecting the two plant processes. She lectured to them prior to their laboratory, and provided them with supplementary materials to guide their thinking. The goal for the topics from the instructor's perspective was one of understanding the broad "picture" without losing too many details. She was very concerned about their level of motivation towards the topics and their preparation for the evaluations.

The instructor was unaware of science education reforms regarding a systems approach to instruction. There was evidence in her interview that she was becoming aware of the learning concept of constructivism. She understood the value of the lab, but apparently had not internalized why her students might learn more from lab activities than from the text or lecture.

Conclusion:

The pre-service teachers' conceptions in this study fell generally into three major themes: egocentrism, interdependency, and societal needs. Plants are important because they provide many useful services to me (egocentrism), so I must care for them (interdependency) and my caring will benefit society as a whole (societal needs).

Conceptions specific to photosynthesis and cellular respiration were divided into categories, reflecting the pre-service teachers understanding of the processes. Five pre-service teachers knew little of either process despite their instruction. Ten participants viewed photosynthesis as the energy process, and eight saw cellular respiration as gas exchange. Photosynthesis was viewed as a complimentary process to humans' cellular respiration, although all participants knew that plants also respire.

Instruction focused primarily on the biochemical ecological level. The context of their instruction was explicit towards connections, but participants' were unable to conceptualize the mechanisms connecting the two processes. Only four pre-service teachers were able to articulate conceptions about the two processes at all ecological levels, although none were scientifically accurate in their descriptions.

Chapter 5: Discussion and Conclusion

The results of this project in view of prior research findings are discussed in this chapter. The chapter offers a model of the pre-service teachers' conceptions on the two plant processes with the potential for considering curriculum development. In the final sections of the chapter, limitations of the project are discussed, as well as recommendations for future research.

Pre-service Teachers Conceptions of Photosynthesis and Cellular Respiration:

In this project, the pre-service teachers attended biology class Monday through Friday for nine-weeks during a summer session. As a laboratory assignment, they participated with a partner in an explaining set involving the two plant processes. During the explaining set, the pre-service teachers verbalized their conceptions of photosynthesis and cellular respiration. Some of their conceptions may be intuitive, and not fully developed. The pre-service teachers compared plants to humans, and applied human characteristics, such as "parenting" skills to plant components.

Misconceptions noted by earlier researchers were observed in this sample of participants, despite instruction that presented the two processes as energy reactions, and as connected. The conceptions identified here may be considered misconceptions, based on their persistence even after instruction. Misconceptions differ from the conceptions held by scientists, and in this circumstances, the pre-service teachers' naïve conceptions regarding photosynthesis and cellular respiration seem to have not been restructured during instruction. Classroom instruction during the research was not confrontational and there was no evidence of dissatisfaction or questioning (Posner, et al, 1982) of their conceptions by the pre-service teachers. They apparently assumed their conceptions to be scientifically accurate.

The processes were not presented either in lecture, or laboratory, as problems in need of a solution. There was no evidence that the pre-service teachers attempted to self-assess their conceptions. The combined single equation of the two processes provided by Jay, for example, is apparently more intuitive than the scientific model. Jay's equation is logical if cellular respiration is considered the gas exchange reaction, and photosynthesis the energy reaction. Combining the reactions into the removal of carbon from carbon dioxide to be used in the production of the carbohydrate, and the immediate release of oxygen from CO_2 coincides with the perceived purposes of each reaction. The intuitive simplicity of a single equation may explain why participants chose it despite its inaccuracy. An equation that provides for energy directly from the sun may be more sensible to the pre-service teachers than the scientifically acceptable conception of two processes. Instruction may need to explicitly highlight the source of each product within both reactions. Carefully tying each product to a specific location, and tracing both reactants and products through the entire process may help the learner restructure their conception. In a systems view, inputs and outputs should be accountable.

The prevalence of Jay's equation, held by at least two other participants, provides evidence of an intuitive search for simplicity. It is much easier to discount details on food, energy, carbohydrates and glucose, when a perceived biochemical equation does not require the distinction. Subtle differences are not necessary in the simpler conception of one equation that removes the oxygen from carbon dioxide and uses the carbon to form glucose from water. As suggested by Simpson and Arnold (1982), conceptions can still be wrong but hold great meaning for the user. With their egocentric and sociological views, the pre-service teachers may have perceived plants as being simpler or less complex organisms than humans. They viewed plants as dependent on humans for their survival. The pre-service teachers' responses indicated plants needed to be watered, fed, and cared for by humans. Carbon dioxide produced by humans was viewed as beneficial. A more accurate view would be a human dependence on plants for survival. Plant dependence on humans is limited to a few horticultural varieties.

A similar argument can be raised for participants' conceptions involving the multiple ecological levels. The pre-service teachers seemingly chose an ecological level of "comfort" that they rarely moved beyond, even when asked. Despite instruction centered primarily on the biochemical ecological level, they focused on the organism and ecosystem levels. Simpson and Arnold (1982a, 1982b) suggested pre-requisite information could be lacking. Stavy, Eisen and Yaakobi (1987) and Eisen and Stavy (1988) specifically concluded a lack of chemistry knowledge prevented the understanding of biological processes. These researchers speculated that use of the concept element as a component rather than a chemical element such as carbon attributed to misunderstanding of biological processes. However, ten of the participants in this study had high school or college-level chemistry. One was taking a college level course concurrently. While it is unknown if participants in this project confused the concept of element, it seems doubtful with their prior chemistry experience. It must be recognized that course enrollment and successful completion are not necessarily indicators of meaningful conceptual understanding. However, only a few participants lamented their inadequate science background. At least four had taken prior biology courses that should have had included explicit instruction in systems.

Instruction may need to be sequenced carefully to consider pre-requisite information. It may be appropriate for instruction to begin at the ecological level of most interest to the learner, and use frequent explicit signposts when moving between ecological levels. Such careful instruction may alleviate confusion of element in referring to system components with its use at the biochemical level.

Rather than a lack of chemistry knowledge the pre-service teachers may have been prevented from their understanding of the processes by their inability to view the plant as a biological system. Chemistry concepts may have seemed irrelevant to these participants without explicit system purpose. These participants attached “a service to humans” purpose to the chemical reactions. The biochemical level substantiated their egocentric view that plants produce oxygen, and take up carbon dioxide to assist human needs. Subsequently both processes could not be connected to energy. They were seemly unaware of the energy connection of cellular respiration, classifying the reaction as gas exchange.

This study focused on the pre-service teachers’ conceptions of photosynthesis and cellular respiration. The results confirmed that these pre-service teachers hold the same or similar conceptions of the two processes that were noted by other researchers in studies nearly twenty years ago, involving participants of various ages. See Table 9.

Table 9
Misconceptions Revisited

General Category of Misconceptions	**Researched Student Conception**	**Researchers**	**Present Project**
Photosynthesis- Food	Food for plants comes from the soil	Bell (1985); Boyes &Stanisstreet, (1991)	Yes
	Plants take in food from the outside environment.	Bell (1985); Anderson *et. al*. (1990);	Yes
	Food for plants includes fertilizer, sun, and water.	Bell (1985); Boyes &Stanisstreet (1991)	Yes
	Plant tissues are made from food plant receives from the soil.	Bell (1985); Simpson & Arnold (1982b);	Yes
Photosynthesis-Gases	Plants do not use air.	Bell (1985)	Majority failed to list air within components.
	Plants use air in the opposite way animals use air.	Bell (1985); Canal (1999)	Yes

Table 9
Misconceptions Revisited-Continued

General Category of Misconceptions	Researched Student Conception	Researchers	Present Project
Photosynthesis-Light	Plants always need light to grow. /photosynthesis doesn't take place continuously.	Bell (1985); Hazel & Prosser (1994).	Not presented
	Plants need light for health and color.	Bell (1985)	Yes, one participant
	The role of chlorophyll is to make leaves green, break down starch, or absorb carbon dioxide.	Bell (1985); Simpson &Arnold (1982a);	No, chlorophyll rarely mentioned.
Respiration	Respiration is gas exchange	Bell (1985); Simpson & Arnold (1982a); Anderson *et. al*. (1990); Sanders (1993); Canal (1999)	Yes
	Plants respire through stomata on leaves.	Sanders (1993): Canal (1999)	Only two students mentioned stomata.

Table 9
Misconceptions Revisited-Continued

General Category of Misconceptions	Researched Student Conception	Researchers	Present Project
Respiration and Photosynthesis as combined processes	Respiration occurs only at night or when photosynthesis is not taking place.	Bell (1985); Sanders (1993)	Not addressed in this project.
	Digestion is the energy releasing process of animals and plants.	Bell (1985); Simpson & Arnold (1982a); Sanders (1993); Boyes & Stanisstreet, (1991)	Not addressed in this project.

Table 9
Misconceptions Revisited-Continued

General Category of Misconceptions	**Researched Student Conception**	**Researchers**	**Present Project**
Respiration and Photosynthesis as combined processes	A source for energy for plants includes water, soil and fertilizer in addition to the sun.	Anderson, *et. al*. (1990); Boyes &Stanisstreet (1991).	Yes
	Students successfully completing high school chemistry could not interpret simple chemical formulas and equations.	Anderson *et. al*. (1990)	Not addressed in this project
	Plants do not respire. (Photosynthesis is the process that provides plans with the energy they need for life processes)	Sanders (1993); Boyes & Stanisstreet (1991)	Yes, one Equation model.

Table 9:Misconceptions Revisited

Discussion of Conceptions:

A few of the questions found in table 9 were not specifically addressed in this study. Even so, participants provided evidence that they held similar conceptions. For example, Natalie described the plants as “eating.” Several of the pre-service teachers suggested that cellular respiration is secondary to photosynthesis. A few suggested the two processes took place at different times.

Stavy, Eisen &Yaakobi (1987) and Eisen & Stavy (1988) concluded in their research that students failed to recognize their bodies as chemical systems. This study seems to support that research. The majority of the pre-service teachers failed to recognize the plant as a biological system, dependent on both photosynthesis and cellular respiration for energy. The majority also failed to recognize the “nested systems” of which the two processes are components. It may be that recognizing oneself as a system, composed of components with specific inputs and outputs, is crucial to understanding analogous processes in other organisms.

This study suggests the pre-service teachers’ conceptions may be compartmentalized. Rather than conceptualizing the processes as a series of biological systems, with the purpose of energy exchange, they were only able to conceptualize on one or two ecological levels. Compartmentalization allows the dependent conception to remain unchallenged. The plant is not viewed as an independent system, which does not need human care. Instead, compartmentalization promotes a view of plants needs being met by other organisms within the ecosystem when only the organism and ecological view are focused upon. Ekborg (2003) concluded that pre-service teachers’ conceptual understandings are too superficial. That conclusion fits well with the nominative knowledge observed within the current sample.

The pre-service teachers in this sample identified nutrients from the soil as being the primary source for new plant growth. Other researchers (Anderson *et al.*, 1990; Ozay & Oztas, 2003) have shown that even with guided learning strategies specifically designed toward conceptual change, children do not link carbon dioxide as the source of growth for new plant material. Even when participants were given the biochemical equations, they did not include CO_2. Perhaps the biochemical equation did not translate to the higher organism level. One participant could only discuss plants at the organism level. The chemical reactant CO_2 may not have been seen as necessary. If the reactant had been written as “carbon dioxide” it may have been more acceptable at the organism level. Participants may have had difficulty translating the symbolic CO_2 to the phrase “carbon dioxide.” Because CO_2 was discussed as a reactant in their classroom, participants may have compartmentalized CO_2 as being exclusively at the biochemical level. Use of the symbol “CO_2” as opposed to “carbon dioxide” may have prevented the pre-service teachers from moving the associated freely between biochemical and organism levels. This is difficult to determine without a more in-depth investigation of chemistry knowledge of these participants.

An understanding of carbon dioxide and the symbolism of CO_2 may be a pre-requisite to movement from the organism to the biochemical level. It may have been appropriate for instruction to assess prior to moving to the biochemical level if the symbolism associated with the chemical equations had meaning.

Participants within this project also had difficulty with the concept of energy. At least one pre-service teacher confused energy with oxygen, suggesting that she thought of them as synonymous. In their instruction, the need for oxygen to produce energy through the Kreb's cycle and electron transport system was stressed which may have lead to the confusion. Researchers Boyes and Stannistreet (1991) concluded that energy misconceptions are not always noticed in a classroom setting. Without assessment of prior knowledge (as suggested by Barker and Carr, 1989a), the instructor had not likely noticed the interchangeable use of energy and oxygen.

Instruction and Conceptions:

A value of science education research is to view conceptions within the context of instruction. This does not necessarily imply that conceptions begin with classroom instruction. Instead the context of instruction provides one view for potential conceptual development. Prior documentation of misconceptions has sought origins for misconceptions within instruction, including language and analogies. Language interpreted may give alternate meanings than the instruction intended. Textbooks may be a source of confusion if misconceptions are not explicitly addressed. Expecting vocabulary proficiency while rapidly changing ecological levels may be exceptionally challenging.

Language and Categorizing:

Stavy and Wax (1983) concluded that conceptual difficulty could be partially attributed to language. In their study of Israeli children, the Hebrew language was focused on. It includes verbs for plant growth and death that are distinctly different from those for animal growth and death. Animal verbs in that language were similar to the words used for living. The Hebrew term "CHAIm" is similar to the term "davar CHAI" which is often applied to a living organism. In this project, the only language difficulty observed was the participants' attempt to keep pace with vocabulary introduced during instruction. Contrary to the approach suggested by Arons (1990) of introducing the concept before the vocabulary, the method of instruction used in this course included the frequent introduction of new vocabulary. The pre-service teachers made numerous errors in vocabulary. They incorrectly and inappropriately applied terminology introduced through instruction. They struggled to apply scientific vocabulary to their conceptions of the plant processes. ATP was simply a vocabulary with no apparent connection to energy needs.

The text used by pre-service teachers in this project used appropriate vocabulary, in the judgment of the researcher. The processes were described in the context of energy reactions, and each chapter transitioned to the next using a narrative approach. Unlike many textbooks at this level, vocabulary introduction is not a major focus. Although vocabulary introductions are in a “bolded” font, the text does not seem vocabulary intensive. This finding contradicts prior research (Barrass, 1984; Storey, 1989, 1991, 1992) in their investigation of textbooks inappropriate use of vocabulary as a source of misconceptions.

Instruction did focus on attainment and application of vocabulary, and participants tried to follow. The pace of instruction and the amount of vocabulary may have been very challenging. Participants’ use of vocabulary made the interpretation of their explanations for the two processes very challenging. Vocabulary emphasis in addition to rapidly changing focus to multiple ecological levels likely left participants to choose ecological levels based on individual vocabulary attainment.

The instructor’s use of the phrase “opposites” when comparing the two processes may have also been a source of misunderstanding. It was clear to the researcher that each use had a referent at the biochemical level, but it was not as clear that the pre-service teachers recognized the referent. They may have extended her thought to an application at the organism level. This would explain why they seemed to feel one process occurs in animals and another in plants. They may have misconstrued that one process occurs only in sunlight, the other only in the darkness. A few pre-service teachers with nominal process knowledge repeated the phrase “they are opposite.” Canal (1999) details the potential for fostering misconceptions by the use of the phrase “opposites” in reference to both processes.

As Chi *et al.* (1994) suggested it appears that even with direct instruction some misconceptions are more difficult to change than others are. In this project, the instructor told the pre-service teachers that the two processes were connected. She explicitly told them cellular respiration was an energy reaction. Yet, the majority could not explain the connection, and viewed cellular respiration as a gas exchange reaction. Energy (as cited previously by Chi, Slotta & deLeeuw, 1984) was a challenging concept for the pre-service teachers, a few even confusing it with oxygen. They may have considered energy as matter, as had been noted by Chi *et al.* (1994). If energy is seen as matter, then the conception of oxygen and energy being the same has greater credibility. Both energy and oxygen are viewed as substances that a plant needs to survive. Cellular respiration becomes the process by which the plant uses oxygen, and photosynthesis becomes the process by which it uses energy. Neither concept was specifically addressed in either the instruction or evaluation in this instance.

Experiences and Analogies:

Leach, Driver, Scott and Wood-Robinson (1996) noted a slight change after instruction on the use of CO_2 and O_2 by plants. In this project, even after a laboratory experience designed to demonstrate the production of carbon dioxide, only two participants mentioned cellular respiration when asked what was happening within the plants during the observation period. Their first introduction to the two processes was cellular respiration. The pre-service teachers focused on the oxygen portion of gas exchange, which was nearly always described as being in service for humans. In this study, the instructor introduced cellular respiration before photosynthesis, and provided a laboratory experience to measure carbon dioxide output. The pre-service teachers still conceptualized plants as releasing oxygen.

The instruction is this course centered on two analogies to teach these processes. Both were also advanced in the textbook. Barker and Carr (1989a) warned against the use of analogy in teaching these two topics. They felt it lead to more misconceptions. It is not clear in this project if the two analogies were beneficial in forming their individual conceptions by the pre-service teachers or if they served to confirm prior misunderstandings.

Evaluation of the pre-service teachers' understanding of the two plant processes focused primarily at the knowledge level. Exams emphasized vocabulary knowledge over application. The participants seemingly did the same. They attempted to use vocabulary presented to them in class, often with erroneous results. This evidence negates the idea of motivation raised by their instructor. Participants seemed to work toward meaningful understanding but were challenged in their efforts. Questions of strategies for studying were not directly asked of the participants. Those who volunteered admitted they had not prepared for an interview with questions of any depth. Whether participants studied for their level of evaluation (knowledge) or whether they had not studied at all, or had studied inappropriately, was difficult to determine. Their instructor centered on the textbook, mentioning it numerous times in lecture, and referring to its use during her interview. However, there were only a few citations of the text by the pre-service teachers.

There was no evidence of instructional intent to move from the more concrete organism level to the more abstract cellular and biochemical levels. Instead, instruction centered primarily on the biochemical, and did not include information about system relations that might have detailed the application to the organism and ecosystem levels. The textbook chapters on the organism level were among the few chapters not read during the session (Appendix I). Instruction assumed prior knowledge that was not in evidence.

Overall, in this project, there were a few potential origins for the pre-service teachers' conceptions on photosynthesis and cellular respiration. Instruction did not challenge participants to construct their own knowledge and, subsequently, knowledge regarding the two processes may have remained at a fragmented or intuitive level. Analogies used in class may have also contributed to the confusion observed. The evaluations, which held them accountable for their conceptions, focused on a knowledge level. The textbook proposed a reductionist view of biology. At best, the context of their instruction presented the pre-service teachers in this study with an implicit perspective of a biological system. Instruction did not clarify components, interactions, input and outputs of systems, which make biology so challenging to understand.

Justifications for Their Conceptions:

The pre-service teachers in this study cited their everyday experiences as a primary source of information about plants at the organism level. Despite Ausubel's suggestion that the "most single important factor influencing learning is what the learner already knows" (Mintzes, Wandersee & Novak, 1998, p. xix) prior knowledge was never accessed. Some conceptions the pre-service teachers held regarding the organism level were scientifically inaccurate. Seven participants did not understand the function of leaves.

Participants in this project did not often venture beyond authoritative reasons for their responses. When they did, their reasoning was frequently inappropriate to the situation or was difficult to interpret due to their inaccurate use of vocabulary. Natalie said she "experimented for years" to find a cause for her ailing African violet. Yet, she provides no detail of her experimentation and no evidence of controlling variables that determine the response. Jungwirth (1987) suggested that the educational system forces students into blind memorization. It appeared as if the pre-service teachers in this study might have been influenced by that strategy.

Tamir & Zohar (1991) documented other reasoning modes with examples of teleology, anthropomorphism, and tautology. These authors suggest that such reasoning modes may be intuitive. Within this project, all of those reasoning modes were documented. The pre-service teachers seemed unaware that the justifications they provided were unscientific. However, if made aware, it may be possible to use intuitive conceptions to move their reasoning to that which is more scientific.

Instruction should consider Posner *et al.* (1982) suggestions for conceptual change. Jay's one equation for both processes suggests that it will be difficult. The learner must first be dissatisfied with his or her own conception. It will be challenging to ask the learner abandon their simple equation in favor of a complex set of counter-intuitive chemical equations regardless of their accuracy. An historical approach to photosynthesis and cellular respiration is one option for instruction. Another is to assign active investigation to the learner to explore pathways for each component (reactant and product) of both equations. A learner may be asked to follow a particular atom of oxygen from the atmosphere through the plant, and ultimately to be released in photosynthesis. A similar instructional strategy is used in following oxygen in the closed circulatory system. Such a systems approach hopefully will prevent the compartmentalization evidenced in this study.

Once dissatisfaction with the simple equation is achieved, it is important to strive for understanding of the new conception. Instructional strategies that strive for understanding can be employed, such as concept mapping. Posner *et al.* (1982) suggests the third and fourth conditions (being plausible and useful in new situations) may be essential for movement toward the more scientifically accurate conception. Directed problem solving, such as comparing the naïve conception with the newly formed conception in activities which show disruption of either plant process, may assist the learner in moving toward the scientifically accepted conception.

If conceptions of plants include a belief that plant life is dependent on humans, then posing questions asking for consideration of an evolutionary approach to thinking about the two processes may have some merit. How did plants exist on the planet before there were humans? Are there some plants that do not require human care? Can plants exist in areas no longer inhabited by humans? These questions may have been particularly relevant to this sample, because they focused on the organism level.

The pre-service teachers' conceptions of these two plant processes included an egocentric perspective. Participants talked about "our atmosphere" and "our oxygen." This view may be intuitive and, when considered through another framework, may assist in identifying the plant as a biological organism. If an analogy was made between our needs (inputs) as a biological system and resulting outputs, then analogous components may help identify connections between analogue and source (Theile & Tregust, 1995). If the pre-service teachers already analogize the human need for oxygen to the plant's need for carbon dioxide, a comparison of human system to plant system seems a logical step. Instruction could focus on a more accurate comparison, drawing distinctions between the two where the analogy breaks down.

diSessa (diSessa, 1981; diSessa, 1998; Smith, diSessa & Roshelle, 1993) might suggest that egocentricity, even when considering nonhuman biological organisms, is intuitive. Humans may intuitively measure other organisms by the qualities they themselves possess. In some situations, the organism compared may seem similar, and the intuitive notion may be "like me." The learner can determine how the non-self organism functions by this connected mechanism. This notion of "like me" can be integrated into the reality of the organism being studied. As more empirical information is gathered on plants, the intuitive notion of "like me" can either be used as a foundation, or can be rejected. The learner can select "plant experiences" and integrate those experiences into a "coordination class" (diSessa, 1998), which is cued whenever ideas about plants are needed. This mechanism is then useful for gaining more information about the world, either to confirm or refute information gathered in the coordination class.

Such an approach differs from the more simplistic notion of comparing the two-biochemical equations of photosynthesis and cellular respiration as opposites. “Opposite” may convey to the learner a more holistic rejection of the plant system at multiple ecological levels than is intended (Canal, 1999), evidenced in this study by Bob’s comment that plants and humans do not use the same atmospheric gases. Bob may have generalized the presentation of opposite biochemical reactions offered in instruction to the organism level.

Intuitive notions are likely developed prior to any instruction. diSessa refers to them as “sense of mechanism.” In the physical world, these notions are often generated from common experiences with how the world works. Southerland *et al.* (2001) has advanced the idea that elements of mechanism (called p-prims or phenomenological primitives as they arise intuitively from events) also exist in the biological world. The pre-service teachers may have an intuitive sense of the need to reference humans when considering plants. It may be a “self as first referent” p-prim. This p-prim turns inward first, to previous human experiences, when learning about non-human organisms.

Justifications Related to Instruction:

This project was based in the context of instruction. The logic that the pre-service teachers provided as justification of their responses, suggests a “common sense” view. Ekborg ‘s research (2003) suggested that pre-service teachers used “common sense” logic on surveys, and in interviews, when taken out of the context with their instruction. When instruction focused on the more abstract cellular and biochemical levels, the concept of cellular respiration as an energy reaction was diminished. Cellular respiration became a gas exchange reaction conforming the intuitive conception of respiration in humans. Apparently, the pre-service teachers used a “common sense” view even within the context of their instruction, when the topics are on multiple ecological levels and challenging to explain.

Sanders (1993) investigated teachers as a source of misconceptions. The instructor in this project was not investigated for misconceptions, nor did she reveal misconceptions during the study. Her use of analogies and specific phrases may have potentially been origins of some student misconceptions. Taught misunderstandings, if not clarified through further instruction, may hinder movement toward a more scientific conception.

One analogy drawn was of ATP to currency. The instructor referred to the “spending of energy currency” in reference to the breakdown of ATP and the formation of ADP. The second was the reference to molecules NAD and NADP serving the processes as “electron taxis.” The two analogies were repeated throughout the duration of the field observations. They were not explained in detail, nor were there any analogue mapping showing the analogue fit or did not fit the source. Such instructional strategies, as suggested by Thiele &Treagust (1995), avoid over simplification and confusion. These researchers recommend that analogies be cautiously provided in texts. Once in print, a sense of credibility is established, needing careful elaboration through instruction as to where the analogy breaks down. In this study, neither the instructor nor the text provided a map of either analogue to its source. Instruction did seem to assist the pre-service teachers in reasoning through the analogies.

Researchers (Barrass, 1984; Storey, 1989,1991,1992) suggest that textbooks may influence understanding of biological processes. In the textbook the participants in this study used for their course work, the text provides only an overview of the nature of science. It contrasts briefly biology and physics, suggesting biology became a science when the focus switched from “describing the forms in the living world” to describing the “rules of the living world” (Krogh, 2002, p. 14). The text draws no distinction between the challenges of studying a biological system versus that of a physical system. The author has seemly chosen a reductionist view to biology. Chapter two’s major introductory statement gives further evidence to this concept: “Life is carried on through chains of chemical reactions” (Krogh, 2002, p. 19). In an attempt to balance the classical descriptive biology of early naturalists and the need for empirical data gathering in the sciences, the author focuses these chapters on the biochemical and cellular level of the plant processes. The reductionist view expressed by the author of the text may be partially responsible for the compartmentalizing of thought into specific ecological levels observed in this study. Participants who focused at the biochemical or cellular level for their explanations may have been cued by their text. Other participants who focused primarily at the organism or ecosystem level may have been less influenced.

The Systems View:

Only two participants held a systems view of either process. Most of the pre-service teachers may have compartmentalized the two processes. Whether they chose their levels based on comfort with the vocabulary presented, level of understanding, or another criteria is not known. Waheed and Lucas (1992) noted students had greater understanding at the ecosystem level. There is evidence in this project that the pre-service teachers focused slightly more on the organism level. This focus on the organism might be considered an artifact of the methodology in the project. Plant props were used during the explaining sets and cognitive interviews. However, even during the clarifying interviews, participants focused mainly on the organism level, despite being provided details of other ecological levels. The next level of focus by participants was the ecosystem. That focus may have been a result of instruction on ecosystems that preceded the lessons on photosynthesis and cellular respiration.

Waheed and Lucas (1992) suggested that an understanding of photosynthesis must be set within the context of the environment, and include an understanding of the interactions taking place. Their population included students fourteen and fifteen year of age, and all of whom had studied photosynthesis. The researchers concluded that while 93% understood the ecological level, only 20% understood the energy change level. Physiological levels were 57% and 68% respectively. In their study involving fifty-six students, only five had understanding of the process at all four levels.

The current project differed in both method and result. The pre-service teachers were interviewed, in the context of their instruction on photosynthesis and cellular respiration. Instruction used an energy perspective, explicitly tying both photosynthesis and cellular respiration. Both text and instructor implicitly referred to multiple ecological levels. Nearly all of the participants regarded photosynthesis as an energy reaction. Only three participants recognized cellular respiration as an energy reaction. Waheed and Lucas (1992) suggested there should be less understanding of photosynthesis as an energy reaction, as it is often cited for oxygen production. In this study, pairing the two processes together in instruction may have provided a clearer choice that one of the two must be an energy reaction, with cellular respiration being the logical choice as the gas exchange reaction. Or, it may simply be that the pre-service teachers in this sample were older learners than those in Waheed and Lucas' sample, with more reinforcement through instruction of photosynthesis as an energy reaction.

When participants considered multiple ecological levels, the results were mixed. It would seem logical that understanding the processes requires having scientifically correct information at the organism level. Only five of the pre-service teachers in this study had an accurate understanding of the function of a leaf. Waheed and Lucas (1992) applied criteria for "strong evidence", "weak evidence" and "no evidence" in their research to evaluate the understanding of multiple ecological levels. Their definition of "strong" was that "students have mentioned all of the key ideas" and have "shown no misconceptions" (p. 194) Using this definition, no pre-service teachers in the current study fell within the strong category. All revealed evidence of misconceptions with respect to levels.

In the category of "weak evidence", Waheed & Lucas (1992) included "those that had a misconception with the key ideas" (p. 194) but had evidence of recognizing key ideas. Three pre-service teachers (Ann, Bob and Nan) had evidence of recognizing key ideas, but had misconceptions at one or more of the levels. The remaining participants either provided no evidence of understanding key ideas at one or more of the ecological levels, or had more than one misconception within a level.

Waheed and Lucas (1992) concluded their participants had greater understanding at the biochemical level than at the anatomical and physiological level (comparable to the biochemical level within this project). This was not the case with the participants in this study. Several pre-service teachers had no evidence of understanding at the biochemical level (See Table 4). One must be cautious however, in comparing these pre-service teachers with the sample investigated by Waheed and Lucas. Those researchers used only four questions, and their students responded in writing. The pre-service teachers in this study gave oral responses and the questions probed more in depth.

In this study, the participants focused the majority of their conceptions at the organism level. The organism level has the least abstraction. Participants physically touched the plants and their leaves. The participants did not physically manipulate levels above and below the organism level. There were no field trips to connect plants and their functions to the regional ecosystem. The global level probably had greater abstraction than the ecological. Participants also did not directly view the cellular level, although they did hear about cell components in lecture. The biochemical level may have been more abstract than the cellular, being without a specific location, even though the instructor discussed these two levels most frequently.

While caution must be taken in interpretation of the data (see table 4), results contradict the instructor's conception of an apparent lack of motivation by the pre-service teachers. In her interview she suggested that there were students in her class who did not care at all. Based on the analysis of the participants' understanding at multiple ecological levels six of the eighteen attempted to conceptualize the plant processes at the level of their instruction. Importance was apparently derived from their instruction, and they attempted understanding the processes at those abstract levels.

The pre-service teachers of this project also displayed a weak understanding of the connections. In Lin and Hu (2003) interactions identified were between energy flow and matter cycling on two different ecological levels, the organism, and the cellular. In this project, the pre-service teachers focused more on the organism, than on the cellular level. The closest analogy to Lin and Hu's (2003) concept of connections was the connection perceived between the two processes by the participants. During the cognitive interviews, only two pre-service teachers thought plants might be respiring as well as photosynthesizing. Of all the pre-service teachers who responded affirmatively to a connection between the processes, only two provided any explanation. When asked about a potential disruption of the two processes, the pre-service teachers conceptualized photosynthesis as being of primary importance, with cellular respiration being secondary.

Lin and Hu (2003) suggested that biology is a very difficult subject to learn, as it requires three dimensions of thought- macro, micro, and symbolic. It would seem logical that instruction should begin at the level where learners naturally are more focused, the macro level. The authors conclude that learners disconnect from the physical sciences, and that teachers should find more "everyday life" examples to motivate and enhance exposure to biology as an integrative science. Reactions from the pre-service teachers in this study suggest that much of their information about a plant as an organism came from direct experiences, giving merit to the suggestions of Lin and Hu (2003). The pre-service teachers also disconnected from the physical sciences. Gases involved in the two processes were mentioned less than any other as a condition of plant growth.

In this project, there was evidence that at least three pre-service teachers had difficulty conceptualizing photosynthesis and cellular respiration as processes set within the organism. Barak *et al.* (1999) suggest that matter-based language is indicative of a simplistic understanding and also that learning photosynthesis is relatively simple in comparison to other complex interactions within the biological sciences. Matter-based language would suggest that learners do not as yet have a conception of biological processes, and place such processes in the ontological category of matter. Participants in this study showed confusion over the term “cycle” adding the descriptive adjective “life“ when referring to organisms in a food chain. Their use of the phrase “life cycle” raises questions as to their understanding of phrases such as Kreb’s and Calvin cycles. It is not known if the pre-service teachers in this study regarded the photosystems as structures or as processes within the photosynthetic reaction. Participant’s use of the phrase “electron transport chain” was also unclear. They could have been using the term “chain” as either a physical structure or as a process. So few pre-service teachers used these phrases during interviews that it is difficult to draw a valid conclusion. Their confusion over vocabulary does strongly suggest a simplistic understanding.

While Barak *et al.* (1999) recommends an explicit approach to systems, the instruction in this project was more implicit. While forty percent of the participants in Barak’s sample were able to connect photosynthesis with the ecological pyramid, there was less evidence of that connection in this project, specifically at the biochemical level. However, fifty percent of the pre-service teachers who drew meta-representations suggested the plant had an energy relationship with the ecosystem. An examination of the differences in levels reinforces again that the pre-service teachers were focused at the organism level and were likely compartmentalizing the reactions. It may be important in instruction to center the learner at the organism level first, prior to moving towards the more abstract ecological levels.

Results expand on Carlsson's (1999) level 3 category of photosynthesis conceptions. Level 3 includes those conceptions that suggest that plants respire, and are more or less "self-sufficient." Carlsson regarded this level as evidence that pre-service teachers had a deeper understanding of systems with the plant being viewed as an intact biological system. In this project, with three series of interviews, more information is provided. The pre-service teachers did conceptualize that plants respire. This is evidenced by responses to questions of processes being connected, a perspective consistent with their instruction. They did not know how plants respire; nor did they view the respiring plant as an independent biological system. Instead, they conceptualized the plant as being dependent on the actions of humans. At best, they conceptualized that relationships within their ecosystem are interdependent. This may be an important first step toward understanding. A few pre-service teachers even felt that plants needed our CO_2 for these processes. The pre-service teachers also conceptualized plants as being dependent on other organisms for survival, particularly for reproduction processes such as seed dispersal and pollination. These results expand descriptions of category 3 by suggesting that while the plant may be viewed as being involved in respiration, they may not necessarily be seen as "self-sufficient." The pre-service teachers in this study suggested a dependency.

There was no evidence that the pre-service teachers had the correct conception of the plant as an intact biological organism, independent of humans. Carlsson's Category 4 suggests a conception of photosynthesis as both creating order and resources. Carlsson focuses on energy transformations, and that energy becomes available for other reactions within the system. In this project, Ann recognized that energy is available to other organisms through photosynthesis. She provides this evidence supporting her placement in Carlsson's category 4:

> ….this is the sun, it hits the um, the plants, and they create energy, and then we eat the plants, and then we die, and go back into the soil, and they use the nutrients from the soil from our bodies, and then we eat, and then another person eats them, and it's like a cycle.

Yet, when Ann's conception is examined closely, she has blended two main ecological concepts. She co-mingles the idea of energy flowing through the ecosystem, with cycling of matter "nutrients." Carlsson concludes in her research that recognizing cellular respiration is not crucial to understanding plant photosynthesis as a system. Ann's conception suggests otherwise. If Ann, who had a more complete view than other participants, would have had an explicit explanation of the components and interactions of the plant as a biological system, she may not have interwoven the concept of energy flowing, with the concept of matter recycling.

Carlsson stops short of explicitly suggesting the categories as pre-requisites for full understanding of the processes, nor does she convey that her categories are in an order appropriate for instructional design. Her stated intent is to capture the range of photosynthesis experiences within the selected sample of participants. It seems however, that knowledge of these categories may aid instructional design. If learners were placed through assessment into collaborative groups which included representatives of each category, the potential for fuller understanding may have a greater chance of being realized through social constructivism.

Ontological Categories or Phenomenological Primitives:

Explanations by the participants for their responses were challenging to interpret. They attempted to directly apply vocabulary introduced in instruction, and often did so without success. It was difficult to determine reasoning modes when explanations used vocabulary inappropriately. Teleology and tautology were frequent, but difficult to discern definitively from nominal knowledge of the topic.

However, the pre-service teachers in this sample did provide authoritarian reasons for many of their responses, particularly in answering questions of how the two processes were connected, and how they knew specific details of the processes. There were also a few examples of mechanistic proximate, with suggestions that the plant grew using photosynthesis. There were responses that indicated mechanistic ultimate, suggesting differences between the plants were due to genetic factors.

This project used methodology similar to Southerland *et al. (*2001), and even adapted codes for preliminary analysis. These researchers considered conceptual frameworks, and p-prims, with student groups of varying ages from across the United States. They used cards instead of live plants, and conducted one set of interviews, focusing exclusively on the question of "how" the biological phenomena might be explained. This project, while considering the question "how", primarily limited its focus on two biological processes, rather than the broader scope of the Southerland *et al.* project. While their results suggested that twelfth grade students used more mechanistic proximal responses, their only comparison was with younger students. Mechanistic proximate (Table 7) had only slightly more occurrences than authoritarian reasons.

Southerland *et al.* (2001) noted that some participants explained biological phenomena by suggesting an agent, such as god, or nature. One example of "predetermined" can be noted in Anita's comments about plant pigmentation and their use of specific light waves. She suggested that "with the light using the regular plant, they are allowed to use two certain kinds of color" and when asked what is allowing them, she responds that it depends on the pigment they get, as if pigment were distributed randomly.

While this researcher observed a number of tentative responses from participants, the responses remained relatively consistent throughout all three interviews. Southerland's research concluded that explanations were both tentative and shifted across the various interview prompts. Such shifts were not noted in this project, possibly because of the narrow scope of the topics compared with Southerland's broader range of biological phenomena. Since Southerland *et al.* used as criteria for determining p-prims a shift in reasoning mode, and tentativeness of responses; it is difficult to determine if p-prims were evident among the pre-service teacher's conceptions in this project. Explanations generated during the explaining sets seemed to be spontaneous as peers used "familiar" language when speaking to each other concerning the two biological processes. Some conceptions seem tentative; others displayed confidence in their assertions. As noted in Southerland *et al.* (2001), all are responses to a "how" question. Are these p-prims? That is difficult to determine. If "self-as first referent" is a biological p-prim, then instruction should be designed to appropriately cue its use when scaffolding towards a more scientific conception.

There is some evidence in this project in support of biological p-prims. When asked what would happen if photosynthesis were disrupted, Natalie (designated as N) had this exchange with the researcher (R):

> N: I think the plants would die.
> R: The plants would die?
> N: They would do one of two things, they would die, or they would figure out something new to do.
> R: How would they figure out something new to do? What do you mean?
> N: I have no idea, because somehow they figured out how to do this.

Natalie reiterates her conception of “need as a rationale for change” when she answers the following question regarding a disruption in cellular respiration.

> I think they would die, and then we would all die, because they wouldn’t be producing oxygen. And again, they would figure out another way to do it if they could, if not they would die.

Natalie suggests in her comments that when plants need to change as a result of a disruption in their processes, they just do so. The need to change for the sake of survival is the rationale for change. Discounting limitations in the understanding of genetics, Southerland *et al.* describes this “need as a rationale for change” p-prim in her research as meeting both criteria of tentativeness and spontaneity. While Natalie’s exchange with the researcher provides evidence for this p-prim, it does not seem tentative. She repeats the same concept in the following question. Natalie was studying genetics within the course, although her level of understanding was unknown. In general, tentativeness as a criterion for characterizing p-prims was lacking in this project.

The results of this study do not rule out the argument for ontological frameworks. There is evidence that the pre-service teachers may not have correctly categorized energy, and expressed a conception of the term cycle that differs from its biochemical application. The results are also vague in their degree of support for or against biological p-prims. Some pre-service teachers did not exhibit the tentativeness described by Southerland *et al.*(2001). Nor did they shift conceptions between interviews. Factors that may account for differences in the results include the duration of time of the spent with participants, the ages of the participants (the pre-service teachers were older than those studied by Southerland), and the narrow scope of the topics in this study. Exactly how each factor influenced the results is undeterminable. This project does provides evidence for both views.

The results advance a model that represents the conceptions of the pre-service teachers interviewed. The model is advanced within the limits of this study.

Model of the Pre-Service Teachers' Conceptions:

The pre-service teachers in this project focused primarily at the organism level, despite instruction that emphasized cellular and biochemical levels. In their curriculum structure, the pre-service teachers had a previous unit on ecosystem, and instruction on cellular structure. They did not have instruction on the plant as an organism.

The pre-service teachers also suggested a broader sociological view than was provided in their instruction. Participants related societal concerns when discussing the ecosystem jar. They were concerned about the potential for humans to over use resources. They expressed issues of habitat destruction and the need to preserve habitats for others. They had questions of sustainability due to misuse of resources. These pre-service teachers clearly had a sociological view of a plants' role in the ecosystem.

The pre-service teachers in this project also had an egocentric view of plants, including plant dependency on humans. Plants were viewed as dependent on humans for water, care and even carbon dioxide. Plants provided oxygen for humans, used their CO_2, and were supplied with food for growth by humans. According to their view, plants are dependent upon humans for care. Participants readily admitted that care of plants was directly beneficial to humans. The interdependency theme expressed may have its basis in egocentrism. The value of plants is directly tied to the value of their service to us. The intuitive conceptions of “self as first referent” may also contribute directly to the egocentric view. Anthropomorphic reasoning used as justifications for responses may also be based in egocentrism. Characteristics of humans applied to plants began with a human perspective, giving further evidence to an egocentric view.

These two views may have played a role in the compartmentalization of the plant processes, especially when considering the multiple levels these participants focused on. The ecological multiple levels are not equal in their opportunities for experience. Instead, some levels are more familiar.

Abstractness:

The multiple ecological levels upon which a complete understanding of the two plant processes vary in their levels of abstraction. Participants within this project could touch the plants provided as props within their explaining set and cognitive interviews. They described details of experiences of plants within the ecosystem. Although they had studied cells in their laboratory activities, their use of vocabulary associated with the cellular level suggested unfamiliarity with cells. The biochemical level also seemed too abstract for most participants. There was little evidence of direct observation of chemical reactions, as there was with the organism and ecosystem levels. Those two levels likely provided the greatest opportunity for direct sensory information. Other levels were on scales that prevented human experience.

The pre-service teachers focused primarily at the organism and ecosystem levels. Movement in either direction from organism to global or from organism to biochemical increases the level of abstraction. Biochemical and cellular levels are abstract from the human perspective. The global level may be abstract in its largeness. The ecosystem level is itself very complex, and yet is a sub-system to the more encompassing global level. Participants may have limited their focus to organism and ecosystem levels due to the increased abstraction of the other levels. They may also have limited their primary focus to the organism, ecosystem and global levels because their conceptions were based in a sociological view and egocentrism.

Sociological View and Abstractness:

A sociological view may have challenged understanding of the ecological levels, as it is difficult to apply below the organism level. Rarely do societal needs list biochemical and cellular concerns. Cellular levels and biochemical levels are abstractions to most humans when considering society. Immediate societal needs include food, shelter, and water, all very tangible items, with direct organism and ecosystem experience. Participants who revealed glimpses of their societal views may not have been willing to pursue levels below the organism, as they are meaningless abstractions for society. If the frame of reference from which participants viewed photosynthesis and plant cellular respiration included societal needs, then levels above and below the organism may have seemed trivial.

Ecological View and Abstractness:

The egocentric view seemed to have little meaning below the cellular level. The pre-service teachers perceived themselves as composed of cells, but apparently chose not to consider a complexity of self at the biochemical level. The notion of being aware of the body as a chemical system was discussed earlier (Eisen & Stavy,1988; Stavy, Eisen & Yaakobi,1987). It was concluded by these researchers, and evidenced within this study, that a view of self as a system may help in the analogous view of other organisms as being systems. If the complexity of self at the biochemical level is not considered important to the learner, then minimal attention at that level is understandable. It seems trivial to focus at the biochemical level if the underlying view is from a egocentric perspective and the view of self lacks a biochemical component.

When considering the egocentric view, the logical ecological level upon which to focus is the organism level. It is macroscopic with the least abstraction. The pre-service teachers in this study focused primarily on the organism level, with attention also on the ecosystem and global levels. While a sociological view would signal attention to a global perspective, the egocentric view may prevent a thorough understanding of the abstractness of the global level. As the ecological levels move downward in scale, abstraction also increases. The instructor recognized a motivational factor at the ecological level of the ecosystem, and was able to exploit the pre-services interest at that level. If the instructor in this instance had recognized the egocentric related view, she may also have been able to use them as scaffolding for further learning. Instruction may have centered on the plant as an organism first, comparing the system needs of the plant to the system needs of the human organism. Attention to their sociological view may have allowed a greater understanding of the global view. Instruction explicitly emphasizing the plant as an independent biological system may alter a conception of plant dependency. The plant as an independent system may counter the egocentric view simultaneously with the sociological view suggesting a more stewardship approach to ecology.

Illustration of the Model:

Figure 9 captures the model of the pre-service teachers' conceptions in this study. Participants did not view the ecological levels as part of a "nested system." Instead, the majority conceptualized plant processes through a frame of reference that included self and their human society. These underlying views (sociological and egocentric) influenced their conceptions of plants. Figure 9 also suggests that logically, participants focused on the organism, ecosystem and global levels. Other levels may have held too much abstraction for their underlying views. This is not necessarily due to developmental limits, rather a matching of their intuitive notions. It was not logical from their perspective of egocentrism and societal needs to be concerned with biochemical or chemical ecological levels. Focus on other ecological levels by some participants was most likely an attempt to match instruction.

In figure 9, all ecological levels are provided, as they relate to each other. Participants focused most of their conceptions at the organism, ecosystem and global levels, and rarely ventured below. Their focus on global, ecosystem and organism was likely viewed from their perspective of egocentrism and societal needs, which may have an intuitive base. The global view may be more complex and abstract but may have greater potential because of their underlying views of societal needs and egocentrism than cellular or biochemical levels. Participants may have focused on these ecological levels because of their intuitive conception of "self-as-first referent" which allowed only limited conception of self as cellular or biochemical system. "Self-as-first referent" may also include a view of self as member of human society, with needs for survival expressed within the sociological view.

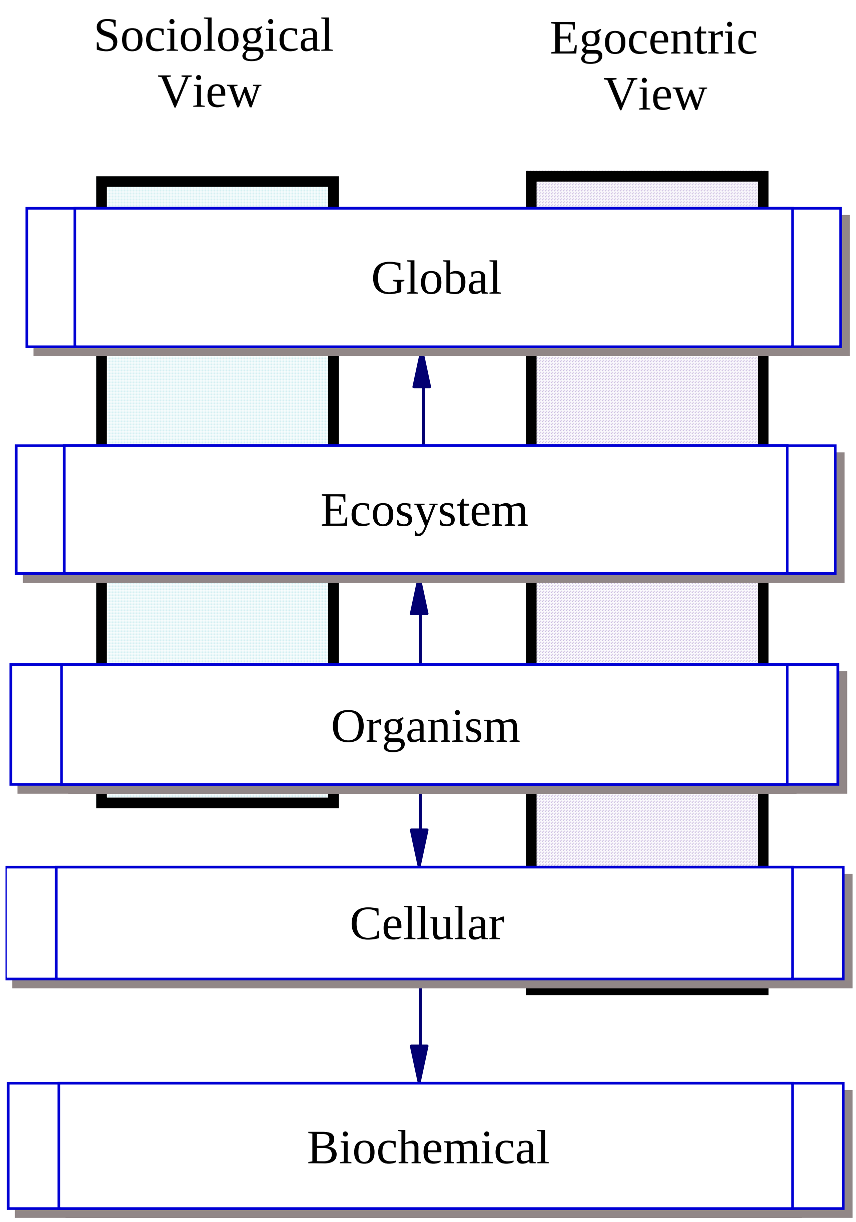

Figure 9: Model of the Pre-Service Teachers' Conceptions

Implications for Classroom Instruction:

One purpose for research in science education is to provide information to improve instruction. This study described the pre-service teachers' conceptions of the processes of photosynthesis and cellular respiration. It focused on conceptions of the processes as being connected, as occurring on multiple ecological levels, and as "nested systems."

The pre-service teachers had misconceptions regarding the two processes similar to those recorded in earlier research (Anderson *et al.* 1990; Bell, 1985; Boyes & Stanisstreet 1991; Canal, 1999; Sanders, 1993; Simpson & Arnold 1982a, 1982b). Further, this project suggests a misconception of the concept of cycle, placing it in an inappropriate ontological category, or at minimum confusing use at the organism and biochemical levels. The pre-service teachers also conceptualized plants as being dependent on humans, and saw them as crucial to maintaining human society.

The results suggest implicit systems instruction may not be sufficient, by itself, to establish an understanding of the two processes. The instructor did not explicitly discuss needs of the plant as a biological system. Nor did she refer to subsystems, which aid in survival and reproduction. Such an approach may have elicited different responses to the questions in the interviews.

Instruction did not elicit prior knowledge, and yet the pre-service teachers demonstrated a dependence on prior knowledge at the organism level. They referenced experiential knowledge, even expressing some inaccuracies. Successful bridging of the knowledge gap between a corrected organism level and both extremes of abstraction may have provided opportunities for conceptual change among the pre-service teachers. Activities that allowed discussion of their experiential experiences of plants may have been appropriate. Pre-assessment of their prior knowledge at the organism level may have elicited responses useful to instruction. Awareness of misconceptions held prior to instruction may have allowed for greater conceptual change as suggested by Posner *et al.* (1982).

diSessa and Sherin (1998) in their review of conceptual change literature, suggest concepts should be based in multiple observations, both theoretical and empirical. With multiple observations and coordination of those observations, ideally a consistent interpretation of the concept emerges. Direct explicit reference to prior experiential knowledge of the pre-service teachers may have allowed for both correction of inaccurate information at the organism level and development of scientifically accurate concepts at levels of greater abstraction.

The pre-service teachers in this study placed a high value on human society, at least within the realm of environmental issues. A problem-based approach to instruction may have helped them recognize the need for examining more ecological levels, and may have promoted a movement toward abstraction. For example, the pre-service teachers may have regarded cellular respiration as an energy reaction if problems had been posed regarding disruption of mitochondrial function. Problems examined in collaborative groupings of the pre-service teachers could serve two functions. They can demonstrate direct applications of knowledge, and provide opportunities for social constructivism. The instructor seemly saw the value of social constructivism in the laboratory setting, but did not view the lecture component of the course as needing the same. Instruction could have centered more on potential environmental problems and might have resulted in more scientifically accurate conceptions of the plant processes. Álvarez, Feuente, and García (2002) researched pre-service teachers using a problem solving approach that resulted in significantly higher scores on assessments of attitude and conceptual knowledge of environmental problems.

The pre-service teachers in this study had an egocentric view of plant processes. They conceptualized plant processes through the lens of their analogous human processes. They viewed plants as organisms intended to provide service for humans. Analogies can be effective instructional tools, provided the analogue and the source are clearly identified, and provided discrepancies are noted (Thiele & Treagust, 1995). Centering instruction on the analogous human and plant need for energy may have drawn closer connections between the two processes. Discussion could have included identification of analogous components of both human and plant, with careful analysis of similarities and differences. The analogous components could have been compared by explicitly recognizing both organisms have need for energy. Although mechanisms for fulfilling those needs differ, multiple ecological levels exist as subsystems in both organisms. Both organisms interact with other organisms in their environment, and both are components within the global ecosystem.

Acknowledging an intuitive comparison between plants and humans seems like a logical instructional strategy. Begun at the organism level, and presented as an analogous system, cellular respiration may not be conceptualized as breathing. Humans also have cellular respiration that is not synonymous with breathing at the organism level. An analogous comparison, at various ecological levels may have promoted better understanding by the pre-service teachers. As it was, they made the comparisons themselves, although they misunderstood the human and the plant as biological systems within other biological systems.

This study strongly suggests that pre-service teachers need explicit system instruction. Movement between ecological levels during instruction needs to be clearly defined. Inputs and outputs within systems, and system components themselves need to be identified. Emergent characteristics need to be noted during instruction as they appear. Drawing direct analogies between components of more familiar systems may be useful in constructing information on new systems not yet fully understood. Identifying a purpose and tying it directly to success of an entire system makes each component seem essential, and non-arbitrary. Learners may be less likely to compartmentalize components if each adds to the functional operation of an entire system.

Implications for instruction were provided throughout chapter five, as specific issues were discussed. In order to capture explicitly the recommendations into one section, specifics are provided with brief rationale and evidence drawn from the study.

- Instruction should be sequenced carefully to consider pre-requisite information.

Participants focused on the level of the organism primarily but instruction focused on the biological and cellular levels. There is evidence that the pre-service teachers had misconceptions at the level of the organism, which may have prevented them from understanding more abstract levels. Some did not understand the function of the leaves, challenging their understanding of chloroplasts and chlorophyll.

- Instruction should assess symbolic chemical understanding prior to moving towards the biochemical level.

There is evidence in this study to suggest that the pre-service teachers confused oxygen with carbon dioxide. At least three participants used energy and oxygen interchangeably. Assessment strategies such as concept mapping may assist this recommendation.

- Instruction should make pre-service teachers aware of misconceptions.

There is evidence in this study that the pre-service teachers were unaware of misconceptions regarding the two processes. Their text did not address misconceptions, except implicitly. Instruction explicitly addressed the misconception of plants not respiring but did not address explicitly the system connections between the two processes. Strategies that highlight incommensurate notions, such as the plant using nutrients from the soil as food, may challenge learners' satisfaction with their naïve conception. An experiential approach, such as weighing soil before and after plant growth, or simple experiments with hydroponics might be exceptionally effective.

- Instruction should use problem solving as an approach to highlighting interactions between and within the systems.

Participants within this study were asked questions regarding the disruption of both plant processes. The responses were superficial, centering primarily on the organism, without regard for other ecological levels. Problem solving activities during instruction, if structured to include problems at each ecological level, may help connect the levels. Each level could have a representative question that involves the emergent property below. For example, learners could be asked to speculate on the effect of chlorophyll production cessation at each level.

- Instruction should limit introduction of vocabulary to necessary essentials and allow opportunities to actively develop deeper understanding beyond nominal literacy.

Participants within this study were challenged by vocabulary. Although the text was not vocabulary intensive, instruction and evaluation relied upon vocabulary of the discipline. Participants had little opportunity to use the vocabulary presented until engaged in dialog with their peers during the explaining sets, and with the researcher in the interviews. Instructional strategies that allow for collaboration, or for quick assessment of understanding should be considered (Mintzes *et al.*, 2001).

- Instruction should use analogies, which may be intuitive, to assist in comparing the plant system with the human system.

There is evidence in this study that participants intuitively compared plants to humans, perhaps as a “self-as-first referent” p-prim. P-prims have been used to scaffold towards more scientifically acceptable conceptions within the physical sciences (diSessa & Sherin, 1998). If it intuitive to compare plants to humans, then appropriately constructed analogies of system needs seems useful. This recommendation is made with knowledge of the cautions made by Thiele and Tregust (1995) that analogies can cause misconceptions if analogue and source are not explicitly aligned. Dagher (2001) provides several approaches to instructional analogies applicable to the study of these plant processes. One suggestion is the use of analogies in evaluation, which allows the learner to elaborate on their own self-constructed analogy.

- Instruction should include explicit system references and detailed signposts when moving from ecological levels.

Participants in this study asked their instructor questions attempting to clarify the ecological level being discussed. Their questions suggest a need for frequent signposts to set the discussion within the context of the specific ecological level. Participants suggested photosynthesis was the energy reaction, and most could not place cellular respiration as an energy reaction. They may not have understood the system need for energy in a form useable for metabolism. Only two participants viewed the plant processes as within a nested system. Frequent reference to the interactions of the levels, and the system components connected with a purpose may have assisted their understanding.

Suggestions for classroom instruction are based upon the conceptions provided by the pre-service teachers interviewed for this study. As is true of all qualitative research, there are limitations and one should not over generalize from the results.

Limitations:

This researcher sought out patterns and themes during all stages of the investigation. It is hoped that by revealing these analytical insights, limitations within the researcher perspective are noted (Berg, 1998).

Literature reviewed has contributed both implicitly and explicitly to both the design and analysis of this study. The researcher was aware of past research attempts on these topics, and was challenged by the potential of capturing the pre-service teachers' conceptions in the context of their instruction. A research journal was analyzed for episodes of unintended bias, to insure equal treatment of all participants, and for potential to re-direct data collection throughout the process.

Qualitative inquiry always includes ambiguities. To protect privacy and confidentiality, participation included all students enrolled in the university course, with an opportunity to earn points towards laboratory assignments. These are, therefore, participants of convenience. As such, generalizations cannot be made towards other populations without questions of applicability. Validity and reliability of these results have more to do with the participants selected and their dialog with the researcher, their instructor, and with each other.

This project has attempted to reduce limitations inherent to qualitative research by triangulation on multiple levels. Data were triangulated through the variety of data sources. Data were gathered from field observations, participant interviews, explaining sets and meta-representations to provide a clearer, richer view of a participant's conceptions of the two processes.

Recommendations for Future Research:

As is true for most research, several new questions arise.

If instruction had been explicit toward systems, would the same misconceptions appear? It seems likely that explicit instruction on the system's use of energy (specifically including inputs and outputs) may have served as incommensurate to the conception of cellular respiration as a gas exchange reaction. If the system were viewed as subsystems, it may have allowed the pre-service teachers to focus on multiple ecological levels, without questioning where within the system they were. While this instruction began with a chapter on energy, concluded with photosynthesis, and included a laboratory activity specifically connecting the two processes, many of the pre-service teachers still could not conceive of cellular respiration as an energy reaction. Explicit labeling of cellular respiration as the input source of energy into the cellular subsystem may have helped.

This group of pre-service teachers apparently held two views upon which their conceptions were based. They valued sociological views of ecological issues, and shared an egocentric view of plants. Both views could have been used effectively to scaffold instruction. It would be informative to explore a classroom in which both views are specifically addressed through instruction. Conversely, a classroom where only one of the two views is explored in depth may reveal significant information as to how learners apply knowledge about plants and their importance. Would pre-service teachers challenged on their view of dependency through collaborative questioning activity still adhere to the idea of a plant's need for humans? Would such an activity shift conceptions of the plant toward a more scientifically accurate view of the plant as an independent biological system?

Is "self as first referent" a biological p-prim? Within the physical sciences, p-prims seem much easier to define. They occur spontaneously, as seen in this project, yet also provide a sense of how a structure works within the universe. Southerland *et al.* (2001) suggest that tentativeness is an attribute of p-prims. That concept itself, however, seems counter-intuitive. Spontaneity and tentativeness are not necessarily obvious in patterns of language. Nor does lack of spontaneity suggest a lack of confidence in the response. Physics students seem to be supportive of the "Ohms" p-prim of working harder to overcome resistance even when inappropriately applied (diSessa and Sherin, 1998). That does not imply tentativeness. P-prims in the physical sciences are basic interpretations of the world that we learn through repeated experiences. Experiences such as photosynthesis and cellular respiration may simply be at too high a level of abstraction for the pre-service teacher. It may be that if p-prims are used to scaffold appropriate conceptions about energy, then conceptions dependent upon a scientifically accurate conception of energy will change. Investigations involving the appropriate cueing of p-prims in the physical sciences may be applicable in the biological sciences as well. If learners are choosing to use their knowledge of the human biological system as a referent for other organisms, it seems appropriate that careful analogies be drawn. Evaluation should involve assessment of understanding of the distinctions. The pre-service teachers in this project had a conception of photosynthesis being the energy process, and cellular respiration being a gas exchange process. Starting instruction with an accurate conception of cellular respiration in plants as an energy reaction may have facilitated a more accurate conception of photosynthesis. A research approach that combines an investigation of the ontological categorization of energy with the possible p-prim of “self as first referent” may provide additional information. Is the first referent that learners use to categorize energy ontologically, as matter or process, the self?

Will pre-service teachers who have inaccurate conceptions of photosynthesis and cellular respiration change these conceptions when actually teaching the topics to their students? The pre-service teachers in this project compartmentalized the two processes and were unable to view them as components of an entire system. When presenting the two topics to their own future students, will they follow the same pattern of compartmentalization? If the instructional materials used by these future teachers emphasize a systems approach, will their societal need for accurate instruction facilitate conceptual change?

Conclusion:

This project investigated the conceptions of pre-service teachers in a midwestern university during a summer session of nine-week duration. It was determined that in general, the participants focused primarily on a few of the ecological levels when discussing the two plant processes. They used sources from their instruction to justify responses, occasionally using teleological, tautological and mechanistic proximate reasoning. There was little evidence of mechanistic ultimate reasoning. They also used authoritarian sources for justification of responses.

The pre-service teachers' conceptions suggested a sociological view of plants in the total environment. Explicit systems-based curricula, which emphasize plants and their interactions with humans, may be useful in shifting to a more scientifically accurate conception of photosynthesis and cellular respiration. Photosynthesis and cellular respiration can then be viewed as components of a biological system, influencing other biological systems. Because both plants and humans can be viewed as biological systems with similar needs, a systems view of the natural world would be a significant step toward achieving a scientifically accurate model of the processes within nature.

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APPENDICES

Appendix A: Project Description

Purpose:

The goals of the experimental research component of this dissertation are:
To investigate and characterize pre-service teacher cognition on the topics of photosynthesis and plant respiration
To determine the extent that pre-service teachers conceptualize photosynthesis and plant cellular respiration as being interconnected, occurring at multiple ecological levels, and as “nested systems.”
To determine the influence of instruction on pre-service teachers conceptualization of these two processes.

Research Procedure:

This project will involve a science class assignment, which all students within the class will be expected to participate, as time permits. The project is within the guidelines of normal educational practice, but details are provided below. There are several components to this project, which will be addressed below individually. The components are: a field observation; an instructor interview; a cognitive interview to students; an “explaining set” and a “clarifying interview.” Each appears below under a separate heading with the details needed for explanation following:

- **Field Observation**
  - Field observations will be conducted. The purpose of the field observations is to consider how instructional practices influence conceptualizations and to document the approach the teachers have chosen for classroom instruction. Field notes will be taken and will focus on both the teachers’ pedagogical approach to the two plants topics of photosynthesis and plant respiration. In addition, notes will be taken on classroom discourse among the students, or teacher to students involving photosynthesis and respiration. Notes will attempt to capture modes of reasoning the students are using to understand the processes; including any misconceptions; and any expressed p-prims within the duration of the observation. The field observations will be audio and video taped. Caution will be taken to not directly tape students who do not wish to participate, as audio and video will be directed towards teacher-centered instruction primarily. If students do participate without assent form, neither image nor voice recording will be included in the project.
- **Teacher Interview**
  - The teachers will be interviewed as to their pedagogical approach to these two plant processes; the type of difficulties the students have expressed in understanding the two plant processes; instructional materials used in the presentation of the content of the two processes; and the teachers’

impression of the reasoning skills students are using to make sense of the processes. The teacher interview questions are accompanying this document and submitted for review, however, these questions are intended to reflect a "semi-structured" interview process and as such, questions may arise during the course of the interview in direct response to the teachers' responses. The teacher interview will be audio and video taped. Teachers will be selected on the basis of the attention to approach of instruction of the two plant processes.

- **Cognitive Interview**
    - Pre-service teachers will be asked, as a course assignment, to be involved in either the cognitive interview or the explaining set. It is possible that the teacher will select students for both the cognitive interview, and the explaining set, as it fits with the instructors' assignment, and as time permits. The instructor will be asked to set the interview schedule and select pre-service teachers most appropriate for each interview type. Pre-service teachers will not be made aware of the reason for their selection into either interview. Cognitive interviews will be conducted on students the teacher selects as being "more comfortable with a talk-aloud protocol" with researcher. The cognitive interview will focus on the plant processes of photosynthesis and respiration, and will use two green plants, of the same species but of varying sizes. Questions will focus on how plants grow and function, using the two plants as specific visual examples. The interview is designed to be a "semi-structured" interview, as the interviewer will attempt to ask questions reflective of the students' direct responses. The cognitive interview questions are accompanying this document. The cognitive interview will be both audio and video taped. These interviews will be individualized.
- **Explaining Set**
    - Pre-service teachers will be asked, as a course assignment to be involved in either the cognitive interview or the explaining set. It is possible that the instructor will select students for both the cognitive interview, and the explaining set, as it fits with the instructors' assignment. The instructor will be asked to set the interview schedule and to select students most appropriate for each interview type. The explaining set will be students set in dyads as selected by their teacher. The instructor will be asked to set them in pairs as a "high achieving" student and a "low achieving" student. Other criteria of selection will be students who can talk comfortably with each other. Students will not be told the rationale for their selection into these dyads (set of two paired students). Dyads will perform four "explaining tasks" with an estimated time of ten minutes on each task. Cards will be prepared so that each student has both an auditory explanation of the tasks, and a visual. The explaining set will be both audio and video taped.

Methods of Analysis:

Task 1: the "warm-up" task. Dyads will be asked to explain to each other how to put together a puzzle. The puzzle is an Escher tessellation design, with the challenge being in placement of the pieces. The purpose of task 1 is to establish the talk-aloud protocol, and the "explaining" procedure of the remaining tasks.

- Task 2: the "plant comparison" task. Dyads will be presented with two green plants of varying size. They will be asked to explain to each other, how the plants achieved this difference.
- Task 3: the "ecosystem in a jar" task. Dyads will be presented with a clear plastic jar which contains two figurines of people, and several plastic representations of plants. They will be asked to imagine these objects as living and life sized, but with all physical needs met. They will be asked to explain to each other both short term and long term effects of the atmospheric conditions within the jar, if both types of organisms remain in the jar.
- Task 4: the meta-representation. Dyads will be asked to draw their representations of plants role in the natural world. They will then be directed to explain the drawings produced to each other. The drawings will be labeled and kept by the researcher.

- **Clarifying Interview**
    - Pre-service teachers who reveal new or previously not documented misconceptions or p-prims in the course of their interviews will be asked for a clarifying interview. These interviews, by nature of the research design can not be listed as specific questions, instead they will follow directly from the responses of specific students within the context of one of the previous interviews. The general phrasing of the questions will be "can you clarify for me what you meant when you said……?." Pre-service teachers will be told by their instructor that the researcher "is particularly interested in gaining more information regarding one or more of your responses" upon selection. It is not anticipated that props will be used during this interview protocol.

The instructor will not be made aware of the student responses within the interviews, nor will pre-service teacher responses directly affect the grade assigned. Pre-service grades will not be affected in any manner as a direct result of non-participation in this project. Although participation will be considered by pre-service teachers to be a "class assignment" other options to earn the same number of points towards their grade will be provided to non-participants.

Audio tapes and video tapes will be made of all interviews and field observations. Audio tapes will be transcribed as soon as possible, checked for accuracy, and then destroyed. Video tapes that may be exceptionally useful to illustrate the reasoning of students, as in a dissertation defense, or an educational setting will be kept as part of the project. Video tapes, which do not reveal exemplar examples of reasoning or use of p-prims, will be destroyed after publication of the dissertation.

Interviews and artifacts collected within this project will be analyzed using segmentation and coding criteria that are typical of qualitative research within the discipline.

Benefits of Research:

In order to move towards a more scientifically acceptable conception of photosynthesis and plant cellular respiration, it is important to know pre-service teachers' conceptions of the two processes. Set within the context of instruction will allow the researcher to determine how instruction influenced instruction. Recognizing that photosynthesis and plant cellular respiration are part of a biological system, provides information for system disruption.

P-prims are considered by some researchers to be useful in the structuring of knowledge systems. In identifying and characterizing the p-prims reflected as students consider photosynthesis and plant respiration, the long-term benefit to the discipline is the potential for direct instructional use. It's an identification of the starting point at which students attempt to understand these complex processes, with the potential of helping them proceed towards a more scientific conception of the processes. Individual student participants within this project will be given more opportunities to reflect on these two topics in preparation for classroom evaluation on these topics. Teacher participants may benefit with the opportunity to reflect and explain the pedagogical approach.

Subject Selection:

The instructor will present the project to the class as a classroom assignment, but with an option to not participate in the video and audiotaping. The instructor will be asked to select students for the cognitive interviews, who will "be very comfortable with the talk-aloud protocol" in the presence of an adult researcher. The instructor will also be asked to pair students based on their performance on an evaluation (a unit exam administered by the classroom teachers) given in an earlier instruction on the same two topics. The instructor will be asked to select the students for the dyads, and will be instructed to pair a "student who knows these processes well, with a student who does not know the processes well." The selection of pre-service teachers for the clarifying interviews will depend upon responses given within the cognitive interviews and explaining sets, when a student response is unclear, or revealing an undocumented misconception regarding the two plant processes, or to follow up on the expression of a p-prim. Instructor selection was made on instructional approach, pedagogical concerns and experience on teaching these two plant processes. The instructor will provide signed consent form. All pre-service teachers included in the project will sign a consent form.

- **Instructor recruitment Script:**
    - Hello. My name is Mary Brown. I'm a graduate student at WMU, working towards a PhD in Science Education. I'm very interested in how students reason through very challenging topics in science. I've focused my research on the topics of photosynthesis and plant respiration. Do you cover those topics in your course? I'm wondering if you would like to help me with my research. I need to work with a classroom that covers those two topics, with a teacher who has at least five years of experience. Do you have any special approaches you use to assist students in working

through these topics? Have you taught more than five years? Would you be willing to allow me to observe a few sessions of you teaching the topic to your class? Would you be willing to have those observations video and audio taped for later transcription? Would you be willing to ask pre-service teachers in your class to talk with me as a classroom assignment? After instruction, I would like to ask some pre-service teachers to talk with me about how they have thought through the details of the two processes. I'd like your help in identifying which pre-service teachers would be very comfortable at talking aloud to me, about two plants of differing sizes. I have about 10 questions, and they are semi-structured, so that I would like the interview to be more like a conversation. Do you think that would be okay? I would also like to ask you to help me to pair some pre-service teachers together, those that talk well with each other, but also paired so that a "high achieving" student is paired with a "low achieving" student. I don't want any of the students to know why they were chosen for which type of interview. And, since it is a class assignment, I think it is fair if you don't know which pre-service teachers have agreed to be an official part of the study, and which have not. They need to be all treated exactly the same way. Would you be willing to help me? The paired pre-service teachers will be doing three tasks for me, with about 5 questions for each task. I would like to ask the pre-service teachers permission to video and audio tape the interview sessions too. Do you think that would be permissible? Is there a conference room near where we could conduct the interviews in private? I am guessing that some pre-service teachers will respond to these interviews with some very interesting insights for my research. May I ask a few pre-service teachers for a second clarifying interview, if they have responded in such a way that reveals something I haven't yet anticipated? I would like to video and audio tape that interview too, for later transcription. Do you anticipate any difficulties with the procedure that I have outlined thus far? Once the pre-service teachers' interviews are completed, I would also like to interview you on your approaches to these two plant processes. Would that be agreeable? I would again like to audio and video tape your responses for later transcription. Do you have any questions? Can you help me with the logistics of your classroom procedure of getting all assent documents to the students and from the students? I would also like you to sign a consent form as well. And, please, if at anytime you would like to excuse yourself, or your class from this project, you may do so.

- **Student recruitment Script**
    - Hello, my name is Mary Brown. I'm a student at WMU, working toward a PhD in Science Education. For a very long time now, I've been interested in how students think about science topics, and I'm particularly interested in how learners come to understand topics like photosynthesis and plant respiration. I have talked with your instructor, and she is also interested in how students come to learn these topics. I understand you have been studying these topics, and I'd like to sit in on one or two of your classes to

> see what you have been doing to learn them. Your instructor has given me permission to audio tape and video tape these sessions. She has also agreed to give you a special class assignment, to talk with me about how you understand these plant functions. I want to video and audio tape those sessions too, and then transcribe what you have said to put in my report to give to my professors at the university. I'm hoping you'll agree to let me do the taping. You may tell me some very interesting things that will help us be better teachers. We all want that goal! If you don't want to be video taped, or for me to use your words in my report, just return the papers unsigned. Your instructor won't know, and I'll still want to talk to you. If you do want to be part of the study, then you'll need to return the papers signed, and agree that you will respect the privacy of the conversations we have when we're together. Some interviews will be individual, some will be in pairs, and sometimes I might ask for a second interview, just because something that was said was exceptionally interesting to me. Do you have any questions?

Risks to Subjects:

There is no identifiable personal risk to the participants. Pre-service teachers who opt out of the study will not be filmed in the field observation. Their instructor will be unaware of their lack of consent, as all paperwork involved will be handled by the researcher.

Protection for Subjects:

Pre-service teacher participants within the study will be provided with a consent form, for video and audio taping. The project will be considered as a normal educational practice, as it is conveyed to the pre-service teacher as a class assignment. Pre-service teachers within the class who decide not to participate will not be videotaped. Only pre-service teachers who consent to the study will be selected. The instructor will be unaware of which students opted out of the study, as that detail will be handled by the researcher. When data is reported in the context of the dissertation, the neither classroom, nor extraneous details of the classroom environment will be revealed. Pre-service teachers will be assigned pseudonyms, and serious efforts will be made to diminish the potential that a particular response could be attributed to a particular person. The researchers will be sensitive to identifying context, so that data originally provided by a female child, may be attributed a male child, as gender is not an issue of research within this project. The only exception will be in situations where the data is exemplar, and student has signed consent to use image for public educational viewing.

Interviews will take place in an adjoining or nearby room (conference room, or science laboratory prep room). Since all pre-service teachers, regardless of the signed consent will be interviewed, pre-service teachers within the classroom, nor the instructor will know which participated in the data collection and which did not. Only audio and video tapes from children with a signed consent form will be used in the dissertation project as data.

Confidentiality of Data:

Within the dissertation, the instructor and pre-service teacher participant identities will be kept confidential. The location and name of schools will be kept confidential. Pre-service teacher and instructor participants will be given a pseudonym within the text descriptions, when it is necessary to quote or otherwise attribute information as coming directly from one person as a source. Data will be retained in a locked file cabinet within an on-campus office, for at least three years. Original data will be destroyed after degree is granted. Audio tapes will be transcribed and then destroyed. Audio tapes and video tapes will be made of all interviews and field observations. Audio tapes will be transcribed as soon as possible, checked for accuracy, and then destroyed. Video tapes that may be exceptionally useful to illustrate the reasoning of students, as in a dissertation defense, or an educational setting will be kept as part of the project. The consent form for all pre-service teachers and the consent form for the instructor will reflect the potential use of video image for educational purposes only. Video tapes, which do not reveal exemplar examples of conceptions on the two plant processes, reasoning or use of p-prims, will be destroyed after publication of the dissertation.

Instrumentation:

See accompanying interview questions for both teachers and students.

Informed Consent Process:

Consent is for the use of video and audio taping for research purposes. The instructor and all pre-service participating, as part of their class assignment will be given the option of non-participation by not signing. The researcher will coordinate the logistics of distribution, and assigning of pseudonyms for the pre-service teachers within the data. The instructor recruitment script is provided in the section on subject selection, and will be done over the phone prior to any classroom interruption. The pre-service teacher script to introduce participants to the project is provided in the section on subject selection. This script will be given orally to the participants prior to the first classroom observation. Only comments of pre-service teachers who have agreed to be audio and video taped will be used as data in this project. The instructor consent form will be given prior to interview.

Method of Data Collection:

Data will be collected via interviews with participants (see details of the interviews with the research procedure section) and through collection of the meta-representation, in explaining set- task #3. Collection methods will be interview and gathering of responses to tasks detailed above. Interviews with pre-service teacher participants will be individual in the case of the cognitive interview; and within the post interview for clarification after the tasks. The tasks ("explaining sessions") will be with pre-service teachers paired in dyads, and the researcher. Cognitive interviews, dyad explaining sets and follow up interviews will take place after the field observation is completed, and classroom instruction on the plant processes is completed. The instructor will allow dyads to explain during class time, in a conference room available within the school. The interview with the instructor will be individual with instructor and researcher. These interviews will take place after class at the same location, after conclusion of instruction on the plant processes. Field observations will be taken with audio and videotape recordings made during the instructor's instruction on both plant processes.

Research Design:

The research design is qualitative, with interviews, field observation and meta-representations. All interviews will be transcribed, segmented and coded for reflection and characteristics of student cognition identified. The coding sheets with description and guides to interpretation are including within this documentation. Meta-representations will be analyzed to determine the extent to which misconceptions and p-prims are expressed, using similar coding procedures. There may be additional codes used, as the design is an active exploratory design with the codes emerging from the data, as discovered. Student names will not be used in the transcripts when transcribed, instead, a pseudonym will be assigned, which will be kept consistent throughout the data collection. Students will be asked to sign a privacy statement as part of their consent form. Within the script of the explaining sets, student dyads will be reminded of the need for not revealing conversations said within the explaining sessions.

Location of Data Collection:

Data will be collected at the university where the pre-service teachers are. Field observations will be made within the science classrooms when possible. Interviews of individuals and dyads will be made in smaller conference rooms made available for use by the school. Consent forms will be distributed to pre-service teachers. The instructor will be unaware of pre-service teachers who did not return forms, until after the data has been collected.

Duration of Study:

This project will take place within the Spring and Summer semesters 2004, at the discretion of the university instructor involved. The instructor will set the dates and times of available for convenience of instruction, and other participants.

Results Disseminated:

Results will be published within context of the dissertation project.

Appendix B: Consent Form

Western Michigan University
Mallinson Institute of Science Education
Principle Investigator Dr. Reneè Schwartz
Student Investigator: Mary Brown

You have been invited to participate in a research project entitled: “Understanding Photosynthesis and Plant Cellular Respiration as ‘Nested Systems’: the Characterization of Pre-Service Teachers’ Conceptions. This research is intended to study how you currently understand the two plant functions. The project is Mary Brown’s dissertation project. This study will be an extra credit option, made available to the entire biology class in this summer session.

As part of the research, you will be asked to tell us what you know about plant functions, and be asked to explain your ideas to another student in your class, while we listen to your explanations. In the explanation session, we’ll ask you to draw an illustration showing your ideas.

Your involvement may benefit your understanding of photosynthesis and cellular respiration, as you will likely spend more time thinking about them. Interviewing of students for conceptions is a standard educational practice, which may help you in your future profession. There are no identified negative aspects of this project identified.

We will be video and audio taping classroom sessions as your instructor works through the unit of instruction on these topics. We will also audio and videotape your answers to the questions we have, when you are interviewed. We are asking your permission to video and audio tape our interviewing sessions with you. We also would like your permission to use the information that you have told us in our report. If you tell us that we cannot use your picture, or your words, there will be no repercussions. Your grade within the course will not be affected negatively if you choose not to participate after a session is started. You can tell us after we have already started taping that you no longer want to be involved. Your responses will just not be included in the study..

If you have any questions or concerns about this study you may e-mail either Mary Brown at brownm@lcc.edu. (phone #1-517-483-1115) or Dr. Reneè Schwartz at r.schwartz@wmich.edu (phone # 1-269-387-5660). You can also call the Chair of the Human Subjects Institutional Review Board (1-269-387-8293) or the Vice President for Research (1-269-387-8298) if questions or problems arise during the course of the study.

The stamped date and signature of the board chair in the upper right corner means this consent document is approved for use for one year by the Human Subjects Institutional Review board. Do not participate if the stamped date is more than one year old.

If you wish to be included in this study, please sign your name.

I, ________________________, want to be in this research study.
(write your name here)

__________________ __________________
Investigator signature Date

I agree that a videotaped image of me may be shown in public for educational purposes only within the context of this project.
_______________________ (write your name here)

When we are done with the study, we will write a report about what we found. We won't use your name or anything else that might identify you in the report. We do not want you to reveal to others the details of the interviews, to respect their privacy too. When we interview, we will ask you to promise not to tell others what was said during the interview. We need you to agree to respect their privacy, and they will agree to respect yours. Please sign agreeing to privacy.

____________________ (write your name here)

Mallinson Institute of Science Education
Principle Investigator Dr. Reneè Schwartz
Student Investigator: Mary Brown

Dear

Based upon our prior conversations, I would like to invite you to participate in a research project entitled Understanding Photosynthesis and Plant Respiration as "Nested Systems": The Characterization of Pre-Service Teachers' Conception. The purpose of this study is to investigate student reasoning regarding these two challenging plant processes. We have discussed the educational value of assessing students in their understanding of these plant functions. We thank you for your willingness to assign this project within your normal classroom procedures.

We would like to ask your permission to interview you regarding the approaches you use towards instruction. The interview will be both audio and videotaped, and later transcribed.

We will also be asking for your assistance in pairing students to interview based upon certain criteria. However, we have promised the students that their non-participation will not affect their grade in your course directly. As time allows, we will attempt to interview all students within your class.

You will be free at any time to excuse yourself from participation in this research. Your name, any other information that might identify you, the name of your school, and your students' names will be kept confidential in all aspects of this research. You are not in any obligation to continue with the project, even once it has begun.

The only risks identified are potential instructional time interrupted for some students on the dates of interviewing. Your interview will take place after instruction is completed, and can be at the convenience for your schedule.

If you have any questions or concerns about your participation in this research, you may contact either researcher via e-mail: Dr. Reneè Schwartz at r..schwartz @wmich.edu (phone # 269-387-5660 or Mary Brown at Brownm@lcc.edu (phone # 1-517-483-1115). You may also contact the Chair, Human Subjects Institutional Review Board (1-269-387-8293) or the Vice President for Research (1-269-387-8298) if questions or problems arise during the course of the study.

The Human Subjects Institutional Review Board has approved by the stamped date and signature of the board chair in the upper right corner.

____________________________ ____________________

Signature date

Permission obtained by: ___________________ _________________

Initials of researcher date

I further give permission for my videotaped image to be shown in public for educational purposes only in the context of this project.

______________________________ _____________________

Signature date

Appendix C: Explaining Question Set

Explaining Question Set:
Note: The prompts will include two plants of the same species, one larger than the other, and one Escher puzzle set of beetles to be used as a warm-up activity.

Directions:
First, I want to thank you both for helping me with my project. However, I want to make one thing very clear. This project needs to respect privacy. So, what is talked about in this room needs to not be discussed with anyone else, who is not in this room. Do you understand what I mean by that?

I am doing a study, which will tell me how you come to understand certain ideas. I want you to feel very comfortable talking to each other, while I am here in the room. This session will be video and tape-recorded, and I don't want you to be concerned with that. I have a brief practice question that I want you to consider while I check my equipment, and get ready. Can you try this for me? I'd like you to explain to each other how you might make these pieces of the puzzle fit together.

(at this point, provide the Escher puzzle pieces). Please remember I want you to talk to each other as you are thinking through this problem.

Okay, thank you very much. You did very well with that. I really appreciate all the discussion that you had. That is the kind of talk that is very interesting to me. In this next session, I'd like you to look at these few statements and questions I have and take turns explaining the statements and answering the questions to each other. In other words, after you (indicate one child) explain the statement to you (indicate other child), I'd like you (indicate to the participants in the reverse order) to explain the same statement again, so that I get the chance to hear both of your explanations. It doesn't matter to me who explains first or second, just so that you both tell the other your explanation in your own words. I would also like you to provide a minimum explanation of thirty seconds during your session. And, if you have use any scientific terminology in your explanation, please be certain you provide a meaning for the terms used.

Do you have any questions?

The TASK 1: Compare the plants **(T1 #1-#6) Note:** questions are on a card, labeled by number, which is then given to the pair)

1. Explain any differences you see in these two plants.

2. Explain how the two plants became different from each other.

3. Explain any special conditions or requirements that the plants needed in order to be the way they are now. Please tell all the details you know.

4. Explain any differences you know between these plants and other organisms. How do plants differ from other organisms?

5. Explain any similarities you know between these plants and other organisms. How are plants similar to other organisms?

6. Explain how you came to know what you know about plants. How did you make sense of what you know about plants?

Ecosystem
Note: use the jar with the greens and doll within.

Are you both finished? Do you need more time?
Okay. I have another problem I would like you think about. You'll have to use your imagination a little bit with this one. This jar represents a life sized sealed enclosure with a live person inside, and living green plants. The top of the enclosure would be completely clear, so that sunlight could pass through the top as well as all the sides. The person would have all the food needed, with the variety necessary. Water would also be unlimited in supply. I would like you to do the same procedure as we just did. In other words, I would like one of you to tell your responses to the statements and questions, and then listen to the others' statements and questions. Please explain very well to your partner what you are thinking about the problem, as you go through the statements and questions. I am very interested in what you think about the problem. Please remember to take turns as you move through the questions, so that one answers the first question first, and the other person answers the second question first. Please use your own words.

(The questions and the assumptions given are provided on a card. The assumptions are bulleted, so they are clear and concise. The questions are labeled by number, which is then given to the pair)
Assumptions:

- All organisms inside the enclosure are living and healthy.
- The enclosure is life size, so there are no space concerns.
- The top of the enclosure is clear to allow light to pass through.
- Food is in unlimited supply.
- Water is in unlimited supply.

TASK 2: Ecosystem jar **(T2 #1-#5)**

1. Tell if you think it would be possible for a person to survive in such an environment. Why or why not?
2. Tell if you think it would be possible for the green plants to survive in such an environment. Why or why not?
3. What do you think will happen to the person as time passes? Please explain your answer.

4. What do you think will happen to the plants as time passes? Please explain your answer.
5. Explain the relationships that are going on in the enclosure. Explain your response thoroughly.

Task 3: Meta-Representation: **T3**
Note: paper and markers provided.

Thank you that was very interesting to me. I would like you both to do one more activity. I'm going to give each a paper, and again, welcome you to explain your representation to each other.

T3: Please draw a picture to explain to me how you think plants are part of the natural world. Show me, through a picture, what you understand their role to be.

(note: The card has the last two phrases repeated, so that students do not need it repeated)

Thank you. After I study your responses that I've recorded on tape, I might want to come back and ask you to explain to me a few more things. You've both said some interesting things, which I would like some time to think these explanations over. Would that be okay?
Thanks!

Appendix D: Pre-service Teachers

Participant Pseudonym	Attendance	Participation
Amy	¾ days	Explaining Set
Anita	¾ days	Explaining Set Cognitive
Ann	4/4 days	Explaining Set Cognitive Clarifying
Betty	4/4 days	Cognitive **
Bob	2/4 days	Explaining Set Cognitive Clarifying
Carl	¼ days	Explaining Set
Charles	4/4 days	Explaining Set Cognitive
Jay	¾ days	Explaining Set Cognitive Clarifying
Joy	4/4 days	Explaining Set
Kay	4/4 days	Explaining Set Cognitive

** Cognitive interview incomplete

Appendix D Continued: Pre-service Teachers

Participant Pseudonym	Attendance	Participation
Kurt	2/4 days	Explaining Set
Nan	4/4 days	Explaining Set
		Cognitive
		Clarifying
Natalie	4/4 days	Explaining Set
		Cognitive
		Clarifying
*Ruby	¾ days	Explaining Set
Sam	4/4 days	Cognitive
Shirley	4/4 days	Explaining Set
		Cognitive
		Clarifying
Suzy	4/4 days	Explaining Set
		Cognitive
Veronica	¼ days	Explaining Set
		Cognitive

* Withdrew from course

Appendix E: Cognitive Interview Questions

Cognitive Interview Questions:

Note- Interview conducted with two same species plants, two different sizes.

Introduction: I would like to ask you a series of simple questions, but I want you to tell me as much as you know about the topic. You will not be evaluated on your responses, I'm just very interested in knowing how you think about plants and what plants do, how they do the things they do, and how that fits into the bigger ideas of life and the environment.

1. Please, tell me any differences you see between these two plants, and why they might be different?

2a. (if student suggests growth) Can you tell me how you think the plant grew?
2b. (if student suggests other) Can you tell me how you think that took place?

3. Please, tell me as much detail as you can about how the plant does that. Are there any special conditions or requirements?

4a. (if student suggests conditions needed) That's very interesting, can you tell me more detail as to how they do that?
4b. (if the student just gives the name of the process) Can you tell me what you mean by that? What do you think the plant is doing while it does that?

5a (if gases are mentioned) Can you tell me more detail about that? What's that like?
5b (if gases are not mentioned) Well, can you tell me why the plant would do that?

6. How do you think the leaves of one plant got larger than the leaves of the other plant?
6a. (if grew larger) What materials are needed? Where did they get the materials they needed to grow larger?
6b. (if any other answer) Alright, can you explain how they did that?

7. How do the plants use the materials they need to grow?
7a. (if they respond with a term) Okay, explain exactly what you mean by that, please.

8. What do you think the plants are currently doing?
8a. (if only one process is mentioned) Okay, that's interesting, can you tell me anything else the plants are doing? (may have to be repeated more than once, dependent on response) ex: anything else?; anything else?
8b. (is nothing, or similar response) So, you don't think the plants are currently involved in any processes, or any life functions? Can you explain why you think that?

9. How do the various parts of the plants, such as the roots, leaves and stem, help the plant to function?
9a. (if don't know) What do you think the roots do? What do you think the leaves do? What do you think the stem does?
9b. (if a term given) Great, can you tell me what you mean by that, and how the part does that function?

10. What role or function do you think plants have within the world? Do you think its role compares to the role of other living things?
10a. (if don't know) Can you tell me how you think plants fit into your world?
10b. (if term given) Great, can you tell me exactly how you think that relates to the function of plants in the world?

11. Do you think plants are different from other living things in what they do? If so, then how do you think they are different?
11a. (if don't know) How do you think of plants when you think of them? Do you think of them as different from other living things?
11b. (if specifics) Please tell me more details as to how you compare plants to other living things. I'm very interested.

12. Do plants interact with other living things in the world? How?
12a. (if don't know or no answer) Do you think they do interact? What can you say about the interactions a plant might have within the world?
12b. (if term given) Okay, what does that mean to you? Can you give me more detail?

13. What do you think photosynthesis is?

14. What do you think cellular respiration is?

15. Please tell me about the two-biochemical equations of photosynthesis and cellular respiration. What do you think is their relationship?

16. How do you think the organelles within the plant play a role in photosynthesis and cellular respiration?

17. What do you think photosynthesis and cellular respiration do for the ecosystem?

18. If photosynthesis were disrupted by some mechanism, what affects do you think there might be? (in the plant organism) (in the rest of the world)?
18a. If cellular respiration were disrupted by some mechanism, what affects do you think there might be? (in the plant organism) (in the rest of the world)

19. How do you think the chemicals, the cells and the structure of the plant such as the roots, leaves, and stems, work together within the ecosystem? How do they work on a global level?

20. Is there anything about how plants function that doesn’t make seem to make sense to you? Please give me some examples of ideas about plants that you still find confusing.

21. How did you come to know about plants and what they do? How did you come to accept the ideas?
* This question was repeated multiple times during the interview.

Appendix F: Instructor Interview Questions

1. Can you explain, in detail, how you decided to take the approach that you did with them on the topics of photosynthesis and plant cellular respiration?

2. I noticed that you started with an overview of the ecosystem, and then brought cellular details, later on. Was that a decision that you made based upon the idea, that they needed a global perspective first?

3. Have you noticed that the students' had difficulties understanding these two processes? What difficulties have you noticed?

4. What strategies have you used in your classroom to ease the challenges you see they might have?

5. I noticed that you had a lot of instructional materials that you prepared. Can you provide me more details as to what your thoughts were in preparing them, how you laid them out, etc...?

6. It seemed to me that you put together the majority of materials together for instruction. You had many things that you had pulled together and organized for them. Did you do that with thoughts of what they were thinking or how they might be challenged?

7. If you could design the absolutely "perfect approach" with no time, no time constraints, no financial constraints involved, and your real goal was to have students understand these two processes, what do you think you would do?

8. How did you select that particular text?

9. How do you think the students reason through these two processes?

10. Do you think they are trying to get a conception of photosynthesis and plant cellular respiration?

11. Do you think they have a view of any of these processes as being part of an ecosystem, or a biological system in general?

12. Do you think they are getting more information from the lab material or more out of the textbook? Where do you think they are getting most of their information?

Appendix G: Coding

"Explaining Sets", Cognitive and Clarifying Interviews had the same Codes and Descriptions.

Codes:

ANALOGY- Analogy
Participant's conception includes an analogy. i.e. "ATP is the energy currency."

ANTHRO-Anthropomorphic- Participant provides an explanation which uses human attributes or characteristics. i.e. "plants want food to live."

ATTRIB - Attribute– Participant conceptualizes plant in terms of a human attribute. Differs from anthropomorphism in that plant is given a human trait. In this intuitive attribute conception, the participant mentions the plants share or does not share the same trait given. i.e. "plants are as good a parents as humans are."

AUTHO-Authoritarian- Participant provides an explanation that only cites the source of the knowledge, i.e. "The book says that plants respire." Includes citation of teacher, or school as the authority.

BIOCHEM- Biochemical – Participant conceptualizes knowledge at the biochemical level, is able to convey relationships at the chemical level. Evidenced by use of CO_2, O_2, H_2O, and other reactants and products of the two reactions. Ex: "The plant releases O_2 as a by product."

CARVBIG-Carnivore must be big organism- Participant provides evidence of the previously documented misconception that carnivores must be the bigger creatures in the food chain, and those organisms which feed on plants must be small. Ex: "plants are then eaten by small organisms, which are then eaten by larger organisms."

CBIOCHEM –Correct Biochemical- Participant has correctly conceptualized the biochemical relationships within photosynthesis and cellular respiration. Ex: "The plant releases O_2 in photosynthesis but uses O_2 in cellular respiration."

CCELLULAR –Correct Cellular-Participant conceptualizes the correct cellular relationships in the processes of photosynthesis and cellular respiration. Ex: "The chloroplasts absorb light."

CELLULAR- Participant is able to conceptualize cellular level processes including organelles and structures within the cell. Ex: "The plant has chloroplasts which absorb light."

CGLOBAL- Correct Global- Participant conceptualizes an accurate global perspective of plants' importance. Ex: "without plants, most other organisms would die."

CO_2=O_2 –Carbon dioxide and oxygen are equal- Participant confuses oxygen with carbon dioxide or carbon dioxide with oxygen. Ex: "Plants make carbon dioxide for people."

CONTEXT-Context-Conceptualizations that are directly indicated within a specific context, such as teacher influence, lab, lecture, experiential, and visual.

DECOMP-Decomposition –Participant's concept of decomposition gives no reference to microbiota as being involved in the process. i.e. "Plants will just decompose and make food for other plants."

DEPENDENCE- Dependence- Participant conceptualizes plants as being dependent on humans. This includes any reference to "ownership" of plants as well. i.e. "without the humans there, the plants would die."

ECOSYS-Ecosystem- Participant conceptualizes accurately the role or function of plants within the ecosystem. This includes mention of plants as populations, or as being within a community. i.e. "plants pass energy to consumers."

ENDO=MITO- Endoplasmic reticulum is the same as the mitochondria.
Participant confuses the endoplasmic reticulum with the mitochondria in either location or function. I.e. "cellular respiration is within the endoplasmic reticulum."

ENERGY = OXY- Energy is the same as oxygen.
Participant conceptualizes energy as oxygen, justifying oxygen needed to produce energy. i.e. "plants release energy in the form of oxygen."

EVOLU-Evolution.
Participant cites evolution within their conceptualization of the plant processes.
i.e. "plants are products of millions of years of evolution."

EXPERIENT-Experiential
Participant conceptualizes experiences outside of the classroom as source for knowledge.
i.e. "I used hot steam on my African violets, so I know they can't tolerate heat."

EXPLAINSET-Explaining Set
Participants are set in dyads with instructor's consultation according to high achievers and low achievers (on their first test). Participants explain responses to questions back and forth. Three tasks involved and one warm up.

EXPLICIT- Explicit
Participant directly uses systems in their conception, or related systems terms, such as components, input, output, interactions, and feedback.
i.e. “The plant interacts with lots of organisms in the ecosystem.”

FOOD/FERT-Fertilizer as plant “food”
Participants concept of a plant need for growth is “plant food” or fertilizer. i.e. “This plant must have had more food.”

FOODCHAIN –Food chain
Participant cites the food chain concept in explanation of interactions or other plant connection, while conceptualizing the two plant processes.
i.e. “plants have a role in the food chain as producers.”

FOODWEBS- Food web
Participant cites food web concept with interactions or other plant connections.
i.e. “plants are an important part of the food web.”

GENETICS- Genetics
Participant cites genetic variation as reason for the differences in the plants.
i.e. “That plant is a dwarf species.”

GLOBAL-Global
Participant conceptualizes a global perspective of plants importance and views both photosynthesis and cellular respiration as energy reactions, crucial in the flow of energy through an open system. i.e. Plants are important to the whole world, as they pass their energy from the sun to other organisms.”

GREENHOUSE- Greenhouse
Participants cites concept of the greenhouse effect in their conception of plant functions.
i.e. “Plants prevent the greenhouse effect by reducing CO_2 build up.”

IMPLICIT-Implicit statement on systems
Participant implicitly refers to systems in their conceptions. i.e. “These all work together to make sugar.”

INFLUPARTN-Influence of Partner
Evidence that participant has direct or indirect influence from prior comments from their dyad partner. i.e. “as she just said” or “ I agree with that.”

INTERACT-Interactions
Participant conceptualizes components of systems and subsystems as interacting. This may be expressed as members of the community interacting with the plants, or as intra-specific interactions.
i.e. “Light has to strike the chlorophyll within the plant cell.”

INTERCONN- Interconnected
Participant conceptualizes photosynthesis and cellular respiration as being connected, with shared molecules within the same biological system.
i.e. “Plants do both processes.”

INTUITIVE- Intuitive
A statement which indicates reasoning from core intuitions, often said with “tentativeness” and while searching for an explanation. i.e. “ Well, I’m not sure. Maybe plants just need chlorophyll.”

KNOW – Know
Participant provides explanation for how they know about plants. i.e. “It’s just common sense, you just have to water them.”

LAB- Lab
Participant uses the context of the lab within their explanation or conception of the two plants processes. i.e. “We hid the plant in a cupboard for two days, in the lab. That’s how I knew.”

LEAF-Leaf
Participants has conceptualized the function of the leaf, or some aspect of the leaf’s growth or anatomy inaccurately.
i.e. “The leaf must shed to grow.” “Leaves deter bugs from the roots.”

LECTURE-Lecture
Participant uses an explicit lecture reference within their explanation of the concept. i.e. “in lecture, she said that plants do respire.”

LIFECYCLE –Life cycle
Participant provides an example or an explanation of life cycle, or of a sycle that is not aligned with the accepted scientific conception. It includes comments which suggest that cycles are lock step procedures and are not necessarily continuous.”
i.e. “A food chain is a sort of life cycle.”

LIGHT – Light
Participant’s concept of what the plant needs for growth includes light.
i.e. “This plant must have had more sunlight.”

LIKEME-Like Me Referent
Participants pre-conceptions compare plants with humans favorably, or as being similar to humans in a positive manner.
i.e. “humans and plants are a lot alike, more so than people know.”

MECHPROX-Mechanistic Proximate
Participant's justification for the conception cites a specific physical/biological agent. i.e. "Plants grow using water, soil and light."

MECHULT-Mechanistic Ultimate
Participant's justification for the conception cites a long-term (usually genetic) agent. i.e. "Maybe this plant is a dwarf species."

METACOG- Meta-cognition
Participant's self reflection of attainments of knowledge includes their source of knowledge and how they have made sense of the knowledge attained.

MISCONCEPT-Misconception
Participant's conception that is not scientifically accurate; especially those misconceptions which have been documented in prior literature.
i.e. "plants don't respire."

MULTILEVEL-Multiple Ecological Levels
Participant conceptions suggest that photosynthesis and/or cellular respiration takes place at multiple ecological levels. It includes within the same paragraph (or statement) correct references to biochemical, cellular, organism, ecosystem or global references. i.e. "The plant photosynthesizes, by absorbing light within the chloroplast to transform energy."

NCBIOCHEM- Not correct biochemical level conception
Participant has an erroneous conception of the biochemical relationships within photosynthesis and cellular respiration.
i.e. "The plant needs O_2 for photosynthesis."

NCCELLULAR- Not correct cellular level conception
Participant has an erroneous conception at the cellular level of the processes of photosynthesis and cellular respiration.
i.e. "Everything takes place in the mitochondria."

NCGLOBAL –Not correct global level conception
Participant's conception at the global level is inaccurate. It includes an inaccurate perspective of plants' importance in the world.
i.e. "Everything dies without plants."

NEED4CHANG-"Need for change" p-prim
Participant's conception includes a preconception that the plant has a need for change and responds to that need. i.e. "Plants will change with the disruption of photosynthesis."

NESTSYST- Nested Systems
Participant's conceptions include a view of systems as being nested, one inside the other, with interactions between the subsystems and components.
i.e. "The smaller parts have to work in order for the larger parts to work."

NOCO$_2$ – No carbon dioxide listed for input
Participant's conceptions do not include carbon dioxide (CO_2) as a needed input for photosynthesis. i.e. "plants don't use CO_2, they need oxygen."; "plants need light, water, and food."

NOR-No respiration
Participant's conceptions suggest that plants do not respire. i.e. "plants don't need cellular respiration."

NOTLIKEME- Not Like Me Referent
Participant's preconceptions compare plants with humans, unfavorably, or as being similar to humans in a negative way.
i.e. "plants can't move around, the way people can."

ONEEQUAT-One Equation
Participant conceptualizes the two processes as one equation. Ex: "…the carbon is taken off the CO_2 molecule, and it is released as O_2. That's respiration."

ORGANISM-Organism
Participant's conception includes knowledge at the level of the plant, or there is evidence that the participant may view the plant as an independent organism. i.e. "plants photosynthesize and make their own food."

OSMOSIS- Osmosis
Participant's conception uses the concept of osmosis. i.e. "plants use osmosis to get water from the soil."

OTHECOL- Other ecological concept
Participant uses other ecological concept in their conception of the two plant processes, such as food chains, the greenhouse effect, either as explanation, or as support for their explanation.

OTHERSUB-Other subjects
Participant uses other biological science or physical science concepts as explanations for plant processes, or incorporates other subjects into their conception of the two plants processes.

OTHORGAN-Other organisms
Participant's conception includes an expressed need for other organisms for the survival of the plant, such as the need for birds and bees for pollination.
i.e. "plants need bees and birds to pollinate."

OZONE- Ozone
Participant's conception uses the ozone concept in their explanation of photosynthesis and cellular respiration, or in their expression of plant as a beneficial organism.
i.e. "plants help stabilize the ozone layer."

PIGGYBACK- Piggyback
Participant's conception of the processes has a beginning in the conception of another participant. This differs from the influenced code, as it may be an extension of the other participant's conception, but without direct citation by the participant.
i.e. 1st participant: "plants would not survive in the jar."
2nd participant: "they wouldn't survive because there isn't enough carbon dioxide."

PLANTNEED- Plant needs
Participant's conception includes the conditions or requirements for plant growth.

PLANTS- Plants
Participant uses the plant as a focus of discussion of photosynthesis and cellular respiration, and expresses such specific plant concepts as seed dispersal, plant conditions, and the interactions of other organisms.

POLLINAT- Pollinate
Participant's conception of plant interactions includes pollination by other organisms.
i.e. "plants interact with bees when they pollinate."

PREDET-Predetermined
An explanation that implies a supernatural cause, or a cause that is inherent in nature. i.e. "plants photosynthesize because that's the nature of plants to do that."

RATIONALE-Rationale
Participant includes a rationale for their conception. The rationale may be the context of their learning, their influence from a dyad partner, an intuitive conception, some mode of reasoning, or a statement of metacognition.

REASONING- Reasoning
The justification participants give for their conceptions, or for the conclusions drawn. i.e. "Plants need photosynthesis to survive."

RELATIVES- Relatives
Participant's conception includes an experience provided by a relative as a form of direct learning. i.e. "I learned about plants from my Grandma."

REPRO- Reproduction
Participant's conception of the two plant processes involve a reference to reproduction, either at the cellular level, or at the level of the organism. i.e. "This plant is older, it's sexually mature, it has buds."

RESP=BREAT- Cellular respiration equals breathing.
Participant's conception of cellular respiration suggests that respiration is breathing, an not an energy reaction.
i.e. "plants breathe out O_2 in cellular respiration."

RESPVREPRO- Cellular respiration is part of the reproductive process.
Participant's conception of cellular respiration suggests that respiration is a reaction that augments, or assists, or is part of the reproduction process.
i.e. "plants use cellular respiration to make buds."

SEEDDISP-Seed Dispersal
Participant's conception suggests that a main interaction of plants within the ecosystem is for seed dispersal. i.e. "plants interact with other organisms when they hook their seeds on them."

SENSE- Sense
Participant provides explanation for how they have made sense of their knowledge about plants. i.e. "Well, I just try to look it up again, to make certain it's correct."

SOCIOVIEW-Sociological view
Participant uses a sociological view within their conception of the plant processes. i.e. "Within the ecosystem jar, people will step backwards, having no need for clothing."

SYSTEMS- Systems
Participant's conceptions of plants are as belonging within a series of systems (photosynthesis and cellular respiration as interconnected); having multiple ecological levels (biochemical, cellular, organism, ecosystem, and global), and as "nested" subsystems within larger systems.

TAUTO- Tautological
Participants provides an explanation which is circular in it's logic. i.e. plants photosynthesize because that's what plants do."

TEACHINFLU-Teaching Influence
Participant uses an explicit experiences with their teacher, or a specific quote from their teacher in the explanation of the concept.
i.e. "Dr. X. called ATP, an energy currency."

TELEO-Teleological
Participant provides an explanation which cites the end result as the agent for determining the nature of the phenomena.
i.e. "Plants use sunlight to make food, that's why they do that."

TEXTBOOK- Textbook
Participant references the textbook within their explanation of the concept.
i.e. "in the book it said ATP is energy."

UTILITY- Utility of plants
Participant's conception of plant includes the suggestion that plants have a purpose in their use by humans. i.e. "plants are used as medicine."

VISUAL- Visual
Participant provides a context for their knowledge about the processes as being from some image or a picture. i.e. "I am trying to remember the picture that I studied."

VOCAB- Vocabulary
Participant uses a vocabulary word that was within the context of their instruction. The term was applied to the plant process. The term was correctly applied.
i.e. "plants are producers."

VOCABERROR- Vocabulary in Error
Participants use a vocabulary word that was within the context of their instruction. The term is in error, wither a hybridized term, or inappropriately applied.
i.e. "Plants are consumers."

WATER- Water
Participant's concept of what a plant needs for growth includes water.
i.e. "this plant must have had more water."

Field Observations and the Instructor Interview
Field observations and the instructor interview was coded differently, with more attention to the teacher's pedagogical approach to the two topics, and more attention to field and their instructor's approach as context for the pre-service teachers' conceptions.

ANALOGY- Analogy
Instructor uses an analogy to aid pre-service's teachers' conception of a concept. i.e. "ATP is the energy currency."

BIOCHEM- Biochemical
Instruction concentrates on the biochemical level of the plant processes.
Ex: "That is how the ATP is made, by electron transfer."

CELLULAR- Cellular
Instruction concentrates on the cellular level of the plant processes.
Ex: "This takes place in the matrix of the mitochondria."

ECOSYS-Ecosystem
Instruction concentrates on the ecosystem level of plants interaction within their community. This includes mention of plants as populations, or as being within a community. i.e. "plants are producers."

EXPLICIT- Explicit
Instructor directly uses systems in their instruction, or related systems terms, such as components, input, output, interactions, and feedback.
i.e. "This is an open system, where energy flows."

GLOBAL-Global
Instruction centers on a global perspective of plants importance and views both photosynthesis and cellular respiration as energy reactions, crucial in the flow of energy through an open system.
i.e. "Plants are produce food for the majority of the living organism on the planet"

IMPLICIT-Implicit statement on systems
Instructor only implicitly refers to systems within the instruction.
i.e. "Without this, there is no source of energy."

INTERCONN- Interconnected
Instruction centers on photosynthesis and cellular respiration as being connected, with shared molecules within the same biological system.
i.e. "Plants can do both."

MISCONCEPT-Misconception
Instructor provides an opportunity for the pre-service teacher to misunderstand the conception. This applies to statements which could lead to misconceptions of the learners. i.e. “photosynthesis and cellular respiration are opposites.”

MOTIVAT-Motivation
Instructor suggests that motivation is a factor in pre-service teacher learning, or within the field observation, if instructor attempts to motivate the participants.
i.e. “There is a whole group that frankly, doesn’t care.”

MULTILEVEL-Multiple Ecological Levels
Instruction suggests that photosynthesis and/or cellular respiration takes place at multiple ecological levels. It includes within the same paragraph (or statement) correct references to biochemical, cellular, organism, ecosystem or global references. i.e. “Chlorophyll within the chloroplasts absorbs the light, which then can raise the electron to a higher energy level.”

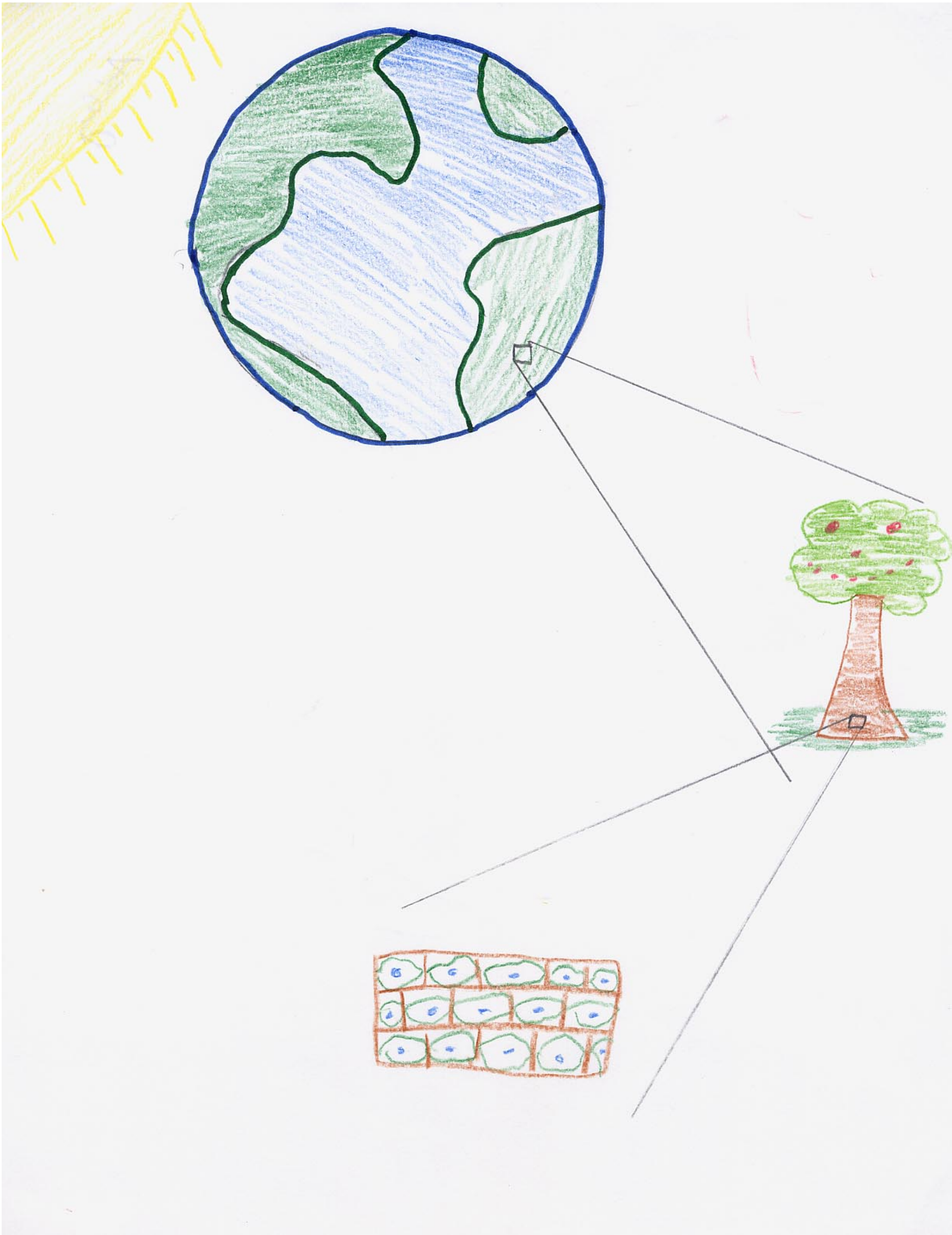
NESTSYST- Nested Systems
Instruction is centered on a view of systems as being nested, one inside the other, with interactions between the subsystems and components.
i.e. “Oxygen must be present for this process to take place, no oxygen, the plant will not be involved in cellular respiration. “

ORGANISM-Organism
Instruction is centered on the level of the plant, or there is evidence that the instructor is referring to the plant as an independent organism.
i.e. “We know from working in the lab with the plants.”

SYSTEMS- Systems
Instructor makes reference to plants as belonging within a series of systems (photosynthesis and cellular respiration as interconnected); having multiple ecological levels (biochemical, cellular, organism, ecosystem, and global), and as “nested” subsystems within larger systems.

TEXTBOOK- Textbook
Instructor specifically references the textbook within her explanation of the concept.
i.e. “Your text has this illustration.”

Appendix H: Ann's Meta-Representation



Appendix I: Textbook Content and Coverage

Chapter #	Title	Week #
Chapter 29	"An Interactive Living World: Populations and Communities in Ecology" (p. 660-691) T=31	One
Chapter 30	"An Interactive Living World: Ecosystems and the Biosphere" (p. 692-725) T=33	One
Chapter 2	"The Fundamental Building Blocks: Chemistry and Life" (p. 18-35) T=17	Two
Chapter 3	"Water, pH and Biological Molecules" (p. 36- 67) T=31	Two
Chapter 4	"Life's Home: the Cell" (p. 68-95) T= 27	Two and Three
Chapter 5	"Life's Border: The Plasma Membrane" (p. 96-115) T= 19	Three
Chapter 6	"Life's Mainspring: An Introduction to Energy" (p. 116-129) T=13	Three
Chapter 7	"Vital Harvest: Deriving Energy from Food" (p.130-147) T=17	Three
Chapter 8	"The Green World's Gift: Photosynthesis" (p.152-169) T=17	Three
Chapter 9	"Introduction to Genetics: Mitosis and Cytokinesis" (p.170-189) T=19	Four
Chapter 10	"Preparing for Sexual Reproduction: Meiosis" (p.190-203) T=13	Four
Chapter 13	"DNA Structure and Replication" (p. 254-267) T=13	Five
Chapter 14	"How Proteins Are Made: Genetic Transcription, Translation, and Regulation" (p.268-291) T=23	Five
Chapter 11	"The First Geneticist: Mendel and His Discoveries" (p. 206-229) T=23	Five
Chapter 12	"Chromosomes and Inheritance" (p. 230-253) T=23	Five

Appendix I Continued: Textbook Content and Coverage

Chapter 16	"An Introduction to Evolution: Charles Darwin, Evolutionary Thought, and the Evidence for Evolution" (p. 320-337) T=17	Six
Chapter 17	"The Means of Evolution: Microevolution" (p. 338-355) T=17	Six
Chapter 18	"The Outcomes of Evolution: Macroevolution" (p. 356-375) T=19	Six
Chapter 20	"Pond Dwellers, Log Eaters, and Self-Feeders: The Diversity of Life" (p.404-435) T=31	Seven
Chapter 21	"Movers and Shakers: The Animal Kingdom" (p. 436-472) T=36	Seven
Chapter 24	"Introduction to Animal Anatomy and Physiology: The Integumentary, Skeletal, and Muscular Systems" (p. 526-549) T=23	Eight
Chapter 26	"Transport, Nutrition, and Exchange: Blood, Breath, Digestion and Elimination" (p. 590-619) T=29	Eight
Chapter 28	"How the Baby Came to Be: Human Reproduction" (p. 634-659) T=25	Nine

Total Reading Assignment = 533 pages; average of 59.2 pages per week.

Chapters that were not assigned during the Nine-week Session
Chapter 1 "Science as Way of Learning: A Guide to the Natural World"
Chapter 15 "The Future Isn't What It Used to Be: Biotechnology"
Chapter 19 "A Slow Unfolding: The History of Life on Earth"
Chapter 22 "An Introduction to Flowering Plants"
Chapter 23 "Form and Function in Flowering Plants"

Appendix J: Details of Chapters Seven and Eight

Chapter/ Section	Section Headings
Seven: Vital Harvest: Deriving Energy From Food	Opens with narrative on 1996 Mt. Everest Climb
7.1	Energizing ATP: Adding a Phosphate Group to ADP
7.2	Electrons Fall Down the Energy Hill to Drive the Uphill Production of ATP
7.3	The Three Stages of Cellular Respiration Glycolysis, the Kreb’s Cycle and the Electron Transport Chain
7.4	First Stage of Respiration: Glycolysis
7.5	Second Stage of Respiration: The Kreb’s Cycle
7.6	Third Stage of Respiration: The Electron Transport Chain
7.7	Other Food, Other Respiratory Pathways
Essays	When Energy Harvesting Ends at Glycolysis, Beer can be the Result
	Energy and Exercise

Appendix J Continued: Details of Chapters Seven and Eight:

MediaLab	Dietary Fad or Miracle Drug? Using Science to Understand Metabolism
Eight: The Green World's Gift Photosynthesis	Opens with narrative of sunset on a pond.
8.1	Photosynthesis and Energy
8.2	The Components of Photosynthesis
8.3	Stage 1: The Steps of the Light-Dependent Reactions
8.4	What Makes the Light-Dependent Reactions so Important?
8.5	Stage 2 of Photosynthesis: The Light Independent Reactions
8.6	Photorespiration: Undercutting Photosynthesis
8.7	A Different Kind of Photosynthesis: The C_4 pathway.
8.8	Another Photosynthetic Variation: CAM Plants
Essay	How Did We Learn? Plants Make Their Own Food, But How?
MediaLab	Capturing Sunlight to Make Food: Photosynthesis

Appendix K: Laboratory Summary Questions

Questions:

A: pH change as an indicator of CO_2 production

1. When you blew bubbles into the beaker what did the color change to?
2. What was in your breath that caused a color change of the water in the beaker?
3. Did the solution in the beaker become more acidic or more basic after you blew bubbles in it?
4. Did the pH of the solution in the beaker increase or decrease after you blew bubbles in it?

B: Plant respiration

1. What test tube changed color and why?
2. Why didn't the tube with the heat-killed corn change color?

C: Photosynthesis and Light:

1. Was there a difference in the amount of starch present in each leaf? Why do you think this was the case?

D: Photosynthesis and Chlorophyll:

1. Was there a difference in the amount of starch present in each leaf? Why do you think this was the case?

E: Photosynthesis and CO_2:

1. Was there a difference in the amount of starch present in each leaf? Why do you think this was the case?