Secondary Biology Preservice Teachers' Conceptual Understanding of the Chemical Processes of Photosynthesis and Cellular Respiration

Edwin Estime

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Secondary Biology Preservice Teachers' Conceptual Understanding of the Chemical Processes of Photosynthesis and Cellular Respiration

By

Edwin Estime´

Doctoral Candidate

A Dissertation

Submitted to the

Faculty of Kennesaw State University

In Partial Fulfillment of the

Requirements for the Degree of

Doctor of Education

In

Secondary Education

Chemistry

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PRESERVICE TEACHERS’ CONCEPTUAL UNDERSTANDING

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There are few people in my life that without their unwavering support, this journey would not be possible. First of course, Dr. Kimberly Cortes, Dr. Michelle Head, and Dr. Carolyn Wallace; this would not be possible without my dissertation committee. Dr. Kim Cortes, my mentor, you have my sincerest thanks. Your influence made me captivated with this topic. Your guidance and suggestions throughout every step of my journey were invaluable. Dr. Head and Dr. Wallace, thank you for wanting to commit as part of the dissertation committee. Thank you for your advice, ideas, and patience in guiding me through this journey. To my friends, Sarah B. Holcomb and Alecia Hagberg, together we struggled, encouraged one another, and together we completed this journey. Jason Faust, I want to thank you so much for the countless times you have read this dissertation and helped me present a work that I can be proud of.

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Most of all, I want to thank the All Mighty for granting me opportunity, meeting the right people, and granting me the strength and health so that I can stand proudly with my head held high.
Abstract

Photosynthesis and cellular respiration are important topics taught in most high school biology curriculum. These processes emphasize the interrelationship between the abiotic and biotic factors found in our world. The portrayal of these relationships to students is recommended by using crosscutting concepts such as Energy and Matter: flow, cycles, and conservation and Systems and System Models, which are discussed in this study. The conceptual knowledge of photosynthesis and cellular respiration has been studied widely amongst middle, high school, and college students. Before this study, only primary preservice teachers were examined for the conceptual knowledge of these biochemical processes. This dissertation sets out to 1) investigate secondary biology preservice teachers’ application of the cycling of matter within photosynthesis and cellular respiration, 2) discover their conceptual understanding of energy and its flow within the biochemical processes, and 3) examine what key chemistry topics the preservice teachers identify are within the processes. Six participants were asked to describe in detail two application questions about the photosynthesis and cellular respiration and two questions where they were to describe the biochemical processes within a single cell. They were also given 45 pre-determined terms related to the processes to create a concept map. Results of this study coincided with other conceptual studies of different populations. Novel to this study, participants generally had a stronger conceptual understanding of biochemical processes of cellular respiration than photosynthesis. It was also discovered that preservice teachers viewed cellular respiration as its own system while photosynthesis was often viewed as a quasi-system which is incomplete without cellular respiration.
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Chapter 1 Introduction

There were two events during the mid-1900s that shook the United States’ view of themselves: the attack on Pearl Harbor and the launch of the Soviet Union’s Sputnik. The launch of Sputnik sparked reform efforts in education nationwide. One of these changes directed how science is taught in K-12 science classrooms (Rutherford, 1997).

Research has shown that the content subject matter knowledge of the teacher is an essential element in the learning process of the student (Haider, 1997). Interestingly, in contrast to class size and group heterogeneity, teacher effect has a greater impact on student achievement (Wright, Horn, & Sanders, 1997). Teachers who had successfully passed more college-level science courses were more likely to have a greater effect on student achievement (Perkes, 1967). The enhancement of quality of educators in the classroom will do more for students who are at risk educationally, those inclined to fail, than decreasing the class size or improving capital stock by any sensible margin (Ferguson, 1991). To this end, the legitimate initial step in enhancing student achievement is distinguishing teachers’ conceptual comprehension of science ideas they are required to teach (Krall, Lott, & Wymer, 2008).

Recently, the knowledge base of preservice science teachers has been widely studied (Van Driel & Jong, 1999). To be effective, preservice teachers must have an appreciation of the content’s complexity, richness, and potential (Haider, 1997). It is important that research is conducted so that there is an understanding of the conceptual knowledge of preservice teachers and development of instructional interventions to help increase their content knowledge. Within education, developmental, and experimental psychology, conceptual change studies began in the 1970s. This movement became of huge interest throughout the 1980s-1990s (diSessa, 2014).
Pfundt and Duit (1988) created a bibliography that consisted of a collection of literally hundreds of studies discussing the topic of student conceptual knowledge.

Research has shown that preservice teachers hold alternative conceptions for a variety of science concepts (Atwood & Atwood, 1996). Typically, conceptual knowledge research consists of a misconception study to which the researcher can apply open-ended questions, multiple-tier diagnostic tests, concept mapping, prediction-observation explanations, interviews, drawings and word associations (Dikmenli, 2010; Kose, 2008; Nyachwya et al., 2011). Misconception research may have many benefits, but there is often a negative connotation to prior knowledge (diSessa, 2014). The tenets of constructivism emphasize growth of knowledge as constructed from prior knowledge (Smith, diSessa, & Roschelle, 1993). This viewpoint accentuates misconceptions as a growth model versus considering it as a deficit to the student.

Photosynthesis and cellular respiration are major biochemical processes that are taught in high schools across the country. According to Georgia Standards of Excellence (GSE), the concepts of photosynthesis and cellular respiration are required concepts in high school biology. Photosynthesis is described as the conversion of light energy (kinetic energy) from the sun into the chemical bonds (potential energy) of a carbohydrate molecule such as glucose. Glucose would then enter the mitochondria and undergo the process of cellular respiration. Inside the mitochondria, glucose molecules undergo a series of chemical reactions to generate ATP (Brown & Schwartz, 2009). Through the formation of the orthophosphate and ADP from the hydrolysis of ATP, the energy to power cellular function is released (Galley, 2004).

The GSE requires that students are to provide explanations on the cycling of matter and the flow of energy within the processes of photosynthesis and cellular respiration (Georgia Department of Education, 2016a). There has been an increased emphasis on the connection of
biological sciences and the interrelationships with other disciplines (Mayr, 1997; Wandersee et al., 2000). These interrelationships and interactions should be comprehended as it illustrates the interconnections of different components of the world. For example, energy and matter flow is an important topic that bridges the biotic and abiotic world (Lin & Hu, 2003). The main themes of cycling of matter and flow of energy are derived from crosscutting concepts included in the Next Generation Science Standards (NGSS). Crosscutting concepts allow for the integration of multiple disciplines in a particular topic. Energy and Matter: flows, cycles, and conservation, and systems and system models are crosscutting concepts discussed in this dissertation (Next Generation Science Standards [NGSS], 2013).

**Purpose**

Photosynthesis and cellular respiration are referred to in terms of energy flow and matter cycling as a bridge between the living world and the non-living world. Teachers of biology should teach the interrelationships between the biotic and abiotic aspects of photosynthesis and cellular respiration. These aspects are especially highlighted in the crosscutting concept, Energy and Matter. As of writing of this dissertation, crosscutting concepts in literature have been limited to its implications in teacher professional development. There is a lack of research of teachers’ conceptual understanding of the crosscutting concepts. As stated above, preservice teachers hold alternative conceptions. Gess-Newsome (1999) believes that teachers must have a “deep and highly structured content knowledge that can be accessed flexibly and efficiently for the purposes of instruction” (p. 53). Brown and Schwartz (2009) asserts that preservice teachers, even with high confidence levels, demonstrates a limited understanding of the content that they are pursuing to teach. Currently, scientific literature exists that describes the alternative conceptions of primary preservice teachers on the topics of photosynthesis and cellular
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respiration (Brown & Schwartz, 2009; Cakiroglu & Boon, 2002; Harlen, 1997). As of the writing of this study, no literature exists that examines secondary preservice teachers’ conceptual knowledge on the same topics. The purpose of this study is to examine and identify secondary biology preservice teachers’ conceptual knowledge of the biochemical processes of photosynthesis and cellular respiration. This study will add on to the existing literature about the conceptual understanding of preservice teachers of the topics of photosynthesis and cellular respiration, will inform inservice teachers who are mentors to preservice teachers and inform education preparation programs so that they can provide meaningful instruction that will address preservice conceptual knowledge. This dissertation attempts to answer the following question: What conceptual understanding do secondary preservice biology teachers hold about the biochemical concepts relating to the cycling of matter and the flow of energy in photosynthesis and cellular respiration?
Chapter 2 Literature Review

This chapter provides the context pertaining to this study. The theoretical framework, misconception research, teacher content knowledge, photosynthesis, cellular respiration and crosscutting concepts are the main topics of this chapter. This chapter will address how the literature within these main topics were the frameworks used as a guide in the development and analysis of this dissertation.

Theoretical Framework

A paradigm is a philosophical stance a researcher maintains that illustrates a collection of fundamental ideas and beliefs which guide the action within the research. The paradigm describes the realities of the world, his/her place in it, and interrelationships of all the inner parts of the world of the researcher (Guba & Lincoln, 1994). Paradigms are often called philosophical assumptions (Creswell, 2012). These core beliefs are comprised of the responses of three fundamental questions: ontological, epistemological, and methodological (Guba & Lincoln, 1994). Ontology is the philosophical assumption that describes the researcher’s understanding of the nature of reality (Guba & Lincoln, 1994), or in simpler terms, an individual’s view of reality and being (Mack, 2010). For instance, if a real reality is accepted, then what can be thought about this reality is "the way things truly are" and "how things truly work" (Guba & Lincoln, 1994). At that point, just those inquiries that identify with matters of real presence and real activity are acceptable; different investigations, such as those concerning matters of taste or moral impact, fall outside the domain of scientific inquiry (Guba & Lincoln, 1994). Epistemology allows the researcher to define what is considered knowledge and how knowledge claims are justified (Creswell, 2012). Mack (2010) summarizes epistemology as to how an individual obtains knowledge. The epistemological assumption is directly correlated with the
ontological assumption (Guba & Lincoln, 1994). Methodology is the process that researchers take to collect data and information (Creswell, 2012). Similar to epistemology, the methodology used is constrained to ontological and epistemological beliefs. Depending on how the researcher answers these fundamental questions influences the methodology, whether it would be qualitative (observational) or quantitative (covariance analysis). The answers to these basic questions will serve as the focal point in which the considered paradigms will be analyzed (Guba & Lincoln, 1994).

Constructivism illustrates how a person gains, develops, and uses cognitive processes. The fundamental assumption of constructivism is that people create knowledge from the interaction between existing knowledge and the new ideas or circumstances they experience. Multiple theories, those of Piaget and Vygotsky for example, have been proposed to clarify the intellectual procedures that are associated in constructing knowledge. While constructivism offers the epistemological framework for many of these theories, it is not itself a rationalization for the psychological elements concerned in acquisition of knowledge (Airasian & Walsh, 1997). As cognitive constructivism resulted from Piaget’s research (1972), which defines learning as an act of accommodation, assimilation, and equilibration, Knowles’s (1979) adult learning principles state that learning is an active process in which people construct new knowledge from current understanding, which is a major theme in constructivist theory (Brandon & All, 2010). The task of the learner is to pick out ideas, transform them, and reconstruct them in a way that makes sense to his/her self.

Relativism is the ontological foundation of constructivism (Guba & Lincoln, 1994). Cupchik (2001) describes the ontological thought of relativism as “local and specific constructed realities” (para, 1). He explains that reality is constructed from meaning-making deeds of the
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knower and groups of individuals (Cupchik, 2001). Guba and Lincoln (1994) argue that these constructions are the product of human intellect but change as the knower becomes more informed and sophisticated. The epistemology of constructivism is described as transactional and subjectivist (Guba & Lincoln, 1994). The researcher and the subject of the researcher must be interactively linked so that the findings or meanings are interpreted (Guba & Lincoln, 1994; Schwandt, 1994). Schwandt (1994) states that constructivists are less concerned with methodology and focused more on the matters of knowing and being. Similarly to Schwandt, Erickson (1985) noted that in interpretive work, methods are the most unremarkable aspect. Understanding the relationship between the researcher’s purpose and the method are often masked by the focus on the method such as data collection and analysis. Schwandt (1994) further explains that the point of paying utmost attention to the details, multifaceted nature, and situated meanings of the regular day to day existed world can be accomplished through an assortment of techniques. Even though researchers may feel professionally constrained to utilize a special dialect for this methodology (such as participant, observation, informant, interviewing), fundamentally, every single interpretive researcher watches, tunes in, asks, records, and inspects. How those techniques may best be characterized and utilized relies upon the researcher’s motivation for doing the study. Motivation (purpose), thus, is formed by epistemological and methodological responsibilities (Schwandt, 1994).

Misconceptions

As of now, no one can pinpoint when and where science originated. Misconceptions are also as old as science. Curious early humans sought to understand the forces of nature that controlled their lives. They used simple scientific methods to make observations, recognizing patterns and relationships, and ultimately trial and error. Often, people would look to the leaders
of their groups for answers to the questions of nature around them. These leaders would often
develop stories in order to explain many unexplainable phenomena. Some of these stories or
explanations persisted through time until it was fully incorporated into the cultures’ beliefs.
Some of these explanations are still with us today. These beliefs became common knowledge or
common sense (Krebs, 1999). Krebs (1999) stated that common sense concepts led to numerous
non-rational explanations of natural phenomena. Even though common sense prompted many
misinterpretations of nature, it did not generally result in dead ends, but instead to a continuing
curiosity and looking for better, more scientifically acceptable answers. There is almost an
infinite amount of misconceptions through the history of humankind (Krebs, 1999).

Beginning in the mid-1970s, an enormous social movement, "misconceptions" started the
present day conceptual change research in education. The development exploded in the mid-
1980s, brought forth tons of literature, and fell off to some degree in the mid-1990s, even though
its impact is still felt (diSessa, 2014). Driver, Viennot, and Tiberghien were important
contributors to misconception research, including instructional intercessions of themes like
primary school students’ conception of matter, middle school students’ conception of heat and
temperature, and high school students’ conception of motion and force (Driver, 1989;
Tiberghien, 1980; Viennot, 1979). Hawkins (1978), Minstrell (1982), and McCloskey (1983a,
1983b) were early important misconception researchers in the U.S. Hawkins portrayed the
existence of misconceptions that efficiently impedes science learning as "critical barriers"
(1978). Others utilized diverse terms for a similar thought, for example, alternative conceptions,
alternative frameworks, intuitive or naive theories, and naive beliefs.

One of the main objectives of science education is to enable students with scientific
concepts and principles that will be beneficial to the individuals participating as scientifically
literate citizens (Sequeira & Leite, 1991). Misconceptions are ideas that are not supported by the scientific community (Luxford & Bretz, 2014). According to research, students come to class holding many misconceptions. Most students develop these misconceptions before beginning formal science instruction and that these misconceptions persist even though scientifically accepted theories and concepts have been introduced and taught (Stein, Larrabee, & Barmen, 2008). Interestingly, misconceptions are often interpretations of natural events derived from leading intellectuals (Lawson & Thompson, 1988). Misconceptions are very robust and resistant to change. As a consequence of this resistance, misconceptions interfere with learning (Smith, diSessa, & Roschelle, 1993). The constructivist learning paradigm is often used to interpret alternative conceptions (or misconception) research. The principle of constructivism illustrates that students “actively construct new meaning by using their present conceptual frameworks to interpret new information in ways that make sense to them” (Garnett, Garnett, & Hackling, 1995). Students will generate mental links between new constructs and existing concepts found within long-term memory. This may explain why misconceptions are often so resistant. It is well established that there is a need to target instruction to combat these misconceptions. Various strategies have been proposed for the diagnosis and remedy of the misconceptions (Wiser, 1995).

Within literature, there are synonymous terms used in place of misconception. These terms can be categorized into two groups: idiographic and nomothetic terms. Wandersee, Mintzes, and Novak (1994) explain that in nomothetic studies "knowledge is evaluated by its conformity to (or deviation from) a standard knowledge base (accepted scientific knowledge)” (p. 179). In other words, students' conceptual knowledge is assessed according to the comparison between their responses to current scientific facts. Nomothetic terms are used in quantitative inquiries that make comparisons to the recognized scientific theories. Examples of nomothetic
terms are misconceptions, naïve conceptions, conflicting notions, classroom mismatches, and erroneous conceptions (Luxford & Bretz, 2014). These terms are often used in experimental (quantitative) studies, which often use pencil-and-paper tests and inferential statistics (Wandersee, Mintzes, & Novak, 1994). Idiographic terms are used in qualitative inquiries that investigate explanations constructed by participants to comprehend their experiences.

Wandersee, Mintzes, and Novak (1994) state that idiographic literally means “self-written” moreover, it relates to “the student’s understanding of natural objects and events [which are] probed, studied, and analyzed” as it attempts to “raise awareness of possible perspectives pupils may bring and difficulties they may have, and hence enable more effective communication to take place” (p. 180). Such terms used in qualitative studies are alternative conceptions, children's science, developing conceptions, personal constructs, and intuitive beliefs (Luxford & Bretz, 2014). Idiographic investigations are typically more naturalistic, tend to use fewer students in greater detail, use student’s self-report information, and use thick description (Wandersee, Mintzes, & Novak, 1994). A full list of terms is represented in Table 2.1.
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Table 2.1

A full list of terms categorized by the type of study (Wandersee, Mintzes, & Novak, 1994)

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In assessing the misconception movement, diSessa (2014) stated that its positive contributions include: visibility for constructivist thought, added foci for instructional problems, and a change from mostly quantitative problem solving of misconceptions into more qualitative study. diSessa argued that despite these positive contributions, the movement consists of many studies devoid of theory as the depth of the misconceptions were not fully explored and the definition of concept often remained unexamined. Typically, any discussion about the learning was minimally discussed and misconception research often highlighted the negative impacts of prior knowledge (2014). In agreement, Smith, diSessa, and Roschelle (1993) explained that saying students’ misconceptions inhibit learning is an overemphasis of the discontinuity between
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experts and students. Ultimately, misconception research conflicts with the basic proposition of constructivism: advancement of knowledge is built upon prior understanding. Smith, diSessa, and Roschelle (1993) illustrated that using students’ prior conceptions as resources for growth of understanding coincides with constructivist theory. This perspective means to portray the interrelationships among diverse knowledge components as opposed to distinguishing particular misconceptions; it accentuates content refinement and reorganization, instead of substitution, as it gives a structure for understanding misconceptions as both imperfect and beneficial (1993).

Teacher Content Knowledge

As interests of the conceptual knowledge of students grew through the 1970s-80s, researchers also investigated the conceptual understanding of teachers (Park & Oliver, 2008). Shulman (1986) identifies three domains of knowledge that are inherent with teacher classroom effectiveness; content, pedagogy, and curriculum. Shulman (1986) defines content knowledge as “the amount and organization of knowledge per se in the mind of the teacher” (pg. 9). Pedagogical knowledge, Shulman (1986) explains, is the knowledge of teaching. Lastly, curriculum knowledge is defined as “full range of programs designed for the teaching of particular subjects and topics at a given level, the variety of instructional materials available in relation to those programs” (Shulman, 1986, p. 10). With this in mind, Schulman (1986) introduces pedagogical content knowledge (PCK). Shulman (1986) summarizes the idea of PCK as “the ways of representing and formulating the subject that make it comprehensible to others” (pg. 9). A study by Perkes (1967), who used a sample of 32 junior high school teachers and their students from the same school district. Through qualitative analysis such as classroom observations, examples of student work, and teacher surveys, Perkes (1967) concluded that the greatest student achievement in science was found when the students had a teacher who had a
higher GPA in college science courses, taken more and successfully passed college science courses, and recently enrolled in science courses. Interestingly, there was more integration of laboratory activities and the fostering of classroom discussions. The content subject matter knowledge of the teacher is an essential element in the learning process of the student (Haidar, 1997). Wright, Horn, and Sanders (1997) concluded in their study, that teacher effects had the greatest impression on student achievement in contrast to other aspects including class size and group heterogeneity. Ferguson (1991) added that “improving the quality of teachers in the classroom will do more for students who are most educationally at risk, those prone to fail, than reducing the class size or improving the capital stock by any reasonable margin, which would be available to policy makers” (p. 47). Krall, Lott, and Wymer (2008) suggest that “the logical first step in improving student achievement is identifying in-service teachers’ understanding of the science concepts they are expected to teach” (pg. 44). In agreement, Smith and Neale (1989) stated that teachers would not develop PCK until they have acquired a deeply principled conceptual knowledge of the content.

Shulman (1986) defined content knowledge as “the amount of organization of knowledge per se in the mind of the teacher” (p. 9). Shulman argues that content knowledge of a teacher should go beyond knowing of facts and concepts but requires understanding of the subject matter in the manner of substantive and syntactic structures (1986). Substantive structure is defined as the multitude of ways whereby the discipline’s fundamental ideas and principles are arranged to incorporate its facts. Syntactic structures of a discipline is the collection of ways of establishing truth or falsehood, validity or invalidity. When there are competing claims about a given phenomenon, a discipline's syntax offers the guidelines for assessing which claim has more warrant. Not only must teachers be able to define accepted truths in a domain for students.
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They also need to be able to explain why a particular claim is considered valid, why it is worth knowing, and how it relates to other claims, both within the discipline and interdisciplinary, both in theory and in practice (1986). Shulman argues:

*We expect that the subject matter content understanding of the teacher be at least equal to that of his or her lay colleague, the mere subject matter major. The teacher need not only understand that something is so; the teacher must further understand why it is so, on what grounds its warrant can be asserted, and under what circumstances our belief in its justification can be weakened and even denied. Moreover, we expect the teacher to understand why a given topic is particularly central to a discipline whereas another may be somewhat peripheral. This will be important in subsequent pedagogical judgments regarding relative curricular emphasis. (p. 9).*

Research has demonstrated that the subject content knowledge of a teacher will either enhance or limit the learning of their students. The content knowledge of a teacher is an essential element in the learning process of the student (Haider & Jalal, 2018). Science teacher educators must instill an appreciation of their content’s complexity, richness, and potential to the preservice teacher in order to effectively instruct students. Science education programs need to assess that the preservice teacher possesses rich science content and has the ability to apply the content to real-life circumstances outside the school (Haidar, 1997). In agreement, Cochran-Smith (2003) stated that preservice teachers’ conceptual knowledge could not be changed through implicit instructional approaches, but it must be addressed explicitly during education preparation programs. Kleickmann et al. (2013) found that university education preparation programs have better success in increasing the content knowledge of preservice teachers.
The focus of this dissertation is analyzing secondary preservice science teachers’ conceptual understanding of high school biology Georgia Standards of Excellence SB1.e. which states:

*Ask questions to investigate and provide explanations about the roles of photosynthesis and respiration in the cycling of matter and flow of energy within the cell (e.g. single-celled alga). (Clarification statement: Instruction should focus on understanding the inputs, outputs, and functions of photosynthesis and respiration and the functions of the major sub-processes of each including glycolysis, Krebs cycle, electron transport chain, light reactions, and Calvin cycle.)(Georgia Department of Education, 2016a).*

According to the Georgia Milestones Assessment System Study/Resource Guide for Students and Parents: Biology, students must understand the following:

- **Light reactions:** These reactions split water molecules, providing hydrogen and an energy source (ATP and NADPH) for the Calvin cycle. Oxygen is given off.
- **Calvin cycle:** This cycle is the series of reactions that form simple sugars using carbon dioxide and hydrogen from water.
- **Glycolysis:** The series of reactions takes place in the cell’s cytoplasm and is anaerobic (without oxygen). The glucose that entered the cell by active transport is broken down by enzymes into pyruvic acid. Two molecules of ATP are also produced.
- **Krebs cycle:** This cycle breaks down the products of glycolysis to produce molecules used in the electron transport chain.
Electron transport chain: This chain consists of a series of proteins in the mitochondrial membranes that convert ADP to ATP by transferring electrons.

(Georgia Department of Education, 2017)

The list above is required by the state of Georgia for high school students to understand; it is expected that preservice and in-service biology teachers have a greater depth and breadth of knowledge of biochemical processes than what is required (Shulman, 1986). This is especially true of photosynthesis and cellular respiration. The current literature addresses the conceptual knowledge of teachers about photosynthesis and cellular respiration (Hashweh, 2005) and primary preservice teacher conceptual knowledge of the same topic (Brown & Schwartz, 2009).

As of the writing of this dissertation, there has not been any research to investigate secondary preservice teachers, which whom will teach these biochemical processes to students. This dissertation research fills this gap by investigating secondary biology preservice teachers’ conceptual understanding of photosynthesis and cellular respiration.

ATP

Almost every metabolic pathway consumes or produces adenosine triphosphate (ATP). ATP coupling is responsible for the overall thermodynamic efficiency of any metabolic sequence whether be catabolic or anabolic. In catabolic reactions that are highly exergonic, most of the energy released is captured in ATP synthesis. While the thermodynamically unfavorable reactions of anabolism are proceeded by the energy from the hydrolysis of ATP (Garrett & Grisham, 2013).

Hydrolysis of ATP must occur to extract the energy. There are two pyrophosphoryl linkage in ATP. The hydrolysis of ATP exhibits large negative $\Delta G^\circ$ because of the “destabilization of the reactant due to bond strain caused by electrostatic repulsion, stabilization
of the products by ionization and resonance, and entropy factors due to hydrolysis and subsequent ionization” (Garrett & Grisham, 2013). When ATP reacts with water, the last phosphate group reacts with the water to form orthophosphate and ADP. The creation of the two new bonds releases the energy to drive cellular functions (Galley, 2004).

**Photosynthesis**

Organisms survive using one or both of two options to meet their cellular energy needs. One way some organisms generate cellular energy is through the process of photosynthesis. These organisms are called phototrophs. In terms of thermodynamics, solar energy supplies the energy for the carbon-carbon bond formation and reduction. The initial step of photosynthesis is the light absorption that occurs by a compound called chlorophyll, which is in the thylakoid membranes. Chlorophyll is comprised of four substituted porphyrin, which are coordinating the cation magnesium. The chlorophyll molecule also contains a long hydrocarbon side chain, which increases solubility within membranes (Boyer, 1999).

There are two types of photosystems. Photosystem I (also known as P700) consists of the primary acceptor chlorophyll $a$ and accessory pigments that absorb light in the range of 600 to 700 nm; Photosystem II (also known as P680) consists of chlorophyll $a$ and $b$ in addition to accessory pigments that absorb light primarily at 680 nm as shown in Figure 2:1. Light energy from the sun is absorbed by the chlorophylls and accessory pigments in the center of P700 (Boyer, 1999). An electron in P700 molecule absorbs the light energy and moves to a higher energy level creating an activated form, P700*. The electron then passes through a chain of electron carriers beginning with A$_0$, a form of chlorophyll that will cause a spontaneous flow of electrons. Phylloquinone (A$_1$) then receives an electron from A$_0$ and transfers an electron to
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Ferredoxin, an iron-sulfur protein. Ferredoxin-NADP⁺ oxidoreductase, a flavoprotein catalyst, will finally transfer electrons from the reduced ferredoxin to NADP⁺ (Boyer, 1999).

Figure 2.1: Illustration of the process of the photosystems I and II within the photosynthesis (Tameeria, 2007).

P700* becomes an electron-deficient species, P700⁺, when the excited electron is transported to A₀. P700⁺ regains an electron from another electron-transport chain that is driven by photosystem II. The light will excite an electron in Photosystem II to produce an activated form, P680*. Pheophytin (Ph), a chlorophyll-like electron acceptor, will accept the activated electron from P680* and transfer an electron to plastoquinone (Boyer, 1999). Reduced plastoquinone then transfers the electron to an electron transport chain linking Photosystems I and II together, which is composed of a cytochrome b6f complex. The cytochrome b6f complex is an assembly of several integral membrane proteins that use heme groups and iron-sulfur
centers to transport the electrons from the reduced plastoquinone to plastocyanin, a blue-copper protein. Reduced plastocyanin transfers an electron to P700\(^+\) (Boyer, 1999).

P680\(^+\) will regain electrons from the decomposition reaction of water. Water-splitting complex, a metalloprotein that contains a cluster of four manganese ions, oxidizes two water molecules to produce four protons, four electrons, and an oxygen molecule. The water-splitting complex will then transfer electrons from the water to the P680\(^+\). Photophosphorylation also accompanies the electron flow caused by the oxidation of water. Photophosphorylation describes the biochemical process of light energy conversion into chemical energy in the form of adenosine triphosphate (ATP) (Boyer, 1999). Protons that are released from the oxidation of water are pumped through the thylakoid membrane from the stromal side to the inner compartment. CF\(_0\) and CF\(_1\), which together comprises ATP synthase of chloroplasts, are located on the outer surfaces of the thylakoid membranes. When the protons flow through CF\(_0\), the proton channel of the thylakoid membrane. Then through CF\(_1\), the membrane protein that contains the binding and catalytic sites for the binding of adenosine diphosphate (ADP) and P\(_i\); it activates the phosphorylation of ADP to ATP. For every pair of electrons transferred from water to NADP\(^+\), one to two ATP molecules are formed by photophosphorylation (Boyer, 1999).

The biochemical energy products of the light reactions, ATP and NADPH, are used by plants to convert carbon from CO\(_2\), into simple organic molecules that are used as building blocks for glucose, sucrose, starch, and other carbohydrates. This process is called dark reactions, the Calvin cycle or light independent cycle, as it does not need the direct involvement of light (Boyer, 1999) which is illustrated in Figure 2.2.
The enzyme ribulose 1,5-biphosphate carboxylase/oxygenase, also known as rubisco, catalyzes the addition of carbon from CO$_2$ to ribose 1,5-bisphosphate creating the intermediate 2-carboxy-3-keto-arabintol (Boyer, 1999). Hydrolysis of the C$_2$ – C$_3$ bond of the intermediate produces two molecules of 3-phosphoglycerate where the carbon dioxide is now carboxyl groups of the two molecules (Garrett & Grisham, 2013). The carboxyl group of 3-phosphoglycerate are phosphorylated by the enzyme 3-phosphoglycerate kinase to generate the intermediate 1,3-bisphosphoglycerate (1,3-BPG). The enzyme glyceraldehyde-3-phosphate dehydrogenase reduces 1,3-BPG with the input of energy from NADPH to produce glyceraldehyde-3-phosphate and NADP$^+$. Glyceraldehyde-3-phosphate follows the pathway of gluconeogenesis (the synthesis of glucose from non-carbohydrate precursors) to produce carbohydrates (Boyer, 1999). Often,
glucose and fructose are viewed as the end-products of photosynthesis, but in reality, the products of photosynthesis are the phosphorylated form of glucose or fructose, which are used as the precursors for the synthesis of sucrose and starch (Boyer, 1999). The regeneration of ribulose-1,5-bisphosphate completes the Calvin cycle. Two of the twelve glyceraldehyde-3-phosphates are used for the synthesis of the carbohydrate. The other ten are rearranged to produce ribulose-1,5-bisphosphate (Boyer, 1999).

**Cellular Respiration**

Nearly all organisms obtain energy in a process called cellular respiration. The purpose of cellular respiration is to harvest the electrons of carbohydrates, such as glucose, to generate ATP molecules for energy. Cellular respiration occurs in three main steps: glycolysis, Krebs’s cycle, and electron transport chain (Bigg et al., 2008). The reaction for the complete degradation of glucose in skeletal muscle is as follows:

$$\text{Glucose} + 36 \text{ADP} + \text{P}_i + 36\text{H}^+ + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 36\text{ATP} + 42\text{H}_2\text{O}$$

According to Garret and Grisham (2013), glycolysis is the paradigm of the metabolic process. Glycolysis is an anaerobic (requires no oxygen) catabolic (degradation of larger reactants to smaller products) process that is carried out in the cytosol of nearly all living cells. Glycolysis allows the extraction of energy from nutrient molecules. Glycolysis occurs in two phases. In the first step of glycolysis, glucose is phosphorylated at the sixth carbon by either hexokinase or glucokinase. The phosphorylation of glucose activates the molecule allowing subsequent reactions in the pathway. Consequently, this reaction is thermodynamically unfavorable. The hydrolysis of ATP makes 30.5 kJ/mol available for this reaction as the phosphorylation of glucose requires 13.8 kJ/mol of energy. The endergonic process of the phosphorylation of glucose is coupled with the exergonic hydrolysis of water which will result in the reaction to take
In the second step of phase one, the carbonyl oxygen of glucose-6-phosphate is shifted from C-1 to C-2 by the enzyme phosphoglucoisomerase (Garrett & Grisham, 2013). The isomerization of the sugar is important as it allows for the phosphorylation at C-1 to be possible.

Phosphofructokinase will then phosphorylate the C-1 of the fructose-6-phosphate yielding fructose-1, 6-bisphosphate. The phosphorylation of fructose-6-phosphate is endergonic:

\[
\text{Fructose-6-P + P}_i \rightarrow \text{fructose-1,6-bisphosphate} \quad \Delta G^\circ = 16.3 \text{ kJ/mol}
\]

The coupling of hydrolysis of ATP to the phosphorylation of fructose-6-phosphate allows this reaction to overall become exergonic:

\[
\text{Fructose-6-P + ATP} \rightarrow \text{fructose-1,6-bisphosphate + ADP} \quad \Delta G = -14.2 \text{ kJ/mol}
\]

The cleavage of fructose-1,6-bisphosphate takes place between the C-3 and C-4 bond of the molecule by the enzyme fructose bisphosphate aldolase to generate two triose phosphates: dihydroxyacetone phosphate and glyceraldehyde-3-phosphate. Of the two triose phosphates, only glyceraldehyde-3-phosphate goes directly into the second phase of glycolysis as the aldehyde can continue to be oxidized. Triose phosphate isomerase must convert dihydroxyacetone into another glyceraldehyde-3-phosphate as the acetone cannot continue due to its inability to be further oxidized. This completes the first phase of glycolysis (Garrett & Grisham, 2013).

At the conclusion of the second phase of glycolysis, four new molecules of ATP and 2 molecules of NADH are generated. Considering that two ATP molecules were consumed during the first step of glycolysis, a net yield of two ATP molecules were produced. Glyceraldehyde-3-phosphate undergoes an oxidation-reduction reaction, which it is oxidized to 1,3-biphosphoglycerate by the enzyme glyceraldehyde-3-phosphate dehydrogenase and NAD\(^+\) is reduced to NADH. Whilst an oxidation of aldehyde to a carboxylic acid is a highly exergonic reaction, the overall reaction involves both the formation of a carboxylic phosphoric anhydride
and the reduction of NAD$^+$ to NADH and is therefore slightly endergonic at the standard state. In this reaction, the free energy that could otherwise be released as heat is directed towards the formation of high energy 1,3-bisphosphoglycerate and the reduction of NAD$^+$. Phosphoglycerate kinase transfers a phosphoryl group from the 1,3-bisphosphoglycerate to ADP to form an ATP (Garrett & Grisham, 2013). This reaction replenishes the ATP deficit created during the first phase as each glucose molecule generates two molecules of glyceraldehyde-3-phosphate. The next reaction begins with a phosphoglycerate mutase reaction, in which the phosphoryl group is moved from C-3 to C-2 of 3-phosphoglycerate to yield 2-phosphoglycerate. This reaction allows the generation of a high-energy phosphate in preparation for ATP synthesis. The enzyme enolase catalyzes the formation of phosphoenolpyruvate from 2-phosphoglycerate. The enzyme removes a water molecule from 2-phosphoglycerate to yield phosphoenolpyruvate. Pyruvate kinase is the enzyme that catalyzes the final reaction of glycolysis. The enzyme transfers a phosphoryl group from phosphoenolpyruvate to ADP to make ATP and pyruvate. (Garrett & Grisham, 2013).

Pyruvate generated in glycolysis is oxidized in the tricarboxylic acid cycle (TCA) or what is often referred as the citric acid cycle or Krebs cycle, named after the German biochemist Hans Krebs. In eukaryotic cells, glycolysis takes place in the cytoplasm of the cell. The pyruvate products will then enter the mitochondria to proceed with the TCA. Prior to TCA, pyruvate will undergo a series of chemical reactions catalyzed by the pyruvate dehydrogenase complex (PDC) to yield acetyl-CoA and NADH. First, pyruvate undergoes decarboxylation and transfers the acetyl group to lipoic acid. This is done by thiamine pyrophosphate (TPP) which when protonated will become the intermediate hydroxyethyl-TPP. The reaction with the oxidized form of lipoic acid and hydroxyethyl-TPP yields an energy-rich acetyl-thiol ester of the reduced lipoic
Acetyl-CoA reacts with oxaloacetate in a Perkin condensation by the enzyme citrate synthase. The product of this reaction is citrate, which contains a tertiary alcohol. The structure of citrate presents a problem as it is difficult to oxidize further. The solution to this problem is the isomerization of citrate to isocitrate by the enzyme aconitase. Water is extracted from citrate to form the intermediate aconitate then it is rehydrated by adding an equivalent of water to the opposite side to yield isocitrate. It is simpler to oxidize isocitrate as it involves breakage of a C—H bond rather than the C—C cleavage required for the direct oxidation of citrate. In the next step of the TCA cycle, isocitrate is oxidized to form oxalosuccinate and secondly decarboxylated to form \( \alpha \)-ketoglutarate. This reaction is also accompanied by the reduction of \( \text{NAD}^+ \) to NADH by the enzyme isocitrate dehydrogenase. \( \alpha \)-ketoglutarate undergoes a similar reaction as isocitrate to produce succinyl-CoA and NADH which are energy-rich products that are important sources of metabolic energy in subsequent cellular processes. In this reaction, \( \text{CO}_2 \) is also released.

Succinyl-CoA synthetase catalyzes succinyl-CoA, which is a high-energy intermediate that drives the phosphorylation of GDP to GTP (in mammals) or ADP to ATP (in plants and bacteria) to create succinate. Succinate dehydrogenase oxidizes succinate to fumarate and reduces FAD to FADH\(_2\). Fumerase will then hydrate fumarate to produce L-malate. In the final step of the TCA cycle, L-malate is oxidized to generate oxaloacetate (starting reactant of the TCA cycle), and NAD is reduced to NADH. Malate dehydrogenase is responsible for this reaction (Garrett & Grisham, 2013). The process of cellular respiration is summarized in Figure 2.3.
Electron Transport Chain

The purpose of the TCA cycle is to release the electrons from the oxidation reactions of pyruvate to ultimately yield CO₂. The liberated electrons are passed via NADH and FADH₂ through a pathway called the electron transport chain (an elaborate and highly organized chain of proteins, cofactors, and coenzymes) to the electron acceptor O₂. The transfer of electrons through the membrane of mitochondria creates a charge gradient across the membrane. The energy stored within the proton gradient drives the synthesis of ATP via ATP synthase. The electron transport chain is composed of four parts: Complex I – NADH-coenzyme Q reductase; Complex II – succinate-coenzyme Q reductase; Complex III – coenzyme Q-cytochrome c reductase; Complex IV—cytochrome c oxidase. Complex I oxidizes one NADH and reduces UQ which results in the
transport of protons from the matrix side of the mitochondria to the cytosolic side. During the TCA cycle, succinate-coenzyme Q reductase converts succinate to fumarate (oxidation reaction) concomitant with the reduction of FAD to FADH$_2$. Electrons of FADH$_2$ are immediately transferred to the Fe-S centers of the coenzyme which are then passed to UQ. The third complex reduces coenzyme Q and passes its electrons to cytochrome c through the Q cycle. This allows protons to push to the cytosolic side of the mitochondria. Complex IV will accept the electrons from cytochrome c and reduce O$_2$ to H$_2$O (Garret & Grisham, 2013).

ATP synthase is an enzyme that contains a proton pump and a rotating molecular motor. ATP synthase consists of principal components, F$_0$ and F$_1$ as shown in Figure 2.4. The F$_1$ unit consists of five polypeptide chains (α, β, γ, δ, and ε) while the F$_0$ includes three hydrophobic subunits (a, b, and c). The stator (a stationary component anchored in the membrane) consists of the a and b subunits of F$_0$, while the c subunits create a major component of the rotor. Protons from the gradient will flow through the a-c complexes of F$_0$ causing the c-ring to rotate. As the c subunits rotate, it will also rotate the stalk, which is comprised of γ, δ, and ε subunits. Attached to the stalk is the αβ complex (a symmetrical sphere of alternating α and β subunits). As the complex rotates, the β subunits will phosphorylate ADP to ATP (Garret & Grisham, 2013) as illustrated in Figure 2.5.
Figure 2:4 - Illustration of the principle components of ATP Synthase, F₀ and F₁ (WikiMedia, 2015).

Figure 2:5 - Protons from the gradient will flow through F₀ causing the c-ring to rotate. This will cause rotation of the F₁. This rotation will ultimately phosphorylate ADP to ATP (WikiMedia, 2010).

GSE requires that the concepts of photosynthesis and cellular respiration be taught within the high school biology setting. Interestingly, the standard asks students to explain the
fundamental ideas of cycling of matter and flow of energy through the lens of the biochemical processes. It should be noted, however, that the cycling of matter and flow of energy are examples of crosscutting concepts.

**Crosscutting Concepts**

The National Research Council (NRC), in their 2011 publication *A Framework for K-12 Science Education: Practices, Core Ideas, and Crosscutting Concepts*, recommended that K-12 science should be constructed around three major dimensions: best practices in science and engineering, the fundamental core ideas of the disciplines of natural science, and the unifying crosscutting concepts that intertwine through the various natural science disciplines (as cited in NGSS, 2013). The overall goal of the implication of cross-cutting concepts in science education can be summed up in this quote:

*Some important themes pervade science, mathematics, and technology and appear over and over again, whether we are looking at an ancient civilization, the human body, or a comet. They are ideas that transcend disciplinary boundaries and prove fruitful in explanation, in theory, in observation, and in design.*

*(American Association for the Advancement of Science, 1989)*

Crosscutting concepts were derived from “Unifying Concepts and Processes” (Duschl, 2012), which served as guiding principles to help students to see the correlation between the various science disciplines through the Advance Placement curriculum (College Board, 2009). Similarly, crosscutting concepts offer students with an organizational context for joining information from the numerous disciplines into a clear and scientifically founded interpretation of the world (National Research Council [NRC], 2011). However, students unsuccessfully were often left to construct relationships between the various science disciplines without instructional
support. The NRC identified these concepts so that they are intentionally incorporated “in the
development of standards, curricula, instruction and assessment”. The NRC (2011)
recommended these seven crosscutting concepts to be used in science education: patterns; cause
and effect; scale, proportion and quantity; systems and system models; energy and matter;
structure and function; and stability and change. This study will focus on the crosscutting

Energy and matter are important ideas in the various disciplines of science and
engineering (NGSS, 2013) as it allows the notion of tracking fluxes of matter and energy in and
out of systems. Limitations and the possibilities of the system can be studied by using this lens
(NRC, 2011). In high school science education, students will explore the conservation of energy
and matter within a closed system. They will also learn the law of conservation of matter and
energy and observe and describe the flow of matter and energy in and out of an open system.

Students learn that the cycling of matter is driven by energy. In engineering, there must be a
careful consideration of the input, output, and flow of energy and matter so that a system may be
created that would maximize the output of energy and matter while minimizing the input of
energy and matter. In biological systems, without the input of energy by the sunlight, plants are
unable to use matter (carbon dioxide and water) to create the energy-rich food molecule
(glucose) that they need to survive (NGSS, 2013).

Recently, the emphasis of misconception research has moved toward more thorough and
complex topics. Particularly, attention has been set on the purpose, process, and connection of
biological science and on the interrelationships that exist amongst other sciences. (Lin & Hu,
2003). Thus, the living world relies totally on the mutualistic interrelations and interactions of
the components of itself (Mayr, 1997) and that there should be a comprehensive understanding
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of the concepts associated with the wholeness of the world and the interrelations within it
(Wandersee et al., 2000). The hierarchy of nature is often inaccurate in biological education and
research. At each level within the hierarchy of nature exists various fields of biology, such as
ecology and molecular biology: in which different concepts and theories are formulated. The
hierarchy allows students to compartmentalize the different fields of biology and enables them to
learn the distinct concepts but have difficulty viewing the interconnected relationships between
each field (Waheed & Lucas, 1992). Energy and matter flow is an important topic within the
hierarchy of nature. In ecology, photosynthesis and cellular respiration depict the cycling of
matter and energy through the ecosystem while in molecular biology photosynthesis and cellular
respiration depicts the cycling of matter and energy within the cell (Lin & Hu, 2003). Lin and Hu
(2003) refer to photosynthesis and cellular respiration as “a bridge between the living world and
the non-living world in terms of energy flow and matter cycling” (p. 1530). Lin and Hu (2003)
suggest that biology teachers should teach the interrelationships between the non-living and
living aspects of photosynthesis and cellular respiration.

NGSS defines “systems and system models” crosscutting concept as “the system under
study – specifying its boundaries and making explicit a model of that system – provides tools for
understanding and testing ideas that are applicable throughout science and engineering” (2013 p.
1). Analysis of the system entails the study of the effect of the system by interacting it with
forces or flow of matter and energy across it. Application of flows into and out of the system is
an important aspect of system design. In a scientific study, an investigation and interpretation of
the data is dependent upon the extent that the system is isolated or external conditions are
controlled (2013). In addition, Wilson et al. (2006) stressed that one of the central principles of
biology is that conceptualization can be made of the intricacies of the biosphere in the
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perspective of the arrangement of interrelated systems that can extend in measure from the
subcellular to the ecosystem. We can follow matter and energy inside these systems to
comprehend them exclusively and between these systems to comprehend their interdependence.
Prior to 2017-2018 school year, the state of Georgia used the Georgia Performance Standards
(GPS) as the framework for high school science instruction. For the school year 2017-2018,
Georgia transitioned to the Georgia Standards of Excellence (GSE) as the framework for public
school education. Very simply, photosynthesis converts the kinetic energy of light from the sun
into the chemical potential energy in bonds of a carbohydrate molecule. Through a series of
chemical reactions, the energy in the carbohydrate bond is transferred into a bond of an
adenosine phosphate compound (ATP) through the process of cellular respiration. Within plants,
ATP provides the energy for photosynthesis to continue (Brown & Schwartz, 2009). As written
within the GPS, the standard implies an oversimplification of the overall processes as seen in
Table 2.2. At the biochemical levels, photosynthesis and cellular respiration are viewed as
opposites, but at the global scale, it is considered to be complementary (2009). Differences in
how cellular respiration and photosynthesis are seen at the global scale versus biochemical levels
are due to the lack of emphasis on the flow of matter within the process (Wilson et al., 2006).
With the new GSE, there is a deliberate attempt to merge the crosscutting concept with the
concepts of photosynthesis and cellular respiration. GSE emphasizes the cycling of matter and
energy through both cycles as seen in Table 2.2. As teachers begin to emphasize the
interdisciplinary concept, students will have deeper and more complex understanding of
photosynthesis and cellular respiration (Duschl, 2012).
Comparison between the Georgia Performance Standard and the Georgia Standards of Excellence of the high school concepts of photosynthesis and cellular respiration.

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<tbody>
<tr>
<td>“SB3.a. Explain the cycling of energy through the processes of photosynthesis and respiration” (Georgia Department of Education, 2006)</td>
<td>“SB1.e. Ask questions to investigate and provide explanations about the roles of photosynthesis and respiration in the cycling of matter and flow of energy within the cell. Instruction should focus on understanding the inputs, outputs, and functions of photosynthesis and respiration and the functions of the major sub-processes of each including glycolysis, Krebs cycle, electron transport chain, light reactions, and Calvin cycle” (Georgia Department of Education, 2016a)</td>
</tr>
</tbody>
</table>

The crosscutting concept also has major applications in the GSE standards in chemistry.

Table 2.3 below illustrates the chemistry standards that can be tied in with energy and matter.

Table 2.3

<table>
<thead>
<tr>
<th>GSE Chemistry standards that can use the crosscutting concept of energy and matter. (Georgia Department of Education, 2016b)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard</strong></td>
</tr>
<tr>
<td>SC1. Obtain, evaluate and communicate information about the use of the modern atomic theory and periodic law to explain the characteristics of atoms and elements.</td>
</tr>
<tr>
<td>SC3. Obtain, evaluate, and communicate information about how the Law of Conservation of Matter is used to determine chemical composition in compounds and chemical reaction.</td>
</tr>
</tbody>
</table>
SC4. Obtain, evaluate, and communicate information about how to refine the design of a chemical system by applying engineering principles to manipulate the factors that affect a chemical reaction.

- a. Plan and carry out an investigation to provide evidence of the effects of changing concentrations, temperature, and pressure on chemical reactions.
- c. Construct an explanation of the effects of a catalyst on chemical reactions and apply it to everyday examples.
- d. Refine the design of a chemical system by altering the conditions that would change forward and reverse reaction rates and the amount of products at equilibrium.

SC5. Obtain, evaluate, and communicate information about the Kinetic Molecular Theory to model atomic and molecular motion in chemical and physical processes.

- a. Plan and carry out an investigation to calculate the amount of heat absorbed or released by chemical or physical processes.

SC6. Obtain, evaluate, and communicate information about the properties that describe solutions and nature of acids and bases.

- a. Develop a model to illustrate the process of dissolving in terms of solvation versus dissociation.
- g. Ask questions to evaluate merits and limitations of the Arrhenius and Bronsted-Lowry models of acid and bases.
- h. Plan and carry out an investigation to explore acid-base neutralization.

Misconceptions of Photosynthesis and Cellular Respiration

Simultaneously within plant cells are the biological processes of photosynthesis and cellular respiration, which share many molecular components. The energy of the sun is transformed into chemical energy in the form of a glucose molecule in the process of photosynthesis. This carbohydrate molecule will then enter the mitochondria and undergo cellular respiration in which the energy within the carbohydrate is transferred to a smaller molecular compound adenosine triphosphate (ATP). Alternative conceptions of the process of photosynthesis and cellular respiration have been widely studied for more than 20 years (Batiza...
et al., 2013) within the populations of K-12 and college (Anderson, Sheldon, & Dubay, 1990; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Gayford, 1986; Hartley, Wilke, Schramm, D’Avanzo, & Anderson, 2011; Haslam & Treagust, 1987; Mohan, Chen, & Anderson, 2009; Wilson et al., 2006; Songer and Mintzes, 1994). A list of known alternative conceptions of photosynthesis and cellular respiration of students of K – college are found in Table 2.4.

Table 2.4

A sample of known alternative conceptions of photosynthesis and cellular respiration in students of the K-12 and college level.

<table>
<thead>
<tr>
<th>Grade Level</th>
<th>Alternative conceptions</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-12</td>
<td>Plants either do not respire or if they do, the only respire in the dark.</td>
<td>(Haslam &amp; Treagust, 1987)</td>
</tr>
<tr>
<td></td>
<td>Cellular respiration and the process of breathing are the same</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Respiration produces energy, rather than convert energy</td>
<td>(Gayford, 1986)</td>
</tr>
<tr>
<td></td>
<td>Respiration and combustion have little in common</td>
<td>(Mohan, Chen, &amp; Anderson, 2009)</td>
</tr>
<tr>
<td></td>
<td>Gases such as carbon dioxide lack sufficient mass to lead to the development of dry biomass in plants.</td>
<td>(Driver, Squires, Rushworth, &amp; Wood-Robinson, 1994)</td>
</tr>
<tr>
<td></td>
<td>Plants get mass from the soil</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Photosynthesis and respiration in plants is an energy conversion process.</td>
<td>(Lin, 2004)</td>
</tr>
<tr>
<td></td>
<td>The soil is an energy providing source.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Photosynthesis produces food, part of which is turned into oxygen and eliminated into the air.</td>
<td>(Wang, 2004).</td>
</tr>
<tr>
<td></td>
<td>Photosynthesis and cellular respiration are mere opposites of each other.</td>
<td>(Canal, 1999)</td>
</tr>
<tr>
<td>College</td>
<td>Oxygen is needed by animals, whereas plants require carbon dioxide</td>
<td>(Anderson, Sheldon, &amp; Dubay, 1990)</td>
</tr>
<tr>
<td></td>
<td>Food that is broken down in respiration leaves an animal’s blood entirely by urine and feces.</td>
<td>(Wilson et al., 2006)</td>
</tr>
<tr>
<td></td>
<td>Energy can disappear.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy is used up during biological processes.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Living organisms can convert matter into energy on a measurable scale.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adenosine triphosphate (ATP) is energy rather than a molecule with chemical potential energy.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cellular Respiration and the process of breathing are the same.</td>
<td>(Songer &amp; Mintzes, 1994).</td>
</tr>
</tbody>
</table>
Wilson et al. (2006) reasoned that alternative conceptions about photosynthesis and cellular respiration persist due to the lack of understanding of the biochemical level and the cycling of matter. Brown and Schwartz (2009) argue that even preservice teachers’ "knowledge is often fragmented, compartmentalized, and poorly organized, making access very challenging" and often hold alternative conceptions found in students (p.5). Current literature only discusses how the use of crosscutting concepts can reform education programs (Bybee, 2014) or main topics of teacher professional development (Karaarslan & Teksoz, 2016; Nollmeyer & Bangert, 2017). This dissertation will add to the literature by investigating the secondary preservice teachers’ conceptual knowledge of the crosscutting concepts: Energy and Matter: Flows, cycles, and conservation, and Systems and System models in the lens of photosynthesis and cellular respiration.

Summary

The study that is presented in this paper takes an idiographic approach to help explain and verify a nomothetic theory; preservice teachers hold alternative conceptions about photosynthesis and cellular respiration (Brown & Schwartz, 2009). Research has shown that preservice teachers have a limited understanding of content (Brown & Schwartz, 2009) and as a result, may negatively affect the achievement of students (Ferguson, 1991). Idiographic methods allow the researcher to reveal individual variables and tendencies within the individual (Runyan, 1983). Data using the idiographic approach are gathered using an open-ended coding scheme.
PRESERVICE TEACHERS’ CONCEPTUAL UNDERSTANDING

such as interviews (Robinson, 2011). Table 2.4 summarizes alternative conceptions held by K-college student groups of the process of photosynthesis and cellular respiration. This dissertation will attempt to fill several gaps in the current literature: 1) investigate how secondary preservice biology teachers’ responses differ when the process of photosynthesis and cellular respiration are asked about directly and in context; 2) investigate secondary preservice biology teachers’ application of cycling of matter and flow of energy within their explanations of photosynthesis and cellular respiration; 3) investigate secondary preservice biology teachers’ conceptual understanding of energy within the processes of photosynthesis and cellular respiration; and 4) understand how secondary preservice biology teachers utilize key chemistry topics within the process of photosynthesis and cellular respiration.
Chapter 3 Methodology

In this chapter, an interpretivist qualitative methods design was used to investigate the conceptual knowledge of secondary preservice teachers regarding the process of photosynthesis and cellular respiration. Their responses were compared to the canonical themes of conceptual understanding of the biochemical processes. Data collection consists of a semi-structured interview and creation of a concept map using key terms from photosynthesis, cellular respiration, and the crosscutting concepts: matter and energy and system and system models. The semi-structured interview consists of prompts that ask the participant to draw models of the various biochemical processes of photosynthesis and cellular respiration. Data analysis will be analyzed qualitatively, as inductive coding will be applied to participant interviews and their concept maps. Member checking and inter-rater reliability were used to establish trustworthiness. This study’s methodology was guided by the research question.

Research Question

The focus of this dissertation is answering the question: What conceptual understanding do secondary preservice biology teachers hold about the biochemical concepts relating to the cycling of matter and the flow of energy in photosynthesis and cellular respiration? This study has four distinct goals: 1) investigate how secondary preservice biology teachers’ responses differ when the process of photosynthesis and cellular respiration are asked about directly and in context; 2) investigate secondary preservice biology teachers’ application of cycling of matter and flow of energy within their explanations of photosynthesis and cellular respiration; 3) investigate secondary preservice biology teachers’ conceptual understanding of energy within the processes of photosynthesis and cellular respiration; and 4) understand how secondary preservice biology teachers utilize key chemistry topics within the process of photosynthesis and cellular
respiration. In order to best address this range of inquiries, this methodology will follow qualitative conventions.

**Qualitative Methods**

Qualitative research describes a wide class of experimental methods intended to portray and decipher the experience of research participants in a content-specific setting. Qualitative discoveries are by and large exhibited in ordinary language and regularly uses participants' own words to depict their experiences (Ponterotto, 2005). With participant-defined data, the length; detail, substance and importance of the information are not dictated by the researcher, yet recorded *as spoken or as it occurs*, recorded in notes or recordings (Dey, 1993).

Traditionally, a qualitative research design has been used to uncover students’ ideas about science, as seen through the misconceptions literature. Additionally, the student describing and clarifying their thoughts is more appealing and more detailed than quantitative processes (Sadler, 1997). For these reasons, qualitative analysis is used in this dissertation. Participants will partake in an interview process to which they will describe through words, symbols, and/or drawing their conceptual understanding and secondly using predetermined words, create a concept map of the biochemical processes.

Qualitative research is a meaningful and thoughtful process in which the researcher looks to find out about and decipher life experiences. Since qualitative methodology “closely involves the researcher with participants and data… questions about how personal experiences, perceptions, and interpretations enter into data are of particular interest” (Sword, 1999, p. 270). However, qualitative researchers frequently do not recognize how, in addition to other things, their own experience, gender, social class, ethnicity, qualities, and convictions influence the emergent construction of reality (1999).
Presence of Self

Reflection on the effects of self not just initiate individual awareness of how the research is formed by one's own biography, yet in addition, gives a setting within which audiences can comprehend fully the researcher’s analysis of the data (Sword, 1999).

I fell in love with teaching as a young teen. My father started me on the piano at the age of 6. By the time I was 10, I was able to play difficult classical pieces by Mozart, Beethoven, and Bach. At 14, I began my teaching career as a piano instructor. Teaching the piano had allowed me to develop a love for teaching and instilling within students my knowledge. As I got older, I began to become more involved within my community. I became a youth leader at my church as an instructor and mentor. I also began tutoring students who struggled in math and science. Reflecting on these experiences, I decided as a junior in college that I would no longer pursue a career in pharmacy, but my calling was within the classroom as a teacher.

I was soon accepted into a Master of Arts in Teaching (MAT) program. As I was progressing through the program, I grew uncertain about my content knowledge in chemistry and my ability to transfer my knowledge. During the program, my classmates and I unsuccessfully asked the program coordinator to create a class in which chemistry content is taught from the lens of secondary education. I had a few opportunities during the graduate program that aided my confidence in my content knowledge. I became a graduate teaching assistant for General Chemistry labs under Dr. Nancy Kirk, who was a mentor to me and was determined that I understood the content before I taught the lab. During my student teaching, Ms. Bonnie Wright guided me and helped to increase my conceptual knowledge of chemistry.

As a doctoral candidate, I had the privilege to work with Dr. Kim Cortes in exploring misconceptions of students in various scientific topics. As I began to think about the topic of this
PRESERVICE TEACHERS’ CONCEPTUAL UNDERSTANDING

dissertation, it became apparent that the experiences of my life have directed me to this point. As I felt weak in my content knowledge during my education preparation program, I seek to know if the weakness I experienced was isolated or is it prevalent within the preservice teacher population. At this point, I decided to qualitatively study the content knowledge of preservice teachers not to point out their misconceptions but instead to understand where they are and hopefully create discussions on how to strengthen their conceptual knowledge.

Participants

There were a few prerequisites that an individual must have met in order to be a participant in this study. First, the individual had to be enrolled in a university education preparation program. Second, the individual must have completed all necessary biology content courses for their degree program within the last year. The majority of this study was conducted at a large southeastern university with a focus on teacher preparation. All participants were students enrolled in a bachelors (N=2) or Master of Arts in Teaching (N=4) grade 6-12 biology teacher preparation program at this university. A recruitment process was used to attract participants for this study. The participants were recruited from a biology pedagogical content knowledge class and the study was explained to them by the researcher and subsequently asked to volunteer. Out of the total pool size of 13, only six volunteered to participate in all parts of the study, thus a sample of convenience. Sky is a 25-year-old Caucasian female who is enrolled in a MAT program. She had a bachelor’s degree in biology from Kennesaw State University (KSU) at the time of the study. She has been out of school for 3 years, during which time she worked as a waitress at the local restaurant. Mya is a 23-year-old Caucasian female who was also enrolled in the MAT graduate program. She received her bachelor’s degree in biology from another local college. Eva is a 22-year-old Caucasian female who is pursuing her bachelor’s degree in biology
education. Liz is a 22-year-old Caucasian female who is also pursuing her bachelor’s degree in biology education. Ted is a 22-year-old Caucasian male who is pursuing his MAT. He received his bachelor’s in ecology and field biology from a local university. His initial plan during his undergrad was to become an ecologist. He enjoyed being a mentor in his youth church group which eventually led him to pursue a career as a teacher. Dan is a 25-year-old Caucasian who is pursuing a MAT graduate degree. After he graduated with his bachelor’s degree in biology, he worked as a lab technician. During that time, he also coached baseball youth leagues. Due to the lack of interest in the lab, he decided to pursue a career in education as he enjoyed working and teaching youth, but teaching will also allow him greater opportunities to coach. A list of science courses completed by the participants are shown in Table 3.1.

Table 3.1
College science courses completed by the participants.

<table>
<thead>
<tr>
<th>Liz Undergrad</th>
<th>Eva Undergrad</th>
<th>Ted Graduate</th>
<th>Mya Graduate</th>
<th>Sky Graduate</th>
<th>Dan Graduate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology I</td>
<td>Biology I</td>
<td>Biology I</td>
<td>Biology I</td>
<td>Biology I</td>
<td>Biology I</td>
</tr>
<tr>
<td>Biology II</td>
<td>Biology II</td>
<td>Biology II</td>
<td>Biology II</td>
<td>Biology II</td>
<td>Biology II</td>
</tr>
<tr>
<td>Chemistry I</td>
<td>Chemistry I</td>
<td>Chemistry I</td>
<td>Chemistry I</td>
<td>Chemistry I</td>
<td>Chemistry I</td>
</tr>
<tr>
<td>Chemistry II</td>
<td>Chemistry II</td>
<td>Chemistry II</td>
<td>Chemistry II</td>
<td>Chemistry II</td>
<td>Chemistry II</td>
</tr>
<tr>
<td>Organic I</td>
<td>Organic I</td>
<td>Organic I</td>
<td>Organic I</td>
<td>Organic I</td>
<td>Organic I</td>
</tr>
<tr>
<td>Organic II</td>
<td>Organic II</td>
<td>Ecology</td>
<td>Ecology</td>
<td>Ecology</td>
<td>Ecology</td>
</tr>
<tr>
<td>Ecology</td>
<td>Invertebrate</td>
<td>Biochem I</td>
<td>Biochem I</td>
<td>Biochem I</td>
<td>Biochem I</td>
</tr>
<tr>
<td>Microbiology</td>
<td>Vertebrate Zoology</td>
<td>Organic I</td>
<td>Plant</td>
<td>Plant</td>
<td>Plant</td>
</tr>
<tr>
<td>Vertebrate Zoology</td>
<td>Microbiology</td>
<td>Plant Ecology</td>
<td>Invertebrate</td>
<td>Systematics</td>
<td>Microbiology</td>
</tr>
<tr>
<td>Microbiology</td>
<td>Vertebrate Zoology</td>
<td>Zoology</td>
<td>Plant</td>
<td>Plant</td>
<td>Plant</td>
</tr>
<tr>
<td>Vertebrate Zoology</td>
<td>Microbiology</td>
<td>Phylogeny</td>
<td>Vertebrate</td>
<td>Zoology</td>
<td>Zoology</td>
</tr>
<tr>
<td>Microbiology</td>
<td>Vertebrate Zoology</td>
<td>Systematics</td>
<td>Plant</td>
<td>Vertebrate</td>
<td>Zoology</td>
</tr>
<tr>
<td>Vertebrate Zoology</td>
<td>Microbiology</td>
<td>Zoology</td>
<td>Ecosystem</td>
<td>Zoology</td>
<td>Ecosystem</td>
</tr>
<tr>
<td>Microbiology</td>
<td>Vertebrate Zoology</td>
<td>Ecosystem</td>
<td>Zoology</td>
<td>Ecosystem</td>
<td>Ecosystem</td>
</tr>
</tbody>
</table>
Development of Data Sources and Collection

Interviews.

In qualitative research, interview remains the most common method of collecting data (King, 2004). Kvale (1983) defines interviews as "whose purpose is to gather a description of the life-world of the interviewee with respect to the interpretation of the meaning of the described phenomena" (p. 174). Stake (2010) additionally suggested that the purpose of interviews is to acquire specific data or interpretation held by the interviewee; gathering a numerical accumulation of data from numerous people; getting some answers concerning a thing that was not observable to scientists. In summary, the interviews develop deep and personally meaningful (but only if you used interpretation) details of the content at hand and can probe aspects of the participant’s epistemology when follow-up questions are used effectively. This study used a semi-structured interview protocol to collect qualitative data because semi-structured interviews allow researchers to create a list of themes, issues, and ideas that will be discussed but the order of the questions is dependent on the direction of the interview. Typically, an interview guide is used, but the researcher is free to ask additional questions (Karjornboon, 2005). Corbetta (2003) adds that the order in which the different topics are managed and the wording of the inquiries are left to the interviewers. Within every subject, the interviewer can lead the discussion as needed, to pose the questions as they see fit in the words he/she considers best, to give clarification and request explanation if the appropriate response is not clear, to incite the interviewee to explain further if essential, and to set up his/her own particular style of discussion (Corbetta, 2003). The
ability of the researcher to probe and prompt for deeper understanding is one of the greatest strengths of semi-structured interviews. Unfortunately, the quality of data is dependent on the experience and the ability of the interviewer to probe and prompt for additional answers (Karjornboon, 2005).

Pilot Study.

The goal the pilot study was to examine the feasibility of the recruitment of the participants, methodology, interview questions, and analysis of the data collected. The interview guide used in this dissertation was first developed for a pilot study and has since been altered to gather richer data. The pilot study consisted of two phases: interview and concept map. The pilot study interview guide, which is found in Appendix A, consists of eight open-ended prompts:

1. A mature maple tree can have a mass of 1 ton or more, yet it starts from a seed that weighs less than 1 gram. How does this happen? (Hartley, Wilke, Schramm, D’Avanzo & Anderson, 2011).

2. John weighs 440 lbs. Through diet and exercise, he loses 220 lbs. How did this happen?

3. Please explain the role of photosynthesis within the cell.

4. Draw what you think of in terms of the process of photosynthesis.

5. Please explain the role of cellular respiration within the cell.

6. Draw what you think of in terms of the process of cellular respiration.

7. Are photosynthesis and cellular respiration within the cell connected? Please explain.

8. What key chemistry topics do you see in photosynthesis and cellular respiration?

The first two questions of the interview were designed to investigate the conceptual understanding of the preservice teachers and their contextual knowledge of the photosynthesis and cellular respiration respectively. Questions 3 and 5 asked for detailed information about the
biochemical processes within the cell. The preservice teachers were asked in Questions 4 and 6 to draw the processes. Afterward, Question 7 required them to explain the relationship between photosynthesis and cellular respiration, and finally Question 8 asked to identify key chemistry topics found in the processes. For the second phase of the pilot study, the students were instructed to create a concept map with the terms found in Appendix B. The terms were derived from important key terms about the processes of photosynthesis and cellular respiration.

There were a few weaknesses with the interview guide. First, to the participants it was not clear that the first two application questions were of the topics of photosynthesis and cellular respiration. As of the result of this, one participant answered Question 1 describing the process of mitosis and meiosis. Secondly, few of the participants found it easier to explain their understanding of the processes verbally rather than drawing it. Shortly after the pilot study, the GSE was fully implemented in the state of GA. The pilot study interview questions were based on the GPS (previous GA standard) photosynthesis and cellular respiration standard. The GSE adds emphasis on the cycling of matter and flow of energy within the biochemical processes and specifically states that the subprocesses of the biochemical processes (light reaction, Krebs cycle, etc.) are understood. Comparison between the GPS and the GSE high school biology standard of photosynthesis and cellular respiration is indicated in Table 2.2.

**Interview Guide.**

In response to the new standards and results of the pilot study, the interview guide used in the pilot study was revised to address the weaknesses discovered in the pilot study and to reflect the sub-standards (cycling of matter and the flow of energy) of the new GSE. The purpose of the interview is to satisfy the first three goals of this dissertation: 1) investigate how secondary preservice biology teachers’ responses differ when the process of photosynthesis and cellular
respiration are asked about directly and in context; 2) investigate secondary preservice biology teachers’ application of cycling of matter and flow of energy within their explanations of photosynthesis and cellular respiration; 3) investigate secondary preservice biology teachers’ conceptual understanding of energy within the processes of photosynthesis and cellular respiration. In this study, participants completed a semi-structured interview. The preservice teachers answered a four-question interview. The interview prompted the teachers to describe either through words or illustration different aspects of the biochemical process of photosynthesis and cellular respiration. In each question, there were specific topics and subjects that must be discussed. The Georgia Standard of Excellence SB1.e. is the source of the major topics that must be discussed within each of the interview prompts. The GSE SB1.e. states the following:

*Ask questions to investigate and provide explanations about the roles of photosynthesis and respiration in the cycling of matter and flow of energy within the cell. Instruction should focus on understanding the inputs, outputs, and functions of photosynthesis and respiration and the functions of the major sub-processes of each including glycolysis, Krebs’s cycle, electron transport chain, light reactions, and Calvin cycle. (Georgia Department of Education, 2016b)*

Each participant was given on a sheet of paper the GSE standard for photosynthesis and cellular respiration at the beginning of the interview as a reference, which they had access to throughout the interview. The number of interview questions was reduced from eight to four. The new interview guide is as follows:
1. A mature maple tree can have a mass of 1 ton (dry biomass, after removing the water), yet it starts from a seed that weighs less than 1 gram. How does this happen? What key chemistry topics are addressed in this scenario? Explain. (Q1)

2. John weighs 440 lbs. Through diet and exercise, he loses 220 lbs. How did this happen? What key chemistry topics are addressed in this scenario? Explain. (Q2)

3. Draw and explain the process of photosynthesis within the cell. What key chemistry topics are addressed in this process? Explain. (Q3)

4. Draw and explain the process of cellular respiration within the cell. What key chemistry topics are addressed in this process? Explain. (Q4)

For each interview question, they were probed about the cycling of matter, flow of energy, and the identification of key chemistry topics. Questions 1 and 2 assessed the contextual knowledge of the preservice teachers’ understanding of photosynthesis and cellular respiration respectively, while Questions 3 and 4 they were asked to explain the sub-processes as well (light and dark reaction, Krebs cycle, Calvin cycle, etc). If those topics were not initially discussed by the participant, they were probed for. For example, the first question asks:

A mature maple tree can have a mass of 1 ton (dry biomass, after removing the water), yet it starts from a seed that weighs less than 1 gram. How does this happen? What key chemistry topics are addressed in this scenario? Explain.

The purpose of the interview prompt above was to gather the participant’s contextual understanding of photosynthesis. Using the GSE SB1.e. standard, other important subtopics would be probed and discussed. Topics of the cycling of matter and flow of energy would be prompted if the preservice teacher did not initially discuss them. The interview guide which was given to the participants of this dissertation is found in Appendix C. For each question, the
interviewees were given the opportunity to answer from the perspective of the GSE standard (discussing cycling of matter and the flow of energy). After the participants completed their thought, they were prompted to discuss the cycling of matter and flow of energy for each interview question. To record the responses of the participants LiveScribe was used, which is a pen and paper digital technology that records what is written and said at the same time. The complete interview guide and probing questions are found in Appendix D. After the interview was conducted individuals were then asked to generate a concept map.

**Word Clouds.**

A word cloud is a visualization of content in which the more regularly utilized words are successfully featured by involving more visual prominence in the representation. Word clouds uncover the frequencies of the diverse words that show up within text. Partly, a comprehension of the general structure of the frequently utilized words enables the audience to have a summary of the main themes in text. Analysis of the word clouds created from various documents ought to rapidly uncover the patterns between the thoughts contained in these documents (McNaught & Lam, 2010). The purpose of the word cloud was to answer the research question, what are secondary preservice biology teachers’ conceptual understanding of energy within the processes of photosynthesis and cellular respiration? The word cloud illustrated what terms were the participants using the most during the interview process.

**Concept Maps.**

Concept maps graphically structure complex concepts (Harris & Zha, 2017) and are visualized as a two-dimensional diagram consisting of concepts joined by labeled lines (words or phrase) to illustrate relationships between those specific concepts (Djanette & Fouad, 2014). Research has validated concept mapping as an effective technique for critical thinking (Harris &
Zha, 2017). Introduced by Novak (1979), it builds on the science of constructivism as it allows the student to organize knowledge as a hierarchical structure in a specific field (Djanette & Fouad, 2014). Concept maps can advance meaningful learning, give extra resources to learning, enable educators to provide feedback to students and assess learning and performance. Concept maps are a visual portrayal of how a student sees the relationship among various ideas; they can likewise fill in as valuable devices for depicting the students’ mental organization in a particular field. Since they are a window of the mind, they distinguish some epistemological obstructions (2014). Previous studies used concept maps to identify alternative conceptions (Canas et al., 2003; Djanette & Fouad, 2014). Alternative conceptions are often clearly identified within the context of a concept map (Canas et al., 2003) as they are identified by incorrect labeling and/or missing or defective links between two or more concepts (Djanett & Fouad, 2014). The purpose of this point of the study is to investigate how secondary preservice biology teachers utilized key chemistry topics within the process of photosynthesis and cellular respiration. Participants were given a large white poster paper and postcards that contained each of the terms found in Appendix B. Using the terms, the participant created a concept map linking the terms and describing the terms according to their conceptual understanding. After both the interview and concept map results were collected, data analysis could begin. Qualitative measures were used to analyze and evaluate concept maps.

Data Analysis

Demographic Survey.

The total interview process took an average of 60 minutes to complete. First, the participants signed and filled out a consent form and a demographic survey (Appendix E). These questions probed the age, ethnicity, if they are either an undergraduate or graduate, and a list of
science classes completed. Demographic/background questions gave the foundation in the analysis of each participant. Demographic information was collected to potentially provide context to answers given during the interview process.

**Interview Analysis.**

Qualitative data analysis consists of working with information, sorting it, breaking it into reasonable parts, combining it, searching for patterns, finding what is critical and what is to be realized, and choosing what the researcher will tell others (Bogdan & Biklen, 1982). The analysis of the interview will help investigate how secondary preservice teachers’ responses differ when the processes of photosynthesis and cellular respiration are asked about directly and in context and how are secondary preservice biology teachers applying cycling of matter and flow of energy within their explanations of photosynthesis and cellular respiration. The audio and the video files gathered from using LiveScribe were transcribed and managed using the data management qualitative software package Atlas.ti 8. A copy of a typical transcript can be found in Appendix F. The drawings and responses of the interview produced by the participants were analyzed through open coding. The goal of open coding is to generate a descriptive, multi-dimensional fundamental framework for further investigation (Khandkar, 2009). In this study, codes emerged from patterns discovered within the responses of the participants. At this point of the study, each complete thought of the participants was coded. A complete thought in this dissertation is defined as an uninterrupted response that the participant stated in attempting to answer a question. If the interviewer probes the participant further within the same question, the following response of the participant is considered as another complete thought. Through open coding, it was discovered that the participants answered the questions in one of four ways; 1) very vague or broad idea with no chemistry aspects in the response; 2) using the chemical
equation or inputs and outputs to explain the phenomenon; 3) identifying the subprocesses of photosynthesis and cellular respiration; or 4) describing in detail the biochemistry within the biological processes. Each of the four themes were assigned a level designation as described in Table 3.2

Table 3.2

*Rubric used to score the responses of the preservice teachers after each interview question*

<table>
<thead>
<tr>
<th>Level Rubric Scheme</th>
<th>Level 1 (L1)</th>
<th>Level 2 (L2)</th>
<th>Level 3 (L3)</th>
<th>Level 4 (L4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1 (L1)</strong></td>
<td>Big idea or no chemical perspective when answering interview question</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Level 2 (L2)</strong> – Use only chemical equation to explain phenomena.</td>
<td>Within their explanations, there are errors.</td>
<td>No error but incomplete in their explanation</td>
<td>No error and complete in their explanation</td>
<td></td>
</tr>
<tr>
<td><strong>Level 3 (L3)</strong> – Discussion of subprocesses</td>
<td>Within their explanations, there are errors.</td>
<td>No error but incomplete in their explanation</td>
<td>No error and complete in their explanation</td>
<td></td>
</tr>
<tr>
<td><strong>Level 4 (L4)</strong> – Discussion of full biochemical process</td>
<td>Within their explanations, there are errors.</td>
<td>No error but incomplete in their explanation</td>
<td>No error and complete in their explanation</td>
<td></td>
</tr>
</tbody>
</table>

Subcategories were created for Level 2-4 which addresses accuracy of the participants responses regardless of the level of response. Subcategory i is designed to code responses that contain errors. Second, subcategory ii indicates that the response contained no errors but was missing key information, and subcategory iii demonstrated full and complete understanding of the phenomenon. Further categories were created to differentiate responses about photosynthesis, cellular respiration, cycling of matter, and flow of energy. A full list of the codes and their categories are found in Appendix G.

McKnaught and Lam (2010) described that a word cloud is a visualization of content in which the more consistently used words are effectively featured by involving progressively visual prominence in the representation. To investigate secondary preservice biology teachers’
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case conceptual understanding of energy within the processes of photosynthesis and cellular respiration, a word cloud analysis was used. Using the word cloud feature in Atlas.ti, the words of the participant for each interview question was quantified and represented as a word cloud. This analysis found that for each interview question, the most used term by the participants was *energy*. The term *energy* then was later coded for its usage. Six themes emerged from this coding: energy-ATP, energy-bonds, energy-chemical, energy-flow, energy-light, and energy-work. Further categories were created within each theme to investigate more deeply the conceptual understanding of the preservice teachers and their knowledge of energy within the biochemical processes. The coding scheme used this section is found in Appendix G. For example, the following categories were created from the theme energy-chemical: ATP, electrons, FADH, fat, food, glucose, NAD, NADH, protons, water, and soil.

**Concept Maps Analysis.**

In this dissertation, the construction of the concept maps is based on the original method as prescribed by Novak and Musonda (1991). Due to the difficulty identifying specific changes in the children’s conceptual knowledge of science in their study, Novak’s research team created concept maps to better represent children’s knowledge. This was done by analyzing the recorded interview and mapping key terms with propositional statements which were based on the relationships stated by the interviewees (1991). The concept maps analysis was used to investigate how secondary preservice biology teachers utilized key chemistry topics within the process of photosynthesis and cellular respiration. 45 predetermined terms regarding the biochemical processes of photosynthesis and cellular respiration were given to each participant of which 14 terms were key chemistry ideas. The participants sorted and linked the terms according to their own conception and understanding. The preservice teachers were asked to
describe why they sorted the terms and to explain relationships between each adjacent term. This data was video recorded. Through the analysis of the recorded data, concept maps were created to portray participants understanding of the described terms and relationships. The analysis of the concept maps consists of discovering how the preservice teachers utilized the 14 key chemistry terms. Their usage of the terms and proposition statements was compared to each other to gain general understanding how the participants conceptualized the terms. The participants’ usage of each terms was also compared to the canonical understanding of the chemistry key ideas. Lastly, the usage of the terms in the concept map were also triangulated to if and when the participants used the same terms or similar terms during the interview for deeper clarity of how the participants conceptualized the key chemistry ideas.

**Trustworthiness**

In regard to trustworthiness, the researcher must ask how they will persuade the audience that the results of the study are meaningful. In order to do this, the researcher must consider the truth value, applicability, consistency, and neutrality of their study (Lincoln & Guba, 1985). In this study, trustworthiness is established by truth value and consistency. For the qualitative researcher, to establish truth value is synonymous with finding credibility within the study. Lincoln and Guba (1985) explain that the employment of the credibility criterion is to first carry out the “inquiry in such a way that the probability that the findings will be found to be credible is enhanced, and second, to demonstrate the credibility of the findings by having them approved by the constructors of the multiple realities being studied” (p. 296). Lincoln and Guba (1985) suggest two major techniques that were used in this study for the implementation of credibility: triangulation and member checking. According to Denzin (1978), there are four different modes
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of triangulation: the use of multiple and different sources, methods, investigators, and theories. Triangulation by different methods is used in this study.

Lincoln and Guba (1985) describe triangulation by different methods as using different forms of data collection such as an interview, questionnaire, observation, or testing. The interview contains two types of questions: contextual and biochemical. Questions 1 and 2 consists of the contextual application of photosynthesis and cellular respiration, while questions 3 and 4 ask for the participants to describe the biochemical processes within a single cell. For each interview question, the participants were asked to explain the phenomena (initial response), explain the cycling of matter and the flow of energy within the phenomena. Each point was compared and contrasted. The terms used in the concept maps were also used to triangulate their ideas of chemistry discussed during the interview process.

The member check, whereby information, codes, interpretations, and conclusions are tested with the individuals from whom the information was initially gathered, is one effective strategy for building up credibility (Lincoln & Guba, 1985). If the researcher is to imply that his or her interpretations are adequate representations of participants’ experiences, it is important that the participants are allowed the chance to respond to the interpretations. In this study, the participants received, via email, their perspective transcription of their interview with the codes created. They were given two weeks to respond under the condition that no response would be interpreted as complete agreement with researcher’s interpretation of their responses and codes. One participant responded to the email, stating that they agreed with the coding of the transcription.

To establish consistency, an inter-rater approach was used in this study. Inter-rater reliability is often seen as a process that is used in quantitative studies. Armstrong, Gosling,
Weinman, and Marteau (1997) argue that "assessing inter-rater reliability is an important method for ensuring rigor" (p. 597) thus establishing consistency. In this study, inter-rater reliability was established by having an expert biochemistry professor examine the codes that were deduced from the interview and the qualitative analysis of the concept map. At this point, a discussion between the professor and researcher took place to ensure that the conclusions of their respective analyses were similar. In this dissertation, the researcher and the professor were in 90% agreement. After a discussion, the differences were settled to ensure a 100% agreement of the coding.

**Human Subjects Procedures**

This dissertation followed all federal, state, and local laws regarding individual institution participating in the study. A research proposal was submitted to the Institutional Review Board (IRB) at Kennesaw State University. The KSU IRB approved the study under IRB 17-002, “Science teachers conceptual understanding of biochemistry high school topics.” Participation of this study was voluntary and they were informed of their rights and signed a consent formed, which is found in Appendix H. Pseudonyms were used to maintain the confidentiality of the participants.

**Summary**

Qualitative methods were used to investigate the four main goals mentioned above. Six preservice teachers volunteered by completing a consent and demographic forms, were interviewed, and participated in creating a concept map using predetermined terms which was recorded by LiveScribe and video recordings. Using recorded data from LiveScriber, data management software Atlas.ti was used to analyze the data by providing an intuitive way to code
the data (using an inductive coding approach). Trustworthiness was established by the means of member-checking and triangulation and inter-rater reliability.
Chapter 4 Results and Discussion

This chapter will address evidence that will answer the research question of this dissertation: What are conceptual understandings that secondary preservice biology teachers hold about the biochemical concepts relating to the cycling of matter and the flow of energy in photosynthesis and cellular respiration? In order to answer the research question thoroughly, four other questions were included:

1. How do preservice teachers’ responses differ when asked in different context of the processes of photosynthesis and cellular respiration?
2. How are the secondary preservice teachers applying cycling of matter and the flow of energy within photosynthesis and cellular respiration?
3. What are the conceptual understanding of energy within the processes of photosynthesis and cellular respiration?
4. How are preservice teachers’ utilizing key chemistry topics within the process of photosynthesis and cellular respiration?

How do preservice teachers’ responses differs when asked in different context of the process of photosynthesis and cellular respiration?

Interview Question 1: Photosynthesis Contextual Initial Response.

Question 1 (Q1) consists of an application question about the biochemical process of photosynthesis,

A mature maple tree can have a mass of 1 ton (dry biomass, after removing the water), yet it starts from a seed that weighs less than 1 gram. How does this happen? What key chemistry topics are addressed in this scenario?
Figure 4:1: The frequency of the initial responses that were coded during the discussion of Q1. The number above each bar indicates the number of participants who were coded at the specific level. illustrates the number of codes for the initial responses of Q1. 8% of all responses by the preservice teachers were labelled Level 1, which indicate the response contain no chemical perspective when answering interview question. Ted stated,

"That's where the plant takes in nutrients through its roots in the soil. It absorbs lights through its leaves, and the chloroplasts in the cells. That's where the light absorbs from. It's within the cells that this process occurs. I remember specifically it's within the chloroplast."

Ted’s statement is within the level of the biological implications of the question. There is no mentioning of any of the chemical aspects of this process. In fact, Ted is even unsure of the biology of this question, "Probably losing my mind, for some reason right now I'm thinking, 'No, that can't be right.'" Ted was not able to discuss any chemistry topics in his initial response.
Figure 4.1: The frequency of the initial responses that were coded during the discussion of Q1. The number above each bar indicates the number of participants who were coded at the specific level.

58% of the responses of Q1 were labelled as Level 2. Level 2i represents that the interviewee attempted to use the chemical equation to explain the phenomena but contained inaccuracies. For example, Eva stated that "the seed is going to take up nutrients from soil. It will use that as energy as well as sunlight and use through photosynthesis". When asked to clarify her use of the word nutrient, she answers, "carbon, nitrogen". In the process of photosynthesis, nitrogen is not a component thus labeling as Level 2i. Sky mentions "a fact that organisms on the growth needs energy and water, photosynthesis...takes in CO₂ plus... I know this. No. Plus oxygen. Water is an output." Sky is asked to clarify her statement; she responds, "output is obviously CO₂". Sky states that for the process of photosynthesis, carbon dioxide is a product which is inaccurate. Level 2ii represents responses that solely use chemical equations to explain
The first interview question asked the secondary biology preservice teachers to explain the processes that must take place for a seed to become a tree. 58% of all responses included an explanation that consisted mostly of the chemical equation of photosynthesis. Mya's response to Q1 is categorized as Level 4ii as it is free from errors but missing detail,

“In the Calvin cycle so it takes CO₂ and it fixes it into larger molecules, and to do that it uses light energy to split water molecules, then it uses both the hydrogens and oxygens with the carbon to form a glucose.”

Mya correctly describes the purpose of the Calvin cycle but leaves out other major processes that would contribute to the growth of the tree.

The first interview question asked the secondary biology preservice teachers to explain the processes that must take place for a seed to become a tree. 58% of all responses included an explanation that consisted mostly of the chemical equation of photosynthesis.

Liz explained how the seed becomes a tree in Q1, “the roots start taking in water, then it just sprouts up, it starts to be able to get sunlight. They need energy to – or they need food to create energy to do self-processes like making more cells to grow.” Liz omitted the role of carbon dioxide in the process of the seed growing. Mya also omitted an important substance in her explanation of Q1,

“It takes CO₂ and fixes it into organic molecules. That can go later into cellular respiration but not all of it will be used for that. It can also be manufactured into glycogen which then becomes biomass and turns into the tree.”

In this statement, Mya failed to mention the role of water in the process of photosynthesis.

Level 2iii represents discussions where the interviewee was able to utilize the chemical equations of the biochemical processes without error or incompleteness. After prompting him for greater detail of the application question, Ted stated that the chemical reaction of photosynthesis is “I remember the formula. CO₂ + H₂O yields C₆H₁₂O₆ and O₂.”

There were no responses in that were labelled Level 3. Mya's response to Q1 is

That's the Calvin cycle so it takes CO₂ and it fixes it into larger molecules, and to do that it uses light energy to split water molecules, then it uses both the hydrogens and oxygens with the carbon to form a glucose.”

Mya correctly describes the purpose of the Calvin cycle but leaves out other major processes that would contribute to the growth of the tree.

The first interview question asked the secondary biology preservice teachers to explain the processes that must take place for a seed to become a tree. 58% of all responses included an explanation that consisted mostly of the chemical equation of photosynthesis.
photosynthesis. While there were no responses that was labeled Level 3, 25% of the responses were labeled as Level 4. This illustrates that few of the participants were able to initially explain biochemically the phenomenon in question.

**Interview Question 3: Photosynthesis Biochemistry Initial Response.**

Q3 asks the participants to explain in detail the biochemical process of photosynthesis in a cell, “Draw and explain the process of photosynthesis within the cell. What key chemistry topics are addressed in this process? Explain.”

Figure 4:2 illustrates the number of the participants’ responses that were coded during their initial response in Q3. There was only one response that was labelled as Level 1. Eva was incapable of correlating any chemical themes to Q3, she also had difficulty with the biological topics of this question,

> “Here is the cell. Here is the nucleus, so that can be in your plants. I cannot for the life of me, remember what that organelle is called but there’s an organelle where it does photosynthesis. Its only in plant cells, which is why these have a cell wall because only plant cells have a cell wall. It's got chlorophyll in it...It is going to absorb wavelength of light, of visible light, except for green. The parts in there are the stroma? That word may not be correct, it may just be stoma?”

She continues stating, “I can see it in my head; it's got layers and there's gaps thylakoid, something- something similar to that word, gaps, I think are in there. That sunlight, it is getting it from the sunlight to glucose what happens in the middle, is a wonderful question.” Eva’s statement was categorized as Level 1.
There were no responses labelled as Level 2. 83% of the responses by the preservice teachers were labelled Level 3 and 4. Level 3 codes illustrates the inclusion of the subprocesses of the biochemical processes in the discussion. Sky attempts to discuss the subprocesses of photosynthesis in her response to Q3, “this is photosynthesis as a whole, as a split [between] light and dark...Light [reactions] requires sun, that's where you're going to have CO₂ come in.” Sky incorrectly states that CO₂ is required as a reactant in the light reactions instead of the dark reactions. Due to this error, Sky’s discussion is labelled as Level 3i.

Similarly to Sky, Liz’s response to Q3 included a discussion of the subprocesses of photosynthesis. Unlike Sky, Liz correctly explains the subprocesses, “Light energy comes into [the plant] with water from the roots and oxygen is produced. Light [cycle] is light dependent reaction. Calvin Cycle is light independent for dark. Then you have carbon dioxide from
atmosphere coming [into the Calvin cycle], and glucose is produced.” Due to this response, it is labelled as Level 3iii. Even though she mentions the reactants and products of each sub-process of photosynthesis, she did not provide enough biochemical detail within those processes to be considered Level 4.

Responses that attempt to describe the full biochemistry of the processes are labelled Level 4. In attempting to give as much detail as possible to Q3, Ted stated, “I remember this. Photosynthesis is basically-- We have the light reactions. I remember that's when light comes in and it does something. It reduces compound...this process ends by producing, acetyl CoA. This is the compound you start with Calvin cycle.” This statement by Ted contains several inaccuracies; (1) acetyl CoA is a reactant of the Calvin cycle, (2) Calvin cycle is powered by ATP, and (3) the Calvin cycle produces water. Ted later recants and states that water is a “reactant.” He concludes, “By the [Calvin cycle] is where your sugar is produced. Let me go to the electronic transport chain. This is where the electrons are pumped back across the membrane to produce ATP. That's what I remember about photosynthesis. I don't know where the Krebs cycle comes in.” Within the final statement, the inaccuracies that Ted mentioned include the electron transport chain in the process of photosynthesis and suggesting that the Krebs's cycle is part of the same biochemical process. In consequence of the inaccuracy, Ted’s statement is coded as Level 4i.

In response to Q3, Dan provided the most detailed description of the biochemical process of photosynthesis,

“We’re going to start with the light-dependent reactions. We have our sunlight and what that's doing here is that's taking our H2O, that going to split apart. We are working in the thylakoid membrane I believe for the light-dependent reaction.
Split that in two. What we really want is those hydrogens. Oxygen is going to be kicked out right from the beginning in those light-dependent reactions. We are then going to move into the stroma for the light independent reactions. There’s some NADPH in there somewhere which is just our electron carriers. We’re going to transfer those hydrogens there and then at the end we’re going to get glucose... we’re just transferring those electrons through NADPH and then we’re expending glucose out.”

Even though Dan provided a brief overview of the biochemical process of photosynthesis, he did not discuss many key aspects of the process such as the use of ATP or the photosystems of the light dependent sub-process thus coded as Level 4ii.

**Interview Question 2: Cellular Respiration Contextual Initial Response.**

Question 2 (Q2) consisted of an application question of the process of cellular respiration, “John weighs 440lbs. Through diet and exercise, he loses 220 lbs. How did this happen? What key chemistry topics are addressed in this scenario? Explain.”

Figure 4:3 illustrates the codes that were used during the initial response of Q2. 67% of the responses were coded as Level 1, while 22% and 11% of the responses were coded as Level 2ii and Level 3, respectively. Level 1 represents responses that did not include any chemistry to explain the process. For example, Eva responded,

“*He restricted his food intake. Which means that he also increased exercise so his body is burning more calories. Because of all of the mechanical work that he is doing. The restricted food intakes-- He doesn't have the calories so his body is getting it from fat. His body's burning the fat.*”
Liz responded in a similar fashion, “He's eating better and he's exercising. He's sweating. He's losing some water weight. When he works out.” There is no indication of what type of biochemical process is taking place that caused the weight loss.

**Figure 4.3:** Frequency of codes of participants' discussion during the initial response in Q2. The number above each bar indicates the number of participants who were coded at each specific level.

Level 2iii coding represents codes that solely uses the chemical equation to answer the question. Their response is correct and complete. Ted declares, “When John was big, and through diet and exercise, he lost weight. Humans undergo cellular respiration. That's when sugars are broken down to release energy for the human to use, or plant, to use, or whatever organism. After many classes where I had to memorize the equation, I'm going to recite it back to you.” Ted then proceeds and correctly writes the chemical equation of cellular respiration as...
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shown in Figure 4:4.

\[
\text{Cellular respiration} \quad \text{energy} \quad \text{energy}
\]

\[
C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O
\]

Figure 4:4: Chemical equation of cellular respiration as depicted by Ted.

Ted’s statement is labeled as Level 2iii as he is able to correctly identify the chemical equation for cellular respiration and did not miss any key substances in the equation.

Dan in his response to Q2 stated, "we take in \(O_2\) when we breathe, plus our glucose, \(C_6H_{12}O_6\) because most of our food is going to be broken down into the form of glucose, break it down into \(6H_2O\) and \(6CO_2\). Then we're going to plus energy, that’s going to be in the form of ATP". Dan correctly recited the cellular respiration chemical equation in his response thus it was labeled as Level 2iii.

Interview Question 4: Cellular Respiration Biochemistry Initial Response.

Question 4 (Q4) asks the preservice teachers to describe biochemically the process of cellular respiration in a cell, “Draw and explain the process of cellular respiration within the cell. What key chemistry topics are addressed in this process? Explain.” Figure 4:5 illustrates the frequency of the codes in this section. Ted attempts to give an overview of cellular respiration by stating, "Let's leave this simple... I remember that with cellular respiration, there were nine different steps for the chemical to have broken down further along the way. More ATP, thereby, energy was broken down and given off.” This statement is labelled Level 1 as he does not give
any more information about the biochemical other than identifying the type of biochemical process.

Figure 4.5: Frequency of initial response codes of Q4. The number above each bar indicates the number of participants who were coded at the specific level.

Sky's response to Q4 was labeled as Level 4i, even though she provided the most detail about the process. Sky briefly identifies the sub-process of cellular respiration, “glycolysis, Krebs cycle and ETC.” She continues stating,

“product of glycolysis is pyruvate...pyruvate is the main molecule that's going to go into Krebs cycle...the biggest thing is that you're producing more NADH and more ATP because the end game is really just producing lots and lots of energy. NADH is getting reduced, so that's another byproduct...”
Sky describes that NADH is reduced to become NAD\(^+\), which on the contrary, NADH is oxidized to become NAD\(^+\).

An example of a discussion labelled Level 4ii, Mya presented a thorough description of cellular respiration in response to Q4,

“\textit{Glycolysis basically just splits glucose in half into two, three carbon chains.}

\textit{Then, we’re going to go through the Krebs cycle. I think I got confused because I will call it the citric acid cycle. We go through the Krebs cycle which, it goes around and around in a lot of little steps until we kick out CO}_2\text{. It’s the last unusable form. It has the lowest energy potential... Then, we are going to use the hydrogen ions and the electron carriers to go through electron transport chain... they are producing more hydrogen ions. They have ADP samplings where it allows the hydrogen ions come back in, and where we are fixing phosphate through to get ATP.}”

\textbf{Summary.}

The first interview question asks the preservice teachers to explain how a seed that weighs less than 1 gram becomes a tree that has a biomass of more than 1 ton. All the participants understood that photosynthesis was the primary reason for the growth but apart from one participant, the preservice teachers could not describe in detail how the seed becomes a tree. This finding coincides to the findings of Brown and Schwartz (2008). In their study examining the conceptual understanding of photosynthesis and cellular respiration of primary preservice teachers, they found that half of their participants did not know how plants used photosynthesis to grow.
57% of responses for Q1 were coded as Level 2i. Ted commented on Question 1, “That’s where the plant takes in nutrients through its roots in the soil.” Similarly, Eva stated, “the seed is going to take up nutrients from soil.” These nutrients come from the soil and allow the plant to gain biomass. Driver et al. (1994) found a similar conception when studying K-12 students’ biological conception of photosynthesis and cellular respiration. Even though Driver et al. (1994) observed this conception within K-12 students, it seems the idea of gaining biomass from soil persists even in preservice biology teachers. Eva further explains that the soil “will be used as energy as well as sunlight and use through photosynthesis.” Eva’s statement is analogous to the findings of Lin and Hu (2010) while studying and analyzing concept maps of seventh graders in the topic of cycling of matter and the flow of energy in photosynthesis, cellular respiration and food chains, in which they found that students suggested that soil is an energy providing source. Driver et al. (1994) emphasizes that, “The universal and very persistent intuitive conception, identified in all studies with subjects of all ages, is that plants get their food from their environment, specifically from the soil” (p. 30). Wilson et al. (2006) adds that students often have difficulty explaining and deriving the composition of the biomass of the plant. For example, both Eva and Ted inaccurately stated that nitrogen is absorbed by the plant for growth. Some preservice teachers were able to accurately trace matter, especially in the process of photosynthesis. For example Dan explained, “we take in $O_2$ when we breathe, plus our glucose, $C_6H_{12}O_6$ because most of our food is going to be broken down into the form of glucose, break it down into $6H_2O$ and $6CO_2$.” In the case of the composition of the plant’s biomass, only Mya fully answered Q1,

“So, $CO_2$ goes into the seed and through photosynthesis it fixes it to glucose. It takes $CO_2$ and fixes it to organic molecules. That can go later into cellular
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respiration but not all of it will be used for that. It can also be manufactured into glycogen which then becomes biomass and turns into the tree.”

Interestingly, 67% of all responses that were coded for their understanding of photosynthesis during Q1 prompt, were labelled Level 2. This indicates that most participants used the chemical equation to address the phenomenon. This is expected due to the nature of Q1. Q1 emphasizes an applied understanding of photosynthesis, as a result, it was not surprising that few responses were categorized at higher levels of reasoning. Q3 inquired about the biochemical process of photosynthesis. All responses except for one were labelled Levels 3 or 4. This is expected due to the nature of the prompt as it is asking the interviewees to give as much detail as possible explaining the biochemistry of the photosynthesis.

67% of all Level 1 responses were found in Question 2; "the interviewee explanation must be broad, vague, lack a chemical perspective or relation to photosynthesis/cellular respiration to be coded as Level 1.” For example, Eva discussed that John in Q2 had to experience caloric deficiency,

"He restricted his intake, his food intake, I guess. Which means that he also increased exercise, so his body is burning more calories. Because of all the mechanical work that he is doing. The restricted food intakes, he doesn’t have the calories, so his body is getting it from fat. His body's burning the fat.”

In agreement, Dan states “Obviously to be able to cut his weight in half, he’s going to have to expend more energy that he's taking in”. Liz simply explained that "the fat shrunk... the fat was used by his body for energy ...looks like it was burned.” There is a common theme with these responses. 100% of the participants discussed about "fat loss", "fat burned", or "burning calories".
Responses such as those of Liz and Sky stated that the fat is burned or the fat shrunk. Liz nor Sky discussed the reaction of the fat and the possible products. Also, the interviewees were not able to identify the products of fat loss or fat burn. Liz mentioned that “the fat shrunk.” In response to this question, Sky mentions that “the loss of matter occurred when exercised and dieted. Exercises involves the burning of excess fat per cellular respiration.” Sky was able to correctly identify the process in which fat is used for energy. This statement is labeled zero because she explains that “I started trying to write respiration that wasn't really helping for me because I was trying to connect it back to pounds. It was not working.” Even though Sky correctly classified this process as cellular respiration, she was not able to write the chemical equation and associate it to the question. Question 2 demonstrated that many of the preservice teachers had difficulty tracing matter during the process of cellular respiration especially if asked in the form as presented in Q2. Wilson et al. (2006) found that undergraduate students were demonstrating the same difficulty in tracing matter through cellular respiration and photosynthesis.

How are the secondary preservice teachers’ applying cycling of matter of and the flow of energy within photosynthesis and cellular respiration?

Cycling of Matter.

Q1 Cycling of Matter.

According to Figure 4:6, which illustrates the number of codes found in the cycling of matter prompt of the Q1, 80% of the responses were labeled Level 2 and the remainder were labeled Level 4. There were no responses during the prompt that were coded as Level 1 and Level 3. Four responses in Q1 were coded as L2i. Eva in her response to the inputs/outputs of the cycling of matter in Q1 stated, “You got sunlight as an input. You got carbon, nitrogen as nutrients, are
an input. *Your output would be...oxygen.*” Eva’s statement describes what she believes is the inputs and outputs of photosynthesis. She lists carbon and nitrogen as inputs to the biochemical process. Nitrogen is not a component in photosynthesis as Eva erroneously described.

![Figure 4.6: Frequency of cycling of matter codes found in the responses of participants during Q1. The number above each bar indicates the number of participants who were coded at each specific level.](image)

In Sky’s discussion during the cycling of matter prompt of Q1, she described the inputs and outputs, “*Inputs of photosynthesis would be carbon dioxide that we breathe out. Now we get air, water, and sunlight, and then outputs would be glucose.*” Sky’s description of the process of photosynthesis in this instant is coded as L2ii. Even though there were no errors in her explanation of the biochemical process, she omitted that oxygen is produced along with glucose.

Liz in her explanation of the cycling of matter in Q1 stated, “*Water is coming in the roots, light's coming in... CO₂ comes in from the atmosphere. [The plant] gives off oxygen, then glucose is an output.*” Liz provides an overall description of the reactants and products of photosynthesis
as shown in her illustration in Figure 4:7. Again, she provides similar answers in her discussion of cycling of matter in Q3, “Water is a matter. Carbon dioxide is a matter. Oxygen is a matter, and glucose is a matter. Water comes in, oxygen comes out, carbon dioxide comes in, glucose comes out.” Since there are no errors with her explanations, they were labelled as L2iii.

![Figure 4:7: Liz's illustration of the biochemical process of photosynthesis within the plant cell.](image)

For Q1, there were two responses that were coded as Level 4ii. Mya in her explanation of cycling of matter for Q1 stated that “the first question- just asking about the biomass fixation which would be that, but part of it too is they have to have energy to do cellular processes which is cellular respiration.” Interestingly, Q1 is based on the concept of photosynthesis. Mya recognizes that to answer the prompt about the cycling of matter of Q1, cellular respiration must be discussed in the following transaction:

Mya: “Okay. Do you want cellular respiration in with it too?

Interviewer: Be as detailed as possible.”
Mya: (continuing to describe the subprocess of cellular respiration)

“which is where we take the glucose and then we split it down and we have glycolysis. Here, we split it into two little pyruvate forms... The Krebs cycle, and then that breaks it down further into eventually CO$_2$, but then we also get our electron carriers in our hydrogen ions and then that goes to the electron transport chain, which goes to ATPs. That provides energy for cellular processes to happen, but again, not all of the glucose goes through this, and then when it’s not, then it becomes glycogen, biomass and starch. Well, it goes within its cellulose.”

Mya: (completing her discussion of the cycling of matter by discussing photosynthesis)

“Photosynthesis has CO$_2$ going in, which is what comes out of cellular respiration. Photosynthesis also puts out oxygen and it puts in H$_2$O, and then through cellular respiration with these hydrogen ions through the electron transport chain, they're making water at the end of it, which also goes back in and renewed oxygen to go in to be at the electron. It pulls the electron.”

The data above illustrates that preservice teacher were more likely to use the chemical equation of photosynthesis (Level 2) to explain cycling of matter. In these cases, the preservice teachers focused on the interrelationship of the inputs and outputs of photosynthesis. Similarly to Mya’s response above, the preservice teachers often included the process of cellular respiration (report the number of students that did this) to help give evidence of the cycling of matter.
**Q3 Cycling of Matter.**

The number of responses coded in the cycling of matter prompt in Q3 is illustrated in Figure 4:8. There were four responses labelled as Level 2 codes. In Eva’s response to the cycling of matter prompt of Q3, she stated,

“Sunlight goes in. It's going to need some energy to- it’s going to need ATP to perform photosynthesis. It's going to require some energy to do that, so that's an input. You're going to get energy out, like glucose. I'm sure there's by-products, I couldn't tell you what they are there. Some oxygen, oh well.”

In Eva’s response, she emphasizes the inputs and the outputs of photosynthesis. She correctly states that sunlight is an input and glucose and oxygen is an output of the biochemical process. In her explanation, she omits that carbon dioxide is also a major input of the chemical reaction. Eva correctly included that ATP is an input in photosynthesis but did not emphasize where ATP is used during the process. Responding to the same prompt, Liz stated, “Water is a matter. Carbon dioxide is a matter. Oxygen is a matter, and glucose is a matter. Water comes in, oxygen comes out, carbon dioxide comes in, glucose comes out.” Similarly to Eva, Liz emphasizes the input and outputs of photosynthesis to explain the cycling of matter within the process. Her statement was labelled as Level 2iii, as she basically summarized the chemical equation of photosynthesis without any errors or omitting the major substances.
There were three responses that were labeled as Level 4ii. Dan’s explanation of the cycling of matter in Q3 was labelled Level 4ii. He stated,

"Okay, the energy is coming in in the form of light, so really all a plant needs the light for is to be able to break that H\textsubscript{2}O down. It's being able to capture the energy from the light from the giant solar panel and it's going to be able to use that energy to break the H\textsubscript{2}O down to go into the light independent reactions so that it can create the glucose. As per the energy coming out, the O\textsubscript{2} is coming out. That O\textsubscript{2} is going to be used in other processes."

Dan describes the breakdown of H\textsubscript{2}O that happens at the beginning of photosynthesis and states that O\textsubscript{2} is going to be used by other processes of the plant. The O\textsubscript{2} that is the product of the
degradation of H$_2$O is released by the plants and is reused. During Sky’s response to the cycling of matter for Q3, she starts describing briefly the Calvin cycle,

“I know CO$_2$ is what gets cycled around the Calvin cycle, and the end product ends up being glucose. You're basically putting in CO$_2$, it's giving off and basically, carbons are getting shuffled around until you produce glucose, and you don't need the sun for that.”

Sky then struggles to explain the source of energy for the Calvin Cycle, “More than likely, this just provides the energy for that, I'm pretty sure, so it's really just the breakdown of water, yes. The splitting of water, I'm pretty sure. I'm pretty sure you split water and that's how you get the energy for the Calvin cycle.” For Q3, Mya explains cycling of matter,

“The cycle of matter is going to come in with the CO$_2$. You can also see it with the water as well. We're bringing in water. Then we are actually using the hydrogen ions to help with these gradients but also with the Calvin cycle and the hydrogen from the glucose. The CO$_2$ is coming in, it's being fixed. Here is all these nice enzymes in here that's coming out as glucose. We're having the matter coming in with the water and the CO$_2$. It's remaining intact. It's going through the cycle or being expelled as oxygen.”

Mya is able to explain the process of photosynthesis biochemically but excludes many details.

**Q2 Cycling of Matter.**

Figure 4:9 illustrates the number of the types of codes of the preservice teachers’ responses during the cycling of matter codes in Q2. 50% of the responses were labelled Level 2ii while the 16% of the responses were labeled Level 1, 2iii, and 4ii each. There was one response coded as Level 1 for Q2. Attempting to explain the process of cycling of matter in cellular respiration, Dan stated “I would just say, this glucose obviously has to come from somewhere.
Maybe he's ingesting less, and eating less, so his body doesn't have as much of that glucose to be able to break down and turn into ATP. At the same time, he's going to be using less oxygen, he's going to be giving off less CO\textsubscript{2}, I think with that nature.” Dan erroneously concluded that John will lose weight by the decrease consumption of oxygen thus a decrease of the production of carbon dioxide.

Three responses to Q2 were coded as Level 2ii. Eva stated that,

“\textit{So, these organic molecules going out, its going in, he’s going to have that transferred to glucose to be used by the body, if it’s not used it will be stored as fat. But he's burning it transferred back to glucose and used. Glycolytic reaction so he is going to sweat while exercise. If you are going to maintain weight, you will want energy in to equal energy out. If you want to lose weight you will want energy in to be less than the energy out.”}

Eva neglected to discuss the other key substances of cellular respiration such as the role of water and oxygen. Liz also omitted an important substance of cellular respiration by stating “\textit{Good food, in a way. More oxygen when he's exercising. Output sweat}” By this statement, Liz failed to mention the product carbon dioxide. She continued by stating:

“\textit{When you work out your body has to take in more oxygen because you need more energy to do normal cell things and also exercise. If you're eating better, which is maybe more plants-- Don't know anything to do with anything.”}

Her ending statements emphasize that she is not confident in her answer. She failed to demonstrate how oxygen is recycled. Similarly, Ted responded that

“\textit{Through breathing that's where the oxygen comes from and through eating that's where the nutrients comes from. Basically, it goes out in the same was we exhale}
the CO₂, I just talked myself into a hole, but we'll just roll from there and then you pee out these. The extra nutrients that your body can't use that's what you poop out, that's the cycle. You take in through breathing and through eating and then it's cycled back out through exhaling and through using the bathroom. The body uses the energy, your body is [like], “Oh, I like that amount of energy”.”

First, Ted excluded water from his explanation of the chemical equation. Second, he described the metabolism of matter as linear rather than a cycle.

![Figure 4:9: Frequency of cycling of matter codes in Q2 of the interview. The number above each bar indicates the number of participants who coded at the specific level.]

For Q2, only one response was coded as Level 2iii. Sky responded to the question about cycling of matter for Q2,

“The inputs, obviously, just be food, water. If you want to be more technical, eat a lot of food and the form of glucose because glucose is what is going to give us
ATP through cellular respiration, and then outputs would still be the same outputs as before, so CO₂—I'm sorry, there's water. I think water like when you're taking it in and then when you're exercising you're producing water. I always forget where water fits in, to be honest. No, water is an input because the electrons follow water. In the electron transport chain, that's how they pump the ATP synthase does pump because they have to follow, they have to go to the oxygen. Yes, water is a by-product. Input is oxygen. Those should be the inputs and outputs on a cellular-like reaction Level, but then if you build a-- You're really talking about John losing weight, and weight in our body is beneath the fat muscles of water and, more than likely, he is burning-- Hopefully, you're just burning glucose off so it's going to be a good amount of fat. You can also start building of muscle, but, in order to actually lose weight, one has to be higher than the other. You either have to have more dieting and basically you're not eating anything or you have to increase your exercise a lot so that way, you're taking in isn't the same as what you get out.”

Interestingly, Sky seemed unsure of the role of water within the cycle of cellular respiration. First, Sky stated that “inputs, obviously, just be food and water”, which she declared it incorrectly as an input or reactant of cellular respiration. She quickly retracts her previous statement and responds “…the same outputs as before, so CO₂—I’m sorry, there’s water”, to explain that water is really an output or a product. Once again, she recants to declare, “No, water is an input because the electrons follow water”. As she is explaining how water is an input, describing the movement of electrons in the electron transport chain, “in the electron transport chain, that's how they pump the ATP synthase does pump because they have to follow, they have
to go to the oxygen”, she recognizes her error then correctly mentions, “water is a by-product. Input is oxygen”.

When asked about the cycling of matter for Q2, Mya reemphasizes the subprocesses of cellular respiration,

“Sure, we have our glycogen and we break that down into the glucose. The matter is not going anywhere, we’re just rearranging it in this process so we’re splitting it apart and rearranging it into the glucose, then we will do cellular respiration. It goes through glycolysis again or again, we’re going from six carbons to three so matter is still not going anywhere at this point. Then when we go through the Krebs cycle, then it goes into our CO$_2$ which again, we’re not getting rid of any matter, we’re just changing it and then it's going to go out eventually. Then that’s where the energy comes in, it's when we start using the ions through and through, which is actually moving chemical energy in stem and the ATP.”

As the result, Mya’s statement was labeled as Level 4ii.

**Q4 Cycling of Matter.**

Figure 4:10 illustrates the number of cycling of matter codes of Q4. 40% of the responses are labelled Level 4ii while 20% of the responses are labelled Level 2ii, 2iii, and 3ii each. In Ted’s explanation of cycling of matter for Q4, he stated “Like I talked about with Johnny, it's like we get this breathing, get this through take in nutrients, eating, some people’s cases supplements, some people’s cases vitamin pills or something like that” As with the Q1, Ted uses the term nutrients to describe the inputs of cellular respiration. Nutrients is a term that is ambiguous. Exactly what nutrient Ted is referring to is difficult to know. He continues
“We take this in, our body uses them to produce energy. We give off carbon
dioxide when we exhale. We give off through our body secretions. These nutrients
that we give off or used by other organisms for their life process just like CO$_2$ is
used by plants.”

Once again, Ted mentions nutrients. It is difficult to say if he is describing water, carbon,
phosphorous, nitrogen, or other trace elements that are essential for life. He ends stating “What
they give off, we take in such as, plants give off oxygen, we use oxygen for cellular respiration.
Plants build these sugars, we eat plants”. His description of the cycling of matter for Q4 is
labelled Level 2ii as he failed to discuss specifically the role of water in the process. It may be
feasible that his usage of the term nutrient may include water.

Figure 4:10: Frequency of ‘cycling of matter’ codes found in the responses of Q4. The number
above each bar indicates the number of participants who coded at the specific level.

Liz’s discussion to the cycling of matter prompt of Q4 is the only response coded as
Level 2iii. She stated, “Glucose is matter. Oxygen is matter. Water is matter. Carbon dioxide is
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matter. You got matter coming in with glucose and oxygen, matter coming out with carbon dioxide and water. ATP is energy that comes out.” She simplistically explains the chemical reaction of cellular respiration by describing the inputs and outputs.

Sky’s response to the question of cycling of matter for Q4 is labelled as Level 3ii. She starts reciting the chemical equation of cellular respiration,

“Right. Again, I guess we're getting more and more complex with it that at the end the day, in this, in cellular respiration, the end goal is really works ATP, and where we get that ATP and you still have to have your inputs which are glucose and oxygen, and then your outputs are going to be water and CO₂.”

In an attempt to explain the subprocesses of cellular respiration, she explains, “the Krebs cycle is what ends up kicking out CO₂. I really don't remember.” She states that she does not remember any of the subprocesses of cellular respiration and the chemical reactions that are specific to each subprocess. She continues stating

“The cycling of matter, it's still going to illustrate our broader cycling of matter picture because you still have glucose going in, oxygen going in. Getting cycled through multiple processes and where to kick out and produce energy and you're going to still have outputs like water and carbon dioxide. You're still cycling all of this through.”

Sky recognizes and describes that the subprocesses will still follow the cycling of matter theme as the same matter that makes up glucose will eventually become carbon dioxide and water.

Dan emphasizes the cycling of matter by explaining how the product of a reaction will become the reactant of the next reaction, “The big thing with cellular respiration is usually we’re using the product of the step before to go on to the next step. We’re taking these pyruvic acids
they're going directly into the Krebs cycle.” Unlike his contemporaries, Dan discusses some of the energy-rich molecules and their function, “Krebs cycle is going to make NAD+ and FADH, that’s going to go directly into the ETC and then that’s going to provide the energy to be able open those channels and create those ATPs.” For Q4, Mya responded,

“We’re taking matter in the form of glycogen when we’re arranging it into glucose, then we split them. We’re taking apart the molecule and we're rearranging it again. We're adding some other molecules in but we're rearranging it until we get CO₂ out and then we are using the energy, in this case, the form of electrons and hydrogen ions. Then when we put those through the electron transport chain. We create a gradient which is a form of chemical energy, and then allowing that basically regulated diffusion back into the inner poles of the mitochondria. We're putting together the ATP. This is not matter transformation. It's just moving them around. This is just, again, all that's just rearranging.”

Dan responded to the same question,

“The big thing with cellular respiration is usually we’re using the product of the step before to go on to the next step. We’re taking these pyruvic acids they’re going directly into the Krebs cycle. Krebs cycle is going to make NAD⁺ and FADH, that’s going to go directly into the ETC and then that’s going to provide the energy to be able open those channels and create those ATPs.”

Dan’s discussion of Q4 is labelled as Level 4ii.
Synopsis.

Figure 4:11 illustrates the percentage of responses for each level per question. For Q1 and Q2, there were no responses labeled as Level 1 or 3. This indicates that the preservice teachers’ response of how matter is cycled consisted only of the inputs and the outputs of the biochemical processes or they were able to explain in detail biochemically. Overall, the majority of the responses about the cycling of matter relied on the chemical equations to explain the phenomenon. Liz stated in her response to the cycling of matter prompt in Q1, “Water is coming in the roots, light’s coming in, CO₂ comes in from the atmosphere. This [process] gives off oxygen, then glucose is an output”. Liz oversimplified the cycling of matter to just describing the inputs and the outputs of photosynthesis. Mya’s response to the cycling of matter to Q3 stated, “The cycle of mater is going to come in with the CO₂. You can also see it with the water as well. We’re bringing in water. Then we are actually using the hydrogen ions to help with these gradients but also with the Calvin cycle and the hydrogen from the glucose. The CO₂ is coming in, it’s being fixed.” Even though Mya was able to explain in some biochemical detail of how matter is cycled, she was missing some key points.
Flow of Energy.

**Q1 Flow of Energy.**

Of all the responses that the preservice teachers replied to the flow of energy prompt of Q1, 50% were labelled Level 2 as shown in Figure 4:12. In response to Q1, Liz stated that “energy input is sunlight energy, and my energy output is ATP”. Q1 assessed the participant’s conceptual understanding of photosynthesis. In the process of photosynthesis, regarding energy, the input is sunlight while the output is glucose. Liz stated that the output for energy is ATP, which is incorrect; therefore, it is labeled as Level 2i.
According to Figure 4:12, 30% of all responses were labelled as Level 3. Ted in response to the flow of energy for Q1 appeared to meet the criteria of a response of Level 3ii. Ted stated,

“light coming in the plant. This is where I'm thinking that this initial surface is going to be the light reaction. I think all these have got to be the initial reactions, of what's going on with the light... the light is being absorbed by the plant through the leaves, through the chloroplast, and it's causing some of the molecules to give up an electron”.

Ted had correctly identified the basic sub-process of the light reaction but excluded the molecule that donates their electrons. Interestingly, Ted continues stating,
“I'm probably confusing Calvin and Krebs, but then there's one called the light-independent reaction. I believe that's the Krebs cycle. That's another one of those that-- I remember it. I remember going over it a thousand times, but sitting here, I can't remember it”.

Ted incorrectly mentions that the Krebs cycle is synonymous to the light-independent reactions. Interestingly he continues stating, “Light-independent doesn't necessarily mean that this plant doesn't just-- without light, or because there's no light, they have to use the cycle, it's just this is another that they can get energy without light.” Ted later discusses that the cycle is another way for the plant to gain energy in contrast to the light-independent cycle as an integral part of the process of photosynthesis to which plants convert light energy to chemical energy. For this reason, Ted’s response to Q1 is coded as Level 3i.

Level 4 coding represents responses that discusses the biochemistry of the biological processes. 20% of the responses fall within this category. Mya describes the flow of energy in Q1 as this,

“We have the sun, the sun helped to pull light reactions as part of photosynthesis, the other chemical light reactions. Those are what breaks the bonds in H₂O, that's where splitting water is actually happening and then the carbon fixation happens in the Calvin cycle, so also the light reactions and the dark reactions. That energy eventually is going to be transformed into glucose which again is being transferred from light energy to chemical energy. Then when we go through cellular respiration, we’re giving out the chemical energy through ATP. The energy is flowing but it doesn’t go back on a cycle. The matter is cycling but the energy flows through in one direction.”
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Mya correctly discusses the biochemical process of photosynthesis in her response to Q1, even though she omitted specific details of the process. For this reason, her response is labelled Level 4ii.

Q3 Flow of Energy.

Figure 4:13 illustrates the flow of energy codes for Q3. 75% of the responses were coded Level 2ii and the remainder of the responses were labeled as Level 4ii. In Eva’s response to Q3, she stated, “I mean, sunlight is coming in and it's being transformed to energy for the cell. The cell is going to use the energy to do a job, whatever type of cell it is, whatever its job is”, coincidently responding to the same question Liz also stated, “Light energy comes in and glucose is used for energy, but glucose itself is not energy but it's used for that”. Eva and Liz’s statements are incomplete regarding this question which is why is labelled Level 2ii.

Sky in describing the flow of energy in the biochemical process of photosynthesis (Q3) states,

“I’m pretty sure most of the energy comes from the sun, but that’s because the sun- - we're using sunlight to split water...Because you're doing a hydrolysis reaction. Hydrolysis reaction splitting the water, and that splitting of water when you're breaking apart a molecule, it's exothermic, so it's giving off energy, energy in the form of ATP, and that ATP is what will get put into the Calvin cycle so that it can basically-- like a Ferris wheel, charge the Ferris wheel so that it can spit out glucose. The cell will use that glucose to undergo normal function.”

There are two main errors with Sky’s explanation of the flow of energy: (1) she describes the splitting of the water molecule as hydrolysis and (2) the splitting of the water molecule releases energy in the form of ATP. It takes energy from the sun to break the bonds of the water molecule. It is impossible for energy to be released from the breakage of the bonds if it needed
energy to break it. It is the electrons of the water that are needed for the next sub-process of photosynthesis.

Figure 4:13: Frequency of codes of the preservice teachers' responses during the 'flow of energy' prompt during question 3. The number above each bar indicates the number of participants who were coded at the specific level.

**Q2 Flow of Energy.**

The codes for the preservice teachers’ responses of the flow of energy prompt in Q2 is illustrated in Figure 4:14. 60% of the responses were labelled Level 2ii while 20% of the responses were labelled Level 1 and Level 2i each.

In her response to the flow of energy prompt, Sky replied,

"-the flow of energy. *He will always be undergoing cellular respiration because he is breathing, and we are human, so he will always be putting out oxygen and he'll need glucose which will take in good food. That's the natural process. It's
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still going to keep going around and around, and that’s still producing our
outputs: CO₂ and water.”

Sky correctly mentions that the process of cellular respiration is responsible for John’s weight
loss. In her discussion, she does not mention anything about energy. She reemphasizes the
cycling of matter, “He’s going to take in oxygen, take in good glucose and food, but, in order for
him to lose weight-- You still have cycling of matter going on, but now losing weight, you’re
shifting out of the cycling of matter. It’s more about his taking in-- he could be taking in less
food.” Her response to the question does not answer the prompt given to her, thus labeled Level 1.

In Eva’s discussion to the prompt for Q2, she states,

“So in you got food. Output. I’ll say like that. If I say food like that, it will be
confusing. Food is going to be changed to glucose. Glucose is coming out as it is
being used. If you want an output, you can say sweat”.

In this statement, Eva is prompted to discuss the flow of energy within the phenomena. Eva
mentions that food(glucose) is the input of energy and the output for energy is sweat (water).
Due to this error, Eva’s discussion is rated as Level 2i.
Liz simplistically explains, “We have food coming in, energy, that helps to create with oxygen-- like on this other page with the cellular respiration cycle. Their glucose comes from food. We have food coupled with oxygen, produces your water or sweat and puts you out some energy.”

Adding more detail, Mya stated,

“When we make ATP, we’re not creating any new substances, we’re just attaching phosphate groups that we already have. We are not creating this phosphate groups. We’re just attaching them. That allows chemical energy. Really, the matter cycling is this part where we’re tracking the number of carbons that go through. Then the energy really doesn’t come. We get some ATP from this because we’re breaking
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some bonds, but the energy really is all being stored in this molecule. Through this process, it's going to come out as ATP which we will then use. We will break that bond again and then we can put it all back together through the same pattern. Again, the energy is just going from glycogen to ATP. Then, we have to expend energy in order to get back to this glycogen.”

The responses of Liz and Mya are both coded as Level 2ii. Liz’s description of the process omitted that carbon dioxide is also released in the process. Mya made the same mistake. Unlike Liz, Mya attempted in greater detail to describe the flow of energy throughout the biochemical process.

**Q4 Flow of Energy.**

Codes of the flow of energy prompt in Q4 is illustrated by

![Figure 4.15](image)

Figure 4:15. 67% of the responses were labeled as Level 2ii as the remainder is labelled as Level 4i. Mya explained the flow of energy for Q4,
“Energy is stored in the chemical bonds in here. Glucose is only used as a storage molecule. It doesn't provide any actual energy, but when we break these bonds, we do get some ATP out in certain areas by breaking those bonds, we're able to furnish it with the ATP. Most of that's happening over here, so we're just taking the chemical energy and the bonds and we're converting it into a usable form in order to use that to do more cell processes”.

Mya correctly discusses that the energy from the bonds of glucose are transferred to ATP but failed to explain this process in detail which is why it was labelled as Level 2ii.

Dan in response to Q4 discussed the energy flow,

“in the Krebs cycle is going to be in the form of NAD$^+$ [and] FADH which are going to be your electron carriers, which are going to carry your electrons through the electron transport chain. Then in the electron transport chain there's NAD$^+$ [and] FADH. You're going to open those membranes and eventually end up as ATP. When those membranes are open, an ATP molecule will come in and then it's going to phosphorylated. Another phosphate is going to be added on to ATP.”

Dan explains in the biochemical process of cellular respiration that NAD$^+$ and FADH are the electron carriers. In this statement there is some confusion. Within the Krebs cycle, NAD$^+$ and FAD molecules enters the cycle to be reduced to NADH and FADH$_2$ respectively. In the electron transport chain, the rich-energy molecule reactants are NADH and FADH$_2$ in which Dan just stated to be NAD$^+$ and FADH. Dan failed to discuss the reduction of NAD$^+$ and the molecule FADH technically does not exist. Due to these errors, Dan’s discussion is labeled Level 4i.
Figure 4:15: Frequency of the number of codes of the 'flow of energy' prompt of Q4. The number above each bar indicates the number of participants who were coded at the specific level.

**Synopsis.**

Figure 4:16 illustrates the percentage of responses of flow of energy that were labelled each level per question. All interview questions except for Q3 did not have a L1 code. Alike the percentage of the cycling of matter responses, majority of the responses for the flow of energy were labeled Level 2. This suggests that the preservice teachers relied on the chemical equation to explain the flow of energy for each of the interview questions. For example, Sky response to the flow of energy prompt of Q1, “Most energy is going to be from the glucose, the breaking down of glucose because plants undergo glycolysis… I know plants use glucose for energy”. In Sky’s statement, she knows that the plant uses energy from glucose but unsure about the mechanisms of how the plant extracts the energy from glucose. Mya’s response to the flow of energy prompt of Q4, “Energy is stored in the chemical bonds of [glucose]. Glucose is only used as a storage molecule. It doesn’t provide any actual energy, but when we break these bonds, we
do get some ATP out in certain areas by breaking these bonds, we’re able to furnish it with the ATP.” Mya is able to talk about in general the flow of energy in cellular respiration, but similarly to all the participants, she has difficulty explaining the flow of energy in the biochemical level. Eva response to Q4 stated, “For glycolysis, it’s like two ATP going to start the process….maybe four ADP out and two in NADH. Then they go into the Krebs’s cycle. Oxygen’s going into that as well. I think you get like a bunch of NADH out of that. Like a couple of more ATP. Then they go through oxidative phosphorylation. In there, phosphorylation you’re adding another phosphate, which is taking your diphosphate to triphosphate.” Eva is attempting to explain the energetics of this process. Similarly to all participants, it proved difficult to explain the mechanism of how energy is transferred from one substance to the next.

*Figure 4.16:* Percentage of the flow of energy responses coded at each level per interview question
Summary.

There is a pattern of how detailed the preservice teachers explained each phenomenon for each prompt. Question 1 and Question 2 were conceptual questions based on the processes of photosynthesis and cellular respiration while Questions 3 and 4 asked students to explain the biochemistry of the same processes. Compared to Question 2, Question 1 had the most responses coded as Level 2. Most preservice teachers were able to recognize that Question 1 referenced photosynthesis and were able to describe using the chemical equation to explain some of the processes that takes place, for example Liz drew an illustration describing her conceptual understanding of phenomenon of Q1 as shown in Figure 4:17.

According Liz, the plant will absorb CO₂ from the atmosphere and water from the soil and with the help of light from the sun will grow to become a tree. Unlike Q1, the preservice teachers had trouble during Q2 in describing chemically the process that was taking place.

Ted’s illustration in Figure 4:18 is an exemplar of such difficulty. Ted’s drawing only emphasizes the ratio between nutrients and exercise during the stages of John’s weight loss but
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failed to include any chemistry implications behind the process. Participants mostly stated that ‘fat shrunk’ due to the diet and exercise of John.

![Image of a drawing showing the process of weight loss through exercise and healthy eating]

*Figure 4:18: Ted's illustration in response to Q3*

Level 3-4 codes were mostly used in processes that were about cellular respiration. Interestingly, the participants were able to be more detailed about the biochemical processes of cellular respiration within the cell (Q4) versus the biochemical processes of photosynthesis in the cell (Q3). Sky is an example of this trend.

*Figure 4:19* is an illustration of Sky’s notes during her response to Q4. In Sky’s illustration, there is a general discussion about each of the subprocesses of photosynthesis; the light reactions and dark reactions. She lists the major substances of the biochemical process such as oxygen, glucose, water, and carbon dioxide but does not mention any of the important substances that play a crucial role within photosynthesis such as photosystems I and II, electron carriers NADP+ and NADPH and the enzyme ATP synthase. Likewise, Sky’s illustration discusses the subprocess of cellular respiration in her response to Q4. She also lists all the important substances of the cycle
such as CO₂, water, glucose, O₂, and ATP. In contrast, she includes many of the dominant substances that contribute to the process of cellular respiration such as pyruvate, NAD⁺ and NADH, and ATP synthase. She also included a detailed description of the flow of hydrogen ions within the process of electron transport chain. Brown and Schwartz (2009) in their study of the conceptual understanding of the process of photosynthesis and cellular respiration in preservice elementary teachers concluded that the preservice teachers struggled the most in their biochemical knowledge of the processes. This is also true in this study as there were more Level 2 codes then there were Level 4 codes. Interestingly, novel to this study, the preservice teachers generally had a greater biochemical conceptual understanding of cellular respiration than the biochemical processes of photosynthesis.

**Figure 4:19:** Sky's response to Q1

Figure 4:20 illustrates the comparison of the percentage of responses labelled for each level for the cycling of matter and flow of energy. As shown, there are some slight differences between
the percentages of level 3 and 4 responses between cycling of matter and the flow of energy. Especially for level 4, there is a slight suggestion that the preservice teachers had a slight better understanding biochemically of the cycling of matter versus the flow of energy. Overall for both the cycling of matter and flow of energy, the preservice teachers relied mostly on the inputs and the outputs of the biochemical processes. The GSE asks the students to discuss the cycling of matter and flow of energy within the subprocesses of the photosynthesis and cellular respiration. Most of the responses of the preservice teachers were not able to meet the level of conceptual understanding of the standard.
Photosynthesis and Cellular Respiration: System

Photosynthesis and cellular respiration can also be taught through the crosscutting concept of systems and system models. NGSS defines this crosscutting concept as “the system under study – specifying its boundaries and making explicit a model of that system – provides tools for understanding and testing ideas that are applicable throughout science and engineering” (2013). In addition, Wilson et al. (2006) stressed that one of the central principles of biology is that conceptualization can be made of the intricacies of the biosphere in the perspective of the arrangement of interrelated systems that can extend in measure from the subcellular to the
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ecosystem. We can follow matter and energy inside these systems to comprehend them exclusively and between these systems to comprehend their interdependence.

Songer and Mintzer (1994) found that their participants did not see a relationship between cellular respiration and photosynthesis. On the other side of the spectrum, Canal (1999) concluded that his participants believed that photosynthesis and cellular respiration are mere opposites of each other. The participants all described that there is a relationship between photosynthesis and cellular respiration. Interestingly, novel to this study, the preservice teachers described cellular respiration as its own system and rarely tied back to photosynthesis, while photosynthesis is usually described and connected with cellular respiration as if it is not a system of its own. For example, during Q1, Dan is prompted to illustrate the cycling of matter,

“I think what we're getting at is we're using the byproducts in photosynthesis to go through respiration, and then we're using this stored glucose here, that the plant created during photosynthesis to then create ATP, so that it can go through its processes.”

Again in Q3, he states,

“A good one here would be when it gives off O₂. It doesn't really need that oxygen to complete the process. So it's going to spit that O₂ out immediately. Then that O₂ is going to go back and it's going to be used in respiration in animals, and things of that nature. As far as your glucose, as I stated earlier, glucose is all about storage. That glucose is going to be stored later on in order to be broken down so that ATP can be created. That plant can grow and can go through all this processes as well.”
When comparing the two statements of Dan, he associates the process of cellular respiration with photosynthesis. In contrast, during Q2, answering the prompt about the cycling of matter, Dan states, “I would just say, this glucose obviously has to come from somewhere. Maybe he’s ingesting less, and eating less, so his body doesn’t have as much of that glucose to be able to break down and turn into ATP.” He later answers Q4 in a similar fashion;

“The big thing with cellular respiration is usually we’re using the product of the step before to go on to the next step. We’re taking these pyruvic acids they’re going directly into the Krebs cycle. Krebs cycle is going to make NAD+ and FADH, that’s going to go directly into the ETC and then that’s going to provide the energy to be able open those channels and create those ATPs.”

His responses of Q2 and Q4 were only describing the process of cellular respiration. All the other participants for Q1 included the process of cellular respiration in their discussion.

Liz, in her explanation to the prompt cycling of matter in Q1, drew a model explaining how cellular respiration relates to photosynthesis as seen in Figure 4.21.
Only 25% of the participants added cellular respiration to their discussion during the prompt of cycling of matter in Q3. All of the preservice teachers whom included cellular respiration in their discussion of Q3 were labeled as level 3 explanations. The other 75% of responses did not include cellular respiration. Interestingly, 50% of those who did not include cellular respiration in their responses were labeled as level 4ii discussion while the other half were coded as level 3. All the preservice teachers only discussed cellular respiration for Q2 and Q4. Especially for Q1, photosynthesis is described in conjunction with cellular respiration. The interconnectedness of photosynthesis and cellular respiration is relatively understood by the scientific community, interestingly, when prompted about the application of photosynthesis (such as the inquiry of Q1), preservice teachers do view it as a quasi-system which is dependent on cellular respiration. In terms of the cycling of matter, all responses included an explanation of how the carbon of CO$_2$ became a carbon in glucose which were later broken down to become energy for the organism. For example, Liz stated that

![Figure 4.21: Liz's illustration explaining the relationship of the cellular processes of photosynthesis and cellular respiration.](image)
“Water is coming in the roots, light’s coming in, then this is giving off, CO$_2$ comes in from the atmosphere. This gives off oxygen, then glucose is an output but it doesn’t go out of it but we use them, like if we eat a plant, we use that for that output for our own energy.”

Liz describes how water and carbon dioxide are the building blocks of glucose, which is an example of cycling of matter. From there on, she inadvertently describes the flow of energy as glucose that is then used as a source of energy for an organism. This is true amongst all the participants except for Dan. A more accurate explanation of the cycling of matter is following carbon. Carbon in the CO$_2$ molecule becomes glucose during photosynthesis and during cellular respiration the carbon is released again as CO$_2$ which will be used by the plant again to repeat these processes.

What are the conceptual understanding of energy within the processes of photosynthesis and cellular respiration?

Word clouds were created for each question to examine what terms were said more frequently by the preservice teachers. A common factor that the word clouds from Figure 4.22-25 portray is that energy is the word that is spoken most numerous.
Figure 4:21: Word cloud of Q1

Figure 4:22: Word cloud of Q2
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Figure 4.23: Word cloud of Q3

Figure 4.24: Word cloud of Q4
An open coding scheme was used to analyze how the participants used the term ‘energy’ as shown in Figure 4.25. Six themes were extracted:

1. ATP as a source of energy - energy is associated with the ATP molecules and its bonds.
2. Chemical energy – energy that is associated with matter such as sugars, fats, and/or any subatomic particles.
3. Bonds – energy that is associated with the bonds of a substance
4. Energy flow – explanation of how energy is transferred from one substance to another
5. Light energy - energy is referred to as light primarily from the sun
6. Work energy – the ability to do work. Any discussion that is not specifically coded with any of the other sub codes.

Figure 4.25: Frequency of each energy theme discovered during the interview. The numbers above each bar represents the number participants who were coded for each term.
Figure 4:25 illustrates the frequency of each energy theme found during the interview with the preservice teachers. To further investigate how the participants are using these energy terms, the energy themes were then coded again to find recurring sub-themes.

Four recurring themes were found for the energy code ATP as illustrated in Figure 4:26.

1. ATP=Energy – ATP and energy are synonymous
2. ATP Bonds breaking – energy is released when a bond is broken in the ATP molecules
3. ATP formation – explanation about the formation of ATP
4. ATP work – ATP is needed to do work within the cell/organism

Figure 4:26: Frequency of the number of ATP sub-codes throughout the interview. The numbers above each bar represents the number participants who were coded for each term.
According to Figure 4:26, only Q1 had examples of responses that was coded for each ATP subcode. $A TP_{Bondbreaking}$ and $A TP_{Formation}$ code were only referenced in Q2 and Q4 (interview questions discussing cellular respiration). Codes $A TP_{Work}$ and $A TP=Energy$ responses were only found. The formation of ATP was described the most (48%) while ATP described as being the same as energy was mentioned the least as illustrated in Figure 4:26. Liz explained, “Glucose is broken down to make ATP”. When prompted to explain what ATP is, Liz replied, “Energy”. Likewise, Sky stated that, “The energy is specifically ATP.” Both Liz and Sky considered that energy and an ATP molecule are equivalent. The statement by Liz and Sky corresponds to the conclusion of the study by Wilson et al. (2006) where ATP is described as energy rather than a molecule with chemical potential energy.

Ted asserted:

$ATP$ breaking is what gives us energy so that we can use... we break down those $ATPs$ because that’s what give the breakage of adenosine triphosphate, when the phosphate breaks off, that’s where the energy comes from”. Mya adds, “when we want to use [ATP] then the bond between the second and the third one, and it provides the energy that can then be used by the cell.

This statement by Ted and Mya were coded as ATP-bond breaking. Ted and Mya describe that process of ATP breakage as an exothermic process. A study conducted by Galley (2004) found that 85% of over 600 college biochemistry and physiology students mistakenly stated that the phosphate breakage of ATP is an exothermic process. Within the same study, fewer than 7% of the students recognized that the O-P bond within in the ATP molecule is a weak bond that requires a minuscule amount of energy to break (2004).
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There were 14 instances during the interviews where energy symbolized the formation of ATP. As shown by Figure 4.26 above, only during Q3, was there no response coded for ATP formation. This may be due to the nature of the question where the preservice teachers are describing the biochemical process of photosynthesis. Sky explanation during Q3, “the hydrogen is what powering the ATP synthase… we care about all of this is because the ATP synthase is creating ATP”. Mya agreed stating, “we create a gradient which is a form of chemical energy, and then allowing that basically regulated diffusion back into the inner poles of the mitochondrion. We’re putting together ATP.”

The final sub-theme of ATP is coded as ATP-work. This category highlights energy as simply ATP completing a task that is needed by the organism or the cell. In total, there were five times when energy is used in this fashion. An exemplar of this sub-theme, Dan stated,

“The inputs as far as growing will have to be your ATP. It’s considered a product when we talk about cellular respiration. When we go into other processes that has to do with growing, that has to do with expanding the range of the plant, that ATP is going to then go in there. It’s going to give it the energy to do the processes that it needs to do”.

Investigating the energy code of bonds, two recurring themes were revealed as shown in Figure 4:27:

1. Bonds of ATP - Energy is described being in the bonds of ATP molecule
2. Bonds of glucose - Energy is described being in the bonds of glucose molecules.
Figure 4:27: Illustrates the frequency of responses coded for bonds of ATP and bonds of glucose per each interview question. The numbers above each bar represents the number participants who were coded for each term.

This section of the analysis examined how the participants specifically used the word bond. Strong and Wilson (1958) argue that the making and breaking of chemical bonds is fundamentally chemistry. 83% of energy terms labeled as bonds were coded as bonds of ATP as shown in Figure 4:27. There is a general consensus within the participants that energy is stored within the bonds of ATP as Mya states, “It’s storing energy within chemical bonds which is what ATP is”. The problem, as seen previously, is their inaccurate idea of how ATP molecules are hydrolyzed. Sky explains, “You’re breaking apart a molecule, breaking bonds to get the energy”. Interestingly, 25 times glucose is mentioned and only twice (by the same person) were the bonds of glucose specifically identified as the storage of energy. Mya stated “Energy is
stored in the chemical bonds here. Glucose is only used a storage molecule." Omission of the discussion of the bonds of glucose by the other participants may be a mere oversight.

Figure 4:29 illustrates recurring themes of chemical energy were found:

1. ATP – energy is described as part of the chemical ATP
2. Electron – energy resides in the subatomic particle electron
3. FADH – energy resides in the energy carrier FADH
4. Fat – energy resides in fat molecules
5. Food – energy resides in food
6. Glucose – energy resides in glucose molecules
7. NAD⁺ - Energy resides in the energy carrier NAD⁺
8. NADH – energy resides in the energy carrier NADH
9. Protons – energy resides in the subatomic particle protons
10. Water – energy resides in the compound water.

Figure 4:28: Illustrates the preservice teachers usage of each chemical energy sub-themes per interview question. The numbers above each bar represents the number participants who were coded for each term.
These terms were chosen by how the participants attached them with the term energy. For example, Mya explained, “when cells need energy, [ATP] is the only form of usable energy. Up until this point, some of it’s stored in glucose, that’s why we’re producing glucose when we need energy. In this process, it turns it into ATP”. Note how glucose and ATP were related to the overall theme of energy in the statement, thus glucose and ATP are coded as chemical energy. Figure 4.28 illustrates the number of each sub-term that were coded as chemical energy per each interview question. Glucose and ATP were the chemicals that were most used as a function of energy.

According to Figure 4:28, majority of the responses of chemical energy codes were found in Q2 and Q4 which discussed the process of cellular respiration in context or the biochemistry respectively. In contrast, there were only three codes that were found in the process of photosynthesis.

Every participant spoke of energy in regard to glucose and ATP according to Figure 4:29. Eva is the only participant who used the term food to describe energy and more specifically during Q2, which is the application question of cellular respiration. Participants such as Dan, Sky, and Mya give evidence of their breadth of knowledge by including terms NAD+, NADH, and FADH in their explanation of chemical energy. Such terms illustrate a greater breadth of knowledge as they describe the intracellular components of these biochemical processes. There are some variances. Dan only mentions NAD+ and FADH, “Krebs cycle is going to make NAD+ and FADH, that's going to go directly into the ETC and then that's going to provide energy to be able to open those channels and create those ATPs”, Mya identified protons (which is often referred as H+ ions) and electrons as chemical energy, “We're adding some other molecules in but we're rearranging it until we get CO₂ out and then we are using the energy, in this case, the form
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of electrons and hydrogen ions”, and Sky acknowledges NADH, “The biggest thing is that you're producing more NADH and more ATP because the end game is really just producing lots and lots of energy. NADH is getting reduced.” Figure 4:28 above shows that water is only considered a source of chemical energy. Sky mentions, “I'm pretty sure you split water and that's how you get the energy for the Calvin cycle”.

Figure 4:29: Illustration of the number and type of the chemical energy terms per interviewee. The numbers above each bar represents the number participants who were coded for each term.

There are three major themes shown in Figure 4:30 that illustrates when the participants discussed energy in regard to flow:

1. Energy flow in photosynthesis - Discussion of flow of energy specifically within the process of photosynthesis

2. Energy flow in cellular respiration - Discussion of flow of energy specifically within the process of cellular respiration
3. Energy flow in both photosynthesis and cellular respiration - Discussion of Flow of energy specifically between the process of both photosynthesis and cellular respiration.

According to Figure 4:30, the flow of energy within cellular respiration was stated in all questions by the participants. For example, Dan stated,

“How it’s going to take energy to break down this glucose. Glucose is a very stable molecule, a six-carbon molecule, so we're having to expend energy to be able to get it out of that stable form into a more unstable form”.

There are a greater number of explanations relating to the flow of energy in cellular respiration.
Interestingly, for Q1 and Q3, which addresses photosynthesis, few of the participants communicated about the process of cellular respiration. In Liz’s explanation of Q1, “Glycolysis happens in the mitochondria of the cell. We have the Krebs cycle and the electron transport chain. [Krebs cycle] produces carbon dioxide. In this part [electron transport chain] you have oxygen coming in; making water...Okay, that's how it's [plant] getting its energy to grow.” Even though Q1 is based on the topic of photosynthesis, Liz in her explanation discusses cellular respiration. As for flow of energy within photosynthesis, as expected the greater number of responses are in Q1 and Q3. Liz simply stated that, “we have light coming in. Light energy, which will transform into chemical energy”. Q4 is the only question where no participants addressed the flow of energy within photosynthesis. There were two responses that described the energy flow through both photosynthesis and cellular respiration. Mya stated,

“We have the sun, the sun helped to pull light reactions as part of photosynthesis, the other chemical light reactions. Those are what breaks the bonds in H₂O, that's where splitting water is actually happening and then the carbon fixation happens in the Calvin cycle, so also the light reactions and the dark reactions. That energy eventually is going to be transformed into glucose which again is being transferred from light energy to chemical energy. Then when we go through cellular restoration we’re giving out the chemical energy through ATP. The energy is flowing but it doesn’t go back on a cycle. The matter is cycling but the energy flows through in one direction”.

As shown by the Figure 4:30 above, this type of response only occurred in Q1 and Q3. Both of these questions are about the topic photosynthesis.
Energy was referred to as *light* 23 times. Figure 4:31 illustrates the frequency each participant used the term *light*.

![Bar Chart](image)

*Figure 4:31* - Frequency of the participant usage of the term *light*.

Figure 4:32 indicates that there were two major themes for energy as work codes:

1. Work in cellular respiration - energy work that is described during cellular respiration.
2. Work in photosynthesis - energy work that is described during photosynthesis.

Energy work that is described during photosynthesis
As shown by Figure 4:32, every question contains references of energy symbolizing work being done by the cell/organism during cellular respiration. For example, Liz explained that “When you work out your body has to take in more oxygen because you need more energy to do normal cell things and also exercise”. The data above suggests that the participants will include the work energy of cellular respiration even though the question is about photosynthesis. Mya responding to Q1 explaining, “The first question- just asking about the biomass fixation which would be that, but part of it too is they have to have energy to do cellular processes which is cellular restoration, which is where we take the glucose and then we split it down and we have glycolysis. Here, we split it into two little pyruvate forms”.

Q2 and Q4 (questions regarding cellular respiration) had the greatest number of codes compared to Q1 and Q3 (questions addressing photosynthesis). There were ten responses that were coded
as “energy work: photosynthesis”. As expected Q1 and Q3 had the all responses that were identified with this code. For example, Sky’s response to Q1 stated,

“In order for the seed to grow into the tree, it's going to need to go through normal cellular reactions. Seed will need energy for growth. That growth includes cellular processes such as producing proteins, cell structures, and general mitosis creating new cells.”

Summary.

The preservice teachers were asked to describe biochemically the flow of energy in photosynthesis. All preservice teachers were able to describe that the sun is the source of energy for the plant. Liz stated that for photosynthesis, “energy input is sunlight energy.” 50% of the preservice teachers attempted to discuss the biochemical role of sunlight. Mya states that “We have the sun, the sun helped to pull light reactions as part of photosynthesis, the other chemical light reactions. Those are what breaks the bonds in H₂O, that’s where splitting water is actually happening.” The results here are similar to what was described by Brown and Schwaltz (2008) in their study. Brown and Schwaltz (2008) discussed how participants provided descriptions of the biochemical process of the energy flow of photosynthesis that were not necessarily scientifically accurate and often failed to mention the absorption of energy by the electrons in photosystems II. The role of sunlight is not to decompose water, but to excite the electrons that were produced by the oxidation of water.

For all four interview questions, analysis of word frequency via word clouds concluded that the term most used by the preservice teachers was energy. Due to this finding, it was deemed important to analyze how the participants used the term energy. Energy was coded and specific themes emerged. Figure 4.25 illustrates the themes found and their frequency. 50 of the 191
times energy was used, it referenced chemical energy. The participants never used this term during the interview, instead used chemical compounds in the context of energy. Of these terms, glucose was the most frequent chemical energy term stated by the participants.

According to Figure 4.26 above, energy referenced as ATP was used 29 times during this study. Liz explained, “Glucose is broken down to make ATP.” When prompted to explain what ATP is, Liz replied, “Energy.” Likewise, Sky stated that, “The energy is specifically ATP.” Both Liz and Sky considered that energy and ATP molecule are equivalent. The statement by Liz and Sky corresponds to the conclusion of the study by Wilson et al. (2006) where ATP is described as energy rather than a molecule with chemical potential energy. Ted asserted that

“ATP breaking is what gives us energy so that we can use… we break down those ATPs because that’s what give the breakage of adenosine triphosphate, when the phosphate breaks off, that’s where the energy comes from”. Mya adds, “when we want to use [ATP] then the bond between the second and the third one, and it provides the energy that can then be used by the cell”.

These statements by Ted and Mya were coded as ATP-bond breaking. Ted and Mya describe the process of ATP breakage as an exothermic process. A study conducted by Galley (2004) found that 85% of over 600 college biochemistry and physiology students mistakenly stated that the phosphate breakage of ATP is an exothermic process. Within the same study, fewer than 7% of the students recognized that the O-P bond within in the ATP molecule is a weak bond that requires a minuscule amount of energy to break. In this study, Galley (2004) surveyed the participants to investigate the possible source of this misconception. Many of the students described that it was during their high school or junior college level biology courses where they were introduced to inaccurate illustration of the energetics of bond breakage and synthesis of the
ATP to ADP conversion. The participants continued stating that during these courses, they were taught that bond breaking was exothermic. Below is a description of the biochemical phenomenon excerpted from a high school biology textbook which illustrates brevity by not including the full detail of the reaction:

The energy carried by ATP is released when a phosphate group is removed from the molecule. ATP has three phosphate groups, but the bonding holding the third phosphate group is unstable and is very easily broken. The removal of the third phosphate group usually involves a reaction that releases energy.

Nowicki, 2018, p.98.

Figure 4:33 graphically summarizes the process of cycling of ATP and ADP which coincides with Nowicki’s statement.

![Diagram of ATP cycle](image)

Figure 4:33: Illustration of ATP cycle normally portrayed in most high school biology textbooks (Muessig, 2013).

Figure 4:34 is a more accurate illustration of how ATP becomes ADP. ATP undergoes hydrolysis. There is energy that must be added in order to break the bond between the second and third phosphate and the bond between the oxygen and hydrogen. Energy is
released when the OH⁻ ion bonds to phosphate and H⁺ is bonded to ADP. The energy released in greater than the energy put into the system and as a result there is a net release of energy for the reaction.

Figure 4: Illustration demonstrating a more accurate explanation of the hydrolysis of ATP to ADP and Pi.

How are preservice teachers’ utilizing key chemistry topics within the process of photosynthesis and cellular respiration?

The preservice teachers were given 45 terms that they had to create a concept map linking and describing the relationship between each term. Of the 45 terms, 14 were chemistry based. One of the main goals of this study is to analyze what key chemistry concepts preservice biology teachers are able to identify. In addition to identifying chemistry topics during the interview, the concept map terms were also analyzed for key chemistry concepts and how they relate to what was discussed during the interview. The data discussed in this section is a portion of a larger concept maps which can be found in Appendix I. This type of qualitative analysis will give an enriched idea of their conceptual understanding of the chemistry in the biochemical processes of photosynthesis and cellular respiration.
Chemistry terms from the concept map were compared with chemistry topics identified by the preservice teachers. Of the 14 chemistry terms used during the concept map, ten of them were used during the interviews; energy, thermodynamics, catalyst (enzymes), electrons, protons, hydrolysis, oxidation, reduction, kinetics, and matter.

Energy was the most used term in the participants’ interviews. As shown earlier, the term energy was used in variety of ways from light energy, chemical energy, and the flow of energy to name a few. This variety of usage of this term was not shown in the preservice teachers’ concept map. Only one participant did not use the term energy in the concept map. Figure 4:35 below illustrates excerpts of all participants’ usage of the term energy and connecting terms with propositional statements.
Analysis of the concept map is vastly different from the descriptions of energy provided by the participants during the interview. The Figure 4.35 illustrates the various usage of energy. For example, Sky in her concept map addresses energy in regard to ATP but during the interview she used energy to discuss bonds, light, chemicals, and work.

Three participants used the term thermodynamics in their concept map as shown in Figure 4.35: Exerts of participants' concept maps illustrating the term energy and other terms that it is connected to with propositional statements.
Thermodynamics is defined as the function of energy in chemical change and in determining the behavior of materials (Brady & Senese, 2004). An example of the concept of thermodynamics in photosynthesis is the supply of energy from the sun for the formation of carbon-carbon bonds of glucose (Boyer, 1999). During the interview, Dan alone used the term ‘thermodynamics.’ Both Luke and Dan correctly related thermodynamics to energy in Figure 4.36. Mya did not provide any propositional statements linking cellular respiration and photosynthesis to thermodynamics. Sky, Eva, and Liz were not sure about the role of thermodynamics in these biochemical processes thus not using the term at all. Although the preservice teachers had a general understanding of the flow of energy within these biochemical systems, 50% of the participants did not seem to know that tracking this flow of energy and how it influences chemical reactions is called thermodynamics.

Figure 4:36: Exerts of Ted's, Mya's, and Dan's illustrating of their usage of the term thermodynamics

Boyer (1999) describes metabolism as the study of the biochemical reactions within an organism. Figure 4:37 illustrates that Dan, Liz, and Eva included the term in their concept map.
Eva’s usage of the term is closest to the scientific understanding of the metabolism as she states that ‘metabolism’ influences the reactions within *photosynthesis* and *cellular respiration*. Dan, in his concept map, illustrates that *metabolism* helps break down *glucose*, while Liz stated that *cellular respiration* controls our *metabolism*. Interestingly, both Dan and Liz used the term ‘metabolism’ during the process of cellular respiration. Research has shown that words in science have alternate meanings in everyday language (Gilbert, Osborne, & Fensham, 1982). *Metabolism* in everyday language is often used to describe how quickly food is digested and how quickly fat is consumed. Both of these vernacular definitions are in many ways describing the process of cellular respiration.

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*Figure 4:37: Exerts of Dan's, Liz's, and Eva's concept map illustrating their usage of the term metabolism*

Only two of the six participants included the term protons in their concept map shown in Figure 4:38. Ted stated that elements are made up of protons. Only Mya discussed the function of protons within the biochemical processes. During the interview, Mya states that, “*The Krebs"
Mya describes hydrogen ions in her interview similar to how she describes protons in the concept map. Based on the comparison of her interview and concept map, Mya conceptualizes that hydrogen ions and protons are synonymous. The lack of usage of the term protons from the other participants can infer that if hydrogen ions was a predetermined term for the concept map, they may have used it. For example, Sky explains that,

“They get more hydrogen outside so that it will eventually flow through ATP synthase or through ATP synthase and that flowing of something from high concentration to low concentration. In this case, the hydrogen is what is powering ATP synthase. Something moving from high to low is creating the energy needed to produce HB. We care about all of this because the ATP synthase is what produces the most ATP. I think it's like 34 or more molecules of ATP.”

Sky can describe the biochemical role of hydrogen ion within ETC, but never once described hydrogen ion as a proton.
Figure 4: Exerts of Ted's and Mya's concept map illustrating their usage of the term protons.

Figure 4: Illustrates the usage of the term catalyst. Catalyst is described as a substance, usually a protein, which accelerates the rate of a reaction (Brady & Senese, 2004). All but Liz used the term in their concept map. Four of the five participants described how catalysts lower the activation energy of a reaction. Ted gave a more simplistic view of catalyst even though it is erroneous. He paired catalyst as a type of reaction even though catalyst only increases the rate of a chemical reaction. The other participants gave examples of catalysts or/and where they are essential.
Figure 4.39: Exert illustrating participants' usage of the term *catalyst*

Five of the six participants of the study used the term *activation energy* in their concept maps as shown in Figure 4.40. Four of the five participants correctly related *activation energy* with catalyst as with the propositional statement that basically describes how a catalyst lowers
the activation energy of a chemical reaction. Ted relates activation energy with types of reaction and uses a proposition statement that illustrates the definition of activation energy. Activation energy is not a type of reaction, but the activation energy of a system needs to be met for a chemical reaction to take place.

Figure 4.40: Exerts of participants' concept map illustrating their usage of the term activation energy

Four of the six participants used the term combustion in their concept map illustrated in Figure 4.41. Both Eva and Ted correctly stated that combustion is a type of chemical reaction. Mya and Sky erroneously stated that ADP to ATP conversion is a combustion reaction. Cellular respiration is a combustion reaction which is defined as a reaction with oxygen that is exothermic (Brady & Senese, 2004). All the preservice teachers could not relate ‘combustion’,
which is an important chemistry concept, to cellular respiration which is similar to the conclusion of Mohan, Chen, and Anderson’s (2009) study where they found that their participants saw little to no connection with cellular respiration and combustion.

As shown in Figure 4:42, four of six participants used hydrolysis either as a term or a propositional statement. Eva and Ted correctly stated that hydrolysis is a type of chemical reaction and Eva continues to describe that this reaction occurs in cellular respiration. Even though they are correct, they lack any details to when and how hydrolysis occurs in the biochemical process. This term also seems to be source of error with the preservice teachers. Hydrolysis is a chemical process of decomposition involving the splitting of a bond and the addition of the hydrogen ion and hydroxide ion of water (Brady & Senese, 2004). With each
instance from Figure 4:42, there are evidence of erroneous conceptions. Ted wrongfully stated that ‘hydrolysis’ is the breakdown of water. Sky stated the water is hydrolyzed to provide energy for the Calvin cycle. Liz, in her concept map, illustrated that NADPH is hydrolyzed to become NADP⁺. Some of the error may have origins from the meaning of the suffix -lysis which Ted defines “lysis is to cut” and hydro means water as summarized by Sky in which she states, “Hydrolysis reaction splitting the water”. In this sense, the preservice teachers view hydrolysis as simply cutting of water rather than a cutting with water. None of the students were able to identify where hydrolysis takes place during these biochemical processes.

*Figure 4:42: Exerts of participants' concept map to illustrate their usage of the term hydrolysis*
A coupled reaction is known as a reaction where the free energy of a thermodynamically favorable transformation and a thermodynamically unfavorable one, are physically joined into a new reaction that is overall thermodynamically favorable. Figure 4:43 demonstrates that three of the six participants used the term *coupling* in their concept maps. Ted incorrectly stated that *coupling* is a *type of reaction*. Sky stated that redox reactions are synonymous to *coupling* reactions. This error may be due to the definition of the vernacular use of the term versus the science academic definition of *coupling*. Redox reactions are a single reaction that contains two parts; an oxidation half reaction and a reduction half reaction. A coupled reaction are two reactions or processes where one is thermodynamically unfavorable and the other one is favorable. Mya interestingly stated that electrons are coupled to ATP Synthase. Boyer (1997) states that within chloroplasts, light energy from the sun is coupled to the protonmotive force which will cause protons to move through the membrane allowing ATP synthase to work. In cellular respiration, electrons, which have been liberated from the oxidation reactions of the electron carriers, are passed through a highly organized chain of proteins and coenzymes collectively referred to as the electron transport chain, are transported to the ultimate electron acceptor O₂ to ultimately yield H₂O. As the result of the movement of electrons, hydrogen ions (protons) are pumped through the mitochondrial membrane creating a proton gradient. This chemiosmotic gradient is coupled with ATP synthase which will create ATP from ADP and inorganic phosphate. There is some validity for Mya to state that electrons are coupled to ATP Synthase, as it is the flow of electrons that creates the proton gradient.
Figure 4.43: Exert of participants' concept map and their usage of the term *coupling*

Figure 4.44 illustrates that five of the six participants used the term *oxidation* as either a term of the concept map or a proposition statement. Liz explained that matter and energy are cycled through via *oxidation and reduction* reactions. Dan added that *oxidation reduction* reactions are due to the movement of electrons. In a chemical reaction, the oxidizing agent is a substance that will get reduced (gain electrons), this may be the reason why Dan has *oxidation* leading to *reduction*. Ted incorrectly states that *electrons* are being added in the process of *oxidation* but correctly identifies *oxidation* as a type of chemical reaction. Sky and Eva provided examples of oxidation within the biochemical processes. Eva correctly states that pyruvate is oxidized to become acetyl CoA. Sky incorrectly states that NAD\(^+\) and NADP\(^+\) are oxidized to NADH and NADPH respectively.
Five of the six participants used the term *reduction* or *reduce* in their concept map as shown in Figure 4:44. As previously shown with the term *oxidation*, the participants show a decent understanding of this chemical concept. Brady and Senese (2004) inform that one definition of reduction is when the system gains electrons. Ted mistakenly states that when losing electrons, reduction is occurring. He does correctly state that it is a type of reaction. Both Eva and Sky provided examples of *reduction*: NAD\(^+\) reduces to NADH. Sky further explains that NADP\(^+\) is reduced to NADPH, which is incorrect.
Three of the six participants used the term kinetics in their concept map as seen in Figure 4:46. All three generally described that kinetics governs the processes of photosynthesis and cellular respiration. None were able to provide examples in the concept map of kinetics within these processes. During the interview, Sky and Mya discussed the rates of reaction. Mya stated that, “Enzyme reactions or anything else which are both biology and chemistry but reaction rates and stuff, this is not a spontaneous process”. While Sky talked about, “how we actually figure out ways like how much food you should take in, how much we're exercising, it's all biochemistry
in the end of it because that's why you want to get your heart rate up. Taking more oxygen, you're going to increase those reactions. We're really talking about kinetics at that point.”

Figure 4: Exert of participants' concept map and their usage of the term kinetics

Figure 4:47 illustrates that five of the six participants used the term matter in their concept map. Eva did not use the term matter, “I couldn’t decide where to put [matter]”. All of the participants used matter to explain that substances that are part of the processes of photosynthesis and cellular respiration are examples of matter.
Summary.

The analysis of the concept maps demonstrates that key chemistry terms such as *matter*, *catalyst*, *activation energy*, are overall conceptually understood by the participants. Terms like *matter*, *catalyst*, and *activation energy* are terms that are stressed within the high school biology curriculum and are essential in teaching the GSE biology standard SB2.e. Because the
participants either reversed or provided incorrect examples of oxidation and reduction suggests that this concept is not fully understood by the preservice teachers. Oxidation and reduction are key chemical processes that are stressed in many university level chemistry courses. Unfortunately, there is not much emphasis of the conceptual understanding of oxidation-reduction reactions within the high school setting as the GSE does not require this topic to be taught to biology or chemistry students. Due to this, the preservice teachers show familiarity of the biochemical applications of reduction and oxidation reactions.

Usage of the other chemistry terms illustrate limited chemistry conceptual knowledge. Few of the participants were able identify that thermodynamics and kinetics played a key role in the biochemical processes, and fewer were able to provide specific examples of their roles within the biochemical processes. During her discussion, Mya confused thermodynamics with kinetics stating, “Enzyme reactions...is not a spontaneous process.” Sozbilir, Pinarbasi and Canpolat (2010) found in their study with 67 prospective chemistry teachers that the participants did not understand the fundamental difference between thermodynamics and kinetics and often confused the two concepts. Sky in her discussion of the process of cellular respiration confused the process of kinetics and equilibrium when stating, “Taking more oxygen, you're going to increase those reactions. We're really talking about kinetics at that point”. This confusion was also documented by Cakmakci (2010) when studying the alternative conceptions of chemical kinetics in undergrad students in Turkey.

Other terms proved to be more difficult as the participants did not use the terms or used them incorrectly. For example, the preservice teachers were not able to correctly use the term combustion and hydrolysis. Both Eva and Ted correctly indicated that hydrolysis is a type of reaction but were not able to give an example where in the biochemical process hydrolysis
occurs, while Sky and Liz used the term incorrectly. Again, Ted and Eva correctly demonstrated in their concept maps that combustion is a type of reaction but were unable to provide a specific example within the biochemical processes. Sky and Eva both incorrectly stated that ATP formation is a combustion reaction.

Academic language versus vernacular language seemed to be the cause of the error in the usage of the terms coupling and metabolism. Coupled reactions have the connotation of two reactions that complement each other such as photosynthesis and cellular respiration or reduction and oxidation reactions. There is evidence that the preservice teachers understand coupling in this manner. This is also the case with the term metabolism. Instead of viewing metabolism as all the chemical reactions within a living system, the preservice teachers mostly described cellular respiration or the degradation of glucose to obtain energy.
Conclusion

The goals of this research were to 1) investigate how secondary preservice biology teachers’ responses differ when the process of photosynthesis and cellular respiration are asked about directly and in context; 2) investigate secondary preservice biology teachers’ application of cycling of matter and flow of energy within their explanations of photosynthesis and cellular respiration; 3) investigate secondary preservice biology teachers’ conceptual understanding of energy within the processes of photosynthesis and cellular respiration; and 4) understand how secondary preservice biology teachers utilize key chemistry topics within the process of photosynthesis and cellular respiration.

Photosynthesis and cellular respiration are topics taught in secondary Georgia public high school biology courses. For students to have a greater understanding and appreciation of these biochemical processes, it should be taught through the lens of the crosscutting concepts. Crosscutting concepts were designed to provide guiding principles from various disciplines and subjects into a clear and scientific interpretation of a phenomenon (NRC, 2011). Of the seven crosscutting concepts recommended by the NRC (2011), two are addressed in this dissertation; Energy and Matter: Flows, cycles, and conservation, and Systems and System models. Energy and matter: flows, cycles, and conservations allows the learner to focus on the Law of Conservation of Matter and Energy and how they flow in and out of a particular system. Systems and system models also allow the study of the effect of the system by interacting it with forces or flow of matter and energy. Educators should strive to incorporate the crosscutting concepts into their lessons. These crosscutting concepts were assessed in this study as six secondary preservice
biology teachers discussed their conceptual understanding of the biochemical processes of photosynthesis and cellular respiration.

In this study, six participants were asked to explain through both application and biochemically the process of photosynthesis and cellular respiration. Within the interview, the participants were asked to identify chemistry topics for each interview question. The preservice teachers were also asked to create a concept map with predetermined terms.

There were several important findings, many of which support the findings of previous studies. Most of the participants were not able to answer how plants used photosynthesis to increase its biomass (Brown & Schwartz, 2008) and had difficulty deriving the composition of the biomass (Wilson et al., 2008). Participants also reported that nutrients from the soil increase the biomass of the plant (Driver et al., 1994) and/or soil is an energy source for the plant (Lin & Hu, 2010). Most of the participants struggled to describe the biochemical processes especially photosynthesis (Brown & Schwartz, 2008). Only 50% of the participants attempted to illustrate the biochemical role of sunlight in photosynthesis. Like what was seen in the studies of Wilson et al. (2006) and Galley (2004), the preservice teachers in this study also believed that ATP is an energy molecule and that its conversion is exergonic.

The preservice teachers also identified chemistry concepts and sorted through predetermined chemistry terms in this study. The analysis suggests that the preservice teachers had stronger conceptual understanding of the terms matter, catalysts, and activation energy. Chemical concepts such as reduction and oxidation, the participants had familiarity of the use of terms, as they often switched the definitions of the terms. Sozbilir, Pinarbasi, and Canpolat (2010) reported that chemistry terms of thermodynamics and kinetics were often confused. This finding was also observed in this study. Another confusion found in this study is between the
PRESERVICE TEACHERS’ CONCEPTUAL UNDERSTANDING

terms *kinetics* and *equilibrium* (Calcmaki, 2010). Another source of error may stem from the difference of vernacular versus academic usage of terms. Examples of such errors were found especially in the usage of the terms *metabolism* and *coupling*.

As this dissertation results coincided with past research, there were novel ideas that this study uncovered. The participants all described the relationship between photosynthesis and cellular respiration. Interestingly, when describing cellular respiration, the participants detailed it as its own system while the description of photosynthesis was proceeded by the description of cellular respiration as if it was not a system of its own. Secondly, participants had greater conceptual understanding of the biochemical process of cellular respiration within the cell than the process of photosynthesis. Third, describing the flow of energy through the biochemical systems proved more difficult for the participants than describing how matter is cycled.

This study also highlighted how the preservice teachers used the term *energy* when describing the processes. Using word clouds, *energy* was the most used term for each interview question. During the interview, the participants understanding of energy is multifaceted as several themes emerged from the analysis of its usage. The various meanings of *energy* were not exemplified in the concept maps.

**Implications**

Many studies focus on misconceptions of students, while this dissertation hopes to shed light on the conceptual understanding of secondary preservice teachers. Hopefully the knowledge gained to create a plan of action that will allow preservice teachers to grow and become more competent in their content knowledge. The findings of this study led to several implications of secondary science education. There is ample research that highlights the misconceptions of K – 12 students. Many of those misconceptions were also found in post-secondary students. Driver et
al. (1984) found that high school students stated that biomass of plants comes from the absorption of water and nutrients via the roots. Song and Mintzes (1994) reported that college undergraduate students believed that there was no relationship between cellular respiration and photosynthesis. Wilson et al. (2006) found that primary preservice teachers believed that ATP is energy rather than a molecule with chemical potential energy.

The participants conceptual understanding of the biochemical process of cellular respiration were overall greater than their understanding of the biochemical process of photosynthesis. This may be due to that cellular respiration is emphasized more in their coursework than photosynthesis. At the collegiate level, photosynthesis and cellular respiration need to be presented in the lens of matter cycling and energy flow, which will illustrate their interconnectedness. Within this study, it is apparent that the participants understood that the products of photosynthesis are the main reactants of the cellular respiration, but they did not readily discuss the products of cellular respiration are the main reactants of photosynthesis.

Teacher preparation programs needs to provide content courses for their students in which is mainly focused on the alternative conceptions of K-12 students. Using alternative conceptions as the framework of the content course, will allow the preservice teachers to compare their current conception with the alternative conception to hopefully increase their understanding of the topic.

Considering these findings, it is important that teacher preparation programs, whether undergraduate or graduate, require prospective teachers to take more content courses. Lee and Luft (2008) interviewed veteran teachers and asked them to rank the most important aspect of PCK from the following list; knowledge of science, knowledge of goals, knowledge of students, knowledge of teacher, knowledge of curriculum organization, knowledge of resources, and knowledge of assessment. From these categories, 100% of the veteran teachers stated that the
knowledge of science is the most important. Haider (1997) suggests that teaching programs need to assess preservice teachers content knowledge and their ability to apply it to real-life circumstances effectively. Mentor teachers also need to provide support in building the preservice teachers conceptual knowledge. It is also important that teacher preparation programs and mentor teachers instruct the preservice teachers to have an appreciation and include application of crosscutting concepts within their teaching. Crosscutting concepts mentioned in this dissertation (Energy and Matter, and Systems and Systems Models) will enable students to make sense of the complexities of biology and allow them to analyze these complexities by looking for discrete patterns. NGSS (2013) identified understanding systems as a common theme that crosses the disciplines of science. They cite “examine the system in detail while treating the effects of things outside the boundary as either forces acting on the system or flows of matter and energy across it” (p. 7). In other words, this framework calls for detailed attention to inputs and outputs of the system. Assaraf and Orion (2005) in their study analyzing 50 eighth graders and their conceptual understanding of Earth System, identified eight emergent characteristics of systems thinking, two of which are “the ability to identify the components of a system and processes” and “the ability to organize the systems’ components and processes within a framework of relationships” (p. 523). For example, all but one preservice biology teacher was not able to truly answer the application interview Q1 and Q2. By tracing matter, specifically carbon, they would be able to follow along as carbon dioxide is transformed to glucose through the biochemical process of photosynthesis, and as the carbon in fat or glucose is transformed to carbon dioxide through the process of cellular respiration. Understanding the components and the processes of these biochemical systems would allow them to see their interconnectedness in any application or
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cellular perspective. Even as the preservice teachers transition to full time teachers, it is important that the school district offer professional development to promote and encourage strong content knowledge.

Limitations

Even though the preservice teachers were able to demonstrate their conceptual knowledge through the interviews and concept map, there were limitations to the study. First, the application questions of photosynthesis and cellular respiration came first before the direct question. The preservice teachers were not primed to think about the biochemical processes until Q3 and Q4. At the beginning of the interview, they were only given the photosynthesis and cellular respiration Georgia high school biology standard which may not have provided enough direction to effectively answer the question. If the questions were flipped (conceptual questions first then the application questions) they may have provided deeper discussions to these questions.

The creation of the concept maps was first planned to be generated by the participants. Due to difficulty and possible lack of familiarity with creating concept maps, the participants did not complete the concept map as planned. As a result of this, the decision was made to use the original method of constructing concept maps (Novak & Canas, 2006). During the concept map portion of the study, the participants organized the terms based on their conceptual understanding and explained the relationships between each term. These discussions were recorded and the data from the recorded video and audio were used to construct a concept map.

There are also slight differences in the depth of conceptual understanding when comparing the concept map and the interviews. For example, the concept map could not show the breadth and depth of knowledge for each participant regarding the term energy. The concept
map could only capture a small amount of the participants’ conceptual understanding of each term. The concept map was not meant to analyze their full understanding but instead serve as a tool that could compare the discussion of the initial interview.

There were only six high school biology preservice teachers that participated in this study. Due to the qualitative nature and small number of participants, the findings of this study cannot be generalized to all high school biology preservice teachers even though similar results from past studies were found in other populations. Further study needs to be done in order to make broader statements about the secondary preservice teacher population.

**Future Work**

Multiple aspects of the biochemical processes of photosynthesis and cellular respiration discussed in this dissertation were outside the scope of the research questions but present possible future work and analysis. The purpose of this dissertation was to analyze the conceptual understanding of the chemistry in the biochemical processes of photosynthesis and cellular respiration of secondary preservice high school teachers. An avenue that can be taken with this study in the future is to interview current secondary high school biology teachers. This will provide data that will allow for comparison between chemistry conceptual knowledge of preservice teachers and current teachers.

In this study, chemistry concepts were emphasized. In the future, analysis can be done on the biology concepts of photosynthesis and cellular respiration. For example, the concept maps were made up of 45 predetermined terms in which only 14 of them were chemistry related. A study can done analyzing the terms and proposition statements between the other 31 terms.

This study attempts to open a discussion of the current conceptual understanding of secondary preservice biology teachers. As of this writing, there is little to no research about the
secondary preservice biology teachers knowledge of the chemistry in the biochemical process of photosynthesis and cellular respiration. There is a great deal of chemistry concepts within this biological topic. Effective teachers have deeper breadth and depth of knowledge of their subject content. Educational programs need to strive to get preservice teachers to this point of conceptual effectiveness. The implementation of crosscutting concepts is a practical tool that will allow preservice and service teachers alike to move beyond the basic understanding as it will allow the intertwining of other subject areas to strengthen the conceptual understanding of a particular topic. This dissertation hopes to encourage discussions and catalyze the creations of interventions to strengthen their conceptual knowledge so that they may become effective high school biology teachers.
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References


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Retrieved October 2018.


Welcome and thank you for your participation today.
My name is Edwin Estime and I am a graduate student at Kennesaw State University conducting a research project for my course on Advanced Qualitative research methods. In this research study I will your conceptual understanding of photosynthesis and cellular respiration.

At this time, I would like to ask for your verbal consent and also inform you that your participation in this interview also implies your consent. Your participation in this interview is completely voluntary. If at any time you need to stop, take a break, or return a page, please let me know. You may also withdraw your participation at any time without consequence. Do you have any questions or concerns before we begin? Then with your permission we will begin the interview.

Phase 1:
1. A mature maple tree can have a mass of 1 ton or more (dry biomass, after removing the water), yet it starts from a seed that weighs less than 1 gram. How does this happen?
2. John weighs 440 lbs. Through diet and exercise, he loses 220 lbs. How did this happen?

Phase 2:
3. Please explain the role of photosynthesis within the cell.
4. Draw what you think of in terms of the process of photosynthesis.
5. Please explain the role of cellular respiration within the cell.
6. Draw what you think of in terms of the process of cellular respiration.
7. Are photosynthesis and cellular respiration within the cell connected? Please explain.

Phase 3:
Based on the questions of phase 2, would you like to go back and answer questions 1-2?

Phase 4:
1. What key chemistry topics do you see in photosynthesis and cellular respiration? Explain.

Phase 5:
Using these terms, create a concept map to illustrating the relationships between each term.
List of predetermined words of concept map

<table>
<thead>
<tr>
<th>Term</th>
<th>Process</th>
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<tbody>
<tr>
<td>Energy</td>
<td>Flow of energy</td>
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<td>Thermodynamics</td>
<td>Flow of energy</td>
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<td>Within the cell</td>
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</tr>
<tr>
<td>Water</td>
<td>Cycling of matter</td>
</tr>
<tr>
<td>CO₂</td>
<td>Cycling of matter</td>
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<tr>
<td>Sunlight</td>
<td>Flow of energy</td>
</tr>
<tr>
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<td>Within the cell</td>
</tr>
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<td>Chloroplast</td>
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<td>Combustion</td>
<td>Chemical Process</td>
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Appendix C

Interview guide given to the participants

I thank you in wanting to participate in this research project. This interview should not take more than 30 minutes. As a science teacher working in a public school in the state of Georgia, you are required to teach according to the state standards. Photosynthesis and respiration is a topic that must be taught according to the state standard SB1. e.

“Ask questions to investigate and provide explanations about the roles of photosynthesis and respiration in the cycling of matter and flow of energy within the cell (e.g., single-celled alga). (Clarification statement: Instruction should focus on understanding the inputs, outputs, and functions of photosynthesis and respiration and the functions of the major sub-processes of each including glycolysis, Krebs cycle, electron transport chain, light reactions, and Calvin cycle)”.

With the standard in mind, answer the following questions. Be as detailed as possible. Please write, draw, and verbalize your thought process.

5. A mature maple tree can have a mass of 1 ton (dry biomass, after removing the water), yet it starts from a seed that weighs less than 1 gram. How does this happen? What key chemistry topics are addressed in this scenario? Explain.


7. Draw and explain the process of photosynthesis within the cell. What key chemistry topics are addressed in this process? Explain.

8. Draw and explain the process of cellular respiration within the cell. What key chemistry topics are addressed in this process? Explain.
Appendix D

Consent form and Demographic Survey

INFORMED CONSENT FORM

Title of Research Study:
Secondary biology teachers' conceptual understanding on biochemistry high school topics

Researcher's Contact Information:
Dr. Kimberly Cortes
470-578-6278
klinenbe@kennesaw.edu

Edwin Estime
404-259-9882
eestime@students.kennesaw.edu

Introduction
You are being invited to take part in a research study conducted by Edwin Estime and Dr. Kimberly Cortes of Kennesaw State University. Before you decide to participate in this study, you should read this form and ask questions about anything that you do not understand.

Description of Project
As a science teacher working in a public school in the state of GA, you are required to teach according to the state standards. There are two biochemistry standards in the high school biology curriculum. The purpose of the study is to determine your conceptual understanding of these biochemistry topics.

Explanation of Procedures
During an audio and video recorded interview, participants will be asked to explain verbally and draw a schematic representation of different biochemical processes.

Time Required
The interview should take no longer than 60 minutes.

Risks or Discomforts
There are no known risks or anticipated discomforts in this study.

Benefits
There are no direct benefits to the subject, but the researcher will learn more about how science teachers conceptually understand biochemistry in order to improve the teaching of the content.

Compensation
Participants will receive a $10 Starbucks or Amazon giftcard (their choice) upon completion of the interview. In addition, Mr. Estime will provide the participant with their choice of biology curriculum materials that he has developed over the years.

**Confidentiality**
The results of this participation will be confidential. The data will be kept on password-protected computer and all files will be password protected.

**Inclusion Criteria for Participation**
All participates must be at least 18 years old and must be either currently enrolled as a student in a science education pre-certification degree or currently teaching biology at the high school or college level.

**Signed Consent**
I agree and give my consent to participate in this research project. I understand that participation in the audio and video recorded interview is voluntary and that I may withdraw my consent at any time without penalty.

__________________________________________________  
Signature of Participant or Authorized Representative, Date

__________________________________________________  
Signature of Investigator, Date

__________________________________________________  
PLEASE SIGN BOTH COPIES OF THIS FORM, KEEP ONE AND RETURN THE OTHER TO THE INVESTIGATOR

Research at Kennesaw State University that involves human participants is carried out under the oversight of an Institutional Review Board. Questions or problems regarding these activities should be addressed to the Institutional Review Board, Kennesaw State University, 1000 Chastain Road, #0111, Kennesaw, GA 30144-5591, (470) 578-2268.
Name ______________________________________________________________
Phone #: __________________________
Email Address: _______________________________________________________
Age ____________
Ethnicity ________________
Check the box that applies to you:

- Undergraduate
- Graduate

Check the boxes of the classes you have successfully passed:

- Biology I
- Biology II
- Chemistry I
- Chemistry II
- Ecology
- Organic Chemistry I
- Organic Chemistry II
- Biochemistry
- Biochemistry I
- Biochemistry II
- Plant Morphology
- Plant Ecology
- Plant Physiology
- Invertebrate Zoology
- Vertebrate Zoology
- Plant Systematics
- Ecosystem Ecology
- Freshwater Ecology
- Marine Ecology
- Microbiology
Complete interview guide with probing questions

I thank you in wanting to participate in this research project. This interview should not take more than 30 minutes. As a science teacher working in a public school in the state of Georgia, you are required to teach according to the state standards. Photosynthesis and respiration is a topic that must be taught according to the state standard SB1. e.

“Ask questions to investigate and provide explanations about the roles of photosynthesis and respiration in the cycling of matter and flow of energy within the cell (e.g., single-celled alga).

(Clarification statement: Instruction should focus on understanding the inputs, outputs, and functions of photosynthesis and respiration and the functions of the major sub-processes of each including glycolysis, Krebs cycle, electron transport chain, light reactions, and Calvin cycle)”.

With the standard in mind, answer the following questions. Be as detailed as possible. Please write, draw, and verbalize your thought process.

1. A mature maple tree can have a mass of 1 ton (dry biomass, after removing the water), yet it starts from a seed that weighs less than 1 gram. How does this happen? What key chemistry topics are addressed in this scenario? Explain.
   a. Thinking about the standard, how does your illustration emphasize the cycling of matter?
   b. What are the inputs? What are the outputs?
   c. Thinking about the standard, how does your illustration emphasize the flow of energy?
   d. What are the inputs? What are the outputs?

2. John weighs 440 lbs. Through diet and exercise, he loses 220 lbs. How did this happen? What key chemistry topics are addressed in this scenario? Explain.
   a. Thinking about the standard, how does your illustration emphasize the cycling of matter?
   b. What are the inputs? What are the outputs?
   c. Thinking about the standard, how does your illustration emphasize the flow of energy?
   d. What are the inputs? What are the outputs?

3. Draw and explain the process of photosynthesis within the cell. What key chemistry topics are addressed in this process? Explain.
   a. Illustrate the process of the light reactions within the cell.
   b. Illustrate the process of the Calvin cycle within the cell.
   c. How does your illustration emphasize the cycling of matter within the cell?
   d. What are the inputs? What are the outputs?
   e. How does your illustration emphasize the flow of energy within the cell?
   f. What are the inputs? What are the outputs?

4. Draw and explain the process of cellular respiration within the cell. What key chemistry topics are addressed in this process? Explain.
   a. Illustrate the process of glycolysis within the cell.
   b. Illustrate the process of the Krebs's cycle within the cell.
   c. Illustrate the process of electron transport chain within the cell.
d. How does your illustrations emphasize the cycling of matter within the cell?

e. What are the inputs? What are the outputs?

f. How does your illustrations emphasize the flow of energy within the cell?

 g. What are the inputs? What are the outputs?
Interviewer: Starting from the top. Thank you in wanting to participate in this research project. This interview should not take more than 30 minute or so, seems to take a little bit longer. As a Science teacher working in a public school in the State of Georgia, you are required to teach according to the state standards. Photosynthesis and respiration is a topic that must be taught according to the state standard SP1E. Standard states: Ask questions to investigate, provide explanations about the role of photosynthesis and respiration, the cycle in the cycling of matter, and flow of energy within the cell. Clarification statement: Instructions should focus on understanding the inputs, outputs and functions of photosynthesis and respiration, and the functions of the major sub-process of each, including glycolysis, cryp cycle, electron transfer chain, light reactions, and the carbon cycle. This is just base stuff for the Georgia standard. With the standard in mind, answer the following questions. Be as detailed as possible, so please write, draw and verbalize your thought process. Question number one, a mature maple tree can have a mass of one tonne yet it starts from a seed that weighs less than one gram. How does this happen? Let me turn this on for you. Go ahead.

Dan: Obviously we're going into germination, photosynthesis. I'll just go ahead and write out the equation for photosynthesis.

Interviewer: All right, keep the standard in mind.

Dan: Yes. I'm going to say CO2, 6 H2O, light, equals 6H12+6O2. As far as the Chemistry topic, I would go with--

Interviewer: Before we get there, just explain a little bit more exactly what you think is going on between the time that it starts as a seed, to the point when it's considered a tree. I see that you got the equations right. How would you draw this out? Let's just say if that was a test question, or a student asked, how would you illustrate that, going from the seed to the tree?

Dan: That's the million dollar question there. That's the thing I think, with teachers. I think what you're getting at is, a lot of us require aids to able to think like this. A lot of us aren't very good at illustrating this, or describing this without the help of maybe some outside source, maybe a PowerPoint, or maybe some other visual aid that someone else used. Honestly, that's something that I will admit that I'm not great at. I can conceptualize all day, I can give you all these great things but as far as things like that, that's something that I definitely struggle with. This is a very good question. This is a very definitely good inquiry based question, but it's something that has a lot of levels. There's a lot of things that need to be broke down, there's a lot of things that you need to go into as far as that goes. Maybe I need some clarification on your part as far as what we're looking for and things of that nature.
Interviewer: Like I was mentioning before, these questions, well, specifically question number one was designed from thinking of the standard. I know you mentioned a lot of different things that were this could actually go with, but only coming from this thing of thinking about photosynthesis and cellular respiration, and these processes. Thinking about that, how would you explain, or using this as your umbrella, how would you explain the seed going into, or becoming a tree? I see that here you started with photosynthesis. How would you use this to explain how does the seed become a tree? I guess.

Dan: Okay, the way I've always explained photosynthesis, photosynthesis is all about storage. It's all about storage in energy. We have our reactants, which are going to be our CO2 and our water. CO2 is coming in, it's going to be taken in by the plant. Immediately, in the first step, photosynthesis which is the light dependent reaction, we're going to go ahead and split that water, and really what we want from that water is those hydrogens right there. Then immediately, oxygen is going to go away. As far as starting from a seed, really what we're trying to do here is we're going to start small, so we're not going to need as many reactions. All that seed is trying to do, is just trying to store up as much glucose as possible, so it's going to go through this process on a smaller scale first, and then it's going to start to grow, it's leaves are going to start take in more sunlight, it's going to start to go through this process a little bit more, glucose is going to be stored, and then that's where respiration is going to come in. As soon as that plant needs to expend energy. Photosynthesis is all about storage, cellular respiration is all about expenditure of energy. We're taking that stored glucose, and we're creating ATP from that.

Interviewer: You mentioning about the seed going through this process of photosynthesis. Can you use that same illustration in regards to when we talk about the cycling of matter? How is matter cycled in this process, when we talk about the seed becoming the tree?

Dan: Say that in a different way maybe?

Interviewer: Okay, I'm trying to remember exactly what you were saying. Usually, most people jot things and I could point out.

Dan: I'm not a big writer, I'm not a big illustrator. I verbalize, and that's what I do, but we can go with that as well.

Interviewer: No, no problem. Cycling in matter. Just thinking about potentially what might have been cycled through that system. You have this equation here, and you conceptualize verbally how a seed becomes a tree. Through that concept that you were playing with, can you talk about how matter is cycled through this photosynthesis, or how matter is cycled through as the seed is becoming the tree?

Dan: Okay, I guess what you're getting at is, as far as photosynthesis goes. That oxygen is then going to be shot off into respiration. This is going to be 6O2 + C6 is 12O6. I'm going to write it right here below.

Interviewer: That's fine.
Dan: Now we're going to make $6\text{CO}_2+\text{H}_2\text{O}+\text{hydrogen}$, which is going to be able to form ATP, of course. I think what we're getting at is we're using the byproducts in photosynthesis to go through respiration, and then we're using this stored glucose here, that the plant created during photosynthesis to then create ATP, so that it can go through it's processes. So that it can grow, it can have roots and shoots, and leaves and all those materials it needs to survive, so that they can reproduce and then its species can be successful.

Interviewer: Sometimes when we're thinking about cycling, we're also thinking about the inputs and the outputs. What comes in, and what comes out. What would be the input, and what would be the output in your mind, the framework that you have created?

Dan: The inputs as far as growing is going to have to be your energy, it's going to have to be your ATP.

Interviewer: Okay.

Dan: Obviously, it's considered a product when we talk about cellular respiration. When we go into other processes that has to do with growing, that has to do with expanding the range of that plant, that ATP is going to then go in there. It's going to give it in the energy to do all the processes that it needs to. As far as in photosynthesis, you got your reactions over here and products over here. Cellular respiration reactants, products. Just reusing that stuff and getting into the idea that nothing is being wasted. Nothing is going to waste or anything like that.

Interviewer: You're saying that looking at this, would you consider this to be your input what's going in is your carbon monoxide and your water, right?

Dan: Yes.

Interviewer: Okay, then you're saying that this being the product, what would you call this then? Would you call this the input or output? How would you label that?

Dan: I would call it the output of photosynthesis. Then I would use it to call it the input of cellular respiration.

Interviewer: Showing that this was being cycled.

Dan: Yes, exactly.

Interviewer: Okay, this is your input for your cellular respiration, right?

Dan: Yes.

Interviewer: What would you consider this, your CO2 and H2O?

Dan: That would be my output of cellular respiration and then we're going to cycle that back through as far as to go on to photosynthesis.
[00:11:35] Interviewer: All right, also in the light of this, the standard also talks about the flow of energy. How energy flows through these systems. How would you illustrate that? How would you talk about energy flowing through photosynthesis or cellular respiration? Now that you have your drawing on.

[00:11:59] Dan: I would just go back to the storage expenditure. Photosynthesis is all about storage. As far as plants go, they're going to able to create glucose from the light energy. They're going to use that glucose, they're going to store it up for later use and then that glucose is going to be used into cellular respiration. Cellular respiration is all about expenditure. We're taking that stored energy in the form of glucose. We're going to break it down through the act of glycolysis and the Krebs cycle and the electron transport chain. Then we're going to create ATPs from there so that we can have the energy to go through cellular processes.

[00:12:43] Interviewer: All together, that's what's going to allow the seed to become this tree.

[00:12:50] Dan: Right.

[00:12:50] Interviewer: All right, cool.

[00:12:55] Dan: I got some of it, right?

[00:12:55] Interviewer: [laughs] Yes, but as I said, in the light of the standard. There is a lot of things that can go into it. But let's take it a step at a time. Let's move on to the second. Probably just draw a line here. All right, John weighs 440lbs. Through diet and exercises, he loses 220lbs, how did this happen? Once again, in light of this, the standard.

[00:13:29] Dan: Obviously to be able to cut his weight in half, he's going to have to expend more energy than he's taking in. As far as John, he's a human, he's an animal, he doesn't do photosynthesis. We're going to take in energy in the form of ingestion, digestion and then that's going to go through into cellular respiration.

[00:13:51] Interviewer: Can you rewrite the equation for cellular respiration?

[00:13:54] Dan: We take in CO2 when we breathe, plus our glucose, C6H12O6 because most of our fluid is going to be broken down into the form of glucose, break it down in two, 6H2O, 6CO2. Then we're going to plus 6C02 plus energy, that's going to be in the form of ATP. Like I said, in order to go from there, in order to go from 440 to 220, he's going to have to expend more energy than he takes in. When he goes through this entire process at some point he is giving off energy in the form of heat, or in the form of whatever, and it's not being replenished fast enough. So the body is having to sacrifice fat, muscle, and it's having to break that down for energy.

[00:15:17] Interviewer: You said that energy comes in the form of ATP so you say these two are synonymous to each other?

[00:15:22] Dan: Yes.
[00:15:23] **Interviewer:** Okay.

[00:15:24] **Dan:** As far as at the cellular level, yes.

[00:15:26] **Interviewer:** At the cellular level, okay. Once again I'm going to ask you about the cycling of matter. How would you explain how matter is cycled?

[00:16:02] **Dan:** I would just say, this glucose obviously has to come from somewhere. Maybe he's ingesting less, and eating less, so his body doesn't have as much of that glucose to be able to break down and turn into ATP. At the same time, he's going to be using less oxygen, he's going to be giving off less CO2, I think with that nature.

[00:16:41] **Interviewer:** All right, what would you say about the flow of energy? How would you illustrate energy flowing through this system here? Of him losing the weight?

[00:17:05] **Dan:** As far as the energy being produced, that energy is going to have to go somewhere, it's not just sitting there, just hanging out. That energy is going to go out into all sorts of processes. It's going to go into regulating homeostasis, it's going to go into all sorts of things that the body needs, brain functions, everything. That energy is going to be used. Eventually this is going to have to start over, and, eventually, if he's losing all this weight it's going to get to the point where his body is going to realize that it doesn't have that glucose, he hasn't ingested any food, nothing has been broken down, so it's going to have to start looking for other resources. It's going to have to start looking into adipose tissues, start getting rid of some of that fat, maybe even sacrificing some muscle, because the muscle is a very high energy tissue, it takes a lot of energy. That energy is going to be expended pretty quickly, and then the body is going to kick in from there and realize that maybe he can do something else to get through this.

[00:18:15] **Interviewer:** You're calling other tissues or whatever the input for this energy? If you're thinking about the flow, where is it coming in, and where is it coming out?

[00:18:27] **Dan:** I would say energy is going into, I'll just say bodily functions, and this can just be a general whatever, brain function, when you talk of internal function. That energy is going to go into there and eventually that energy is going to be depleted, so that glucose is no longer being replenished, and then we're going to have to go to other sources of energy, in order to maybe be able to go through these processes. We're going to look to lipids, proteins. Things of that nature.

[00:19:27] **Interviewer:** From looking at these two processes, what key chemistry concepts do you think covers these two major processes that we've talked about, in regards to a seed becoming a tree, and a man losing weight?

[00:19:47] **Dan:** Are we looking for pretty general, or just whatever?

[00:19:55] **Interviewer:** Whatever comes to mind.
[00:19:56] Dan: As far as photosynthesis and cellular respiration it's just one giant redox reaction. It's just one giant reduction-oxidation reaction. We're just transferring electrons to be able to get to that, those processes. As far as what you're saying, the cycling, the flowing matter, the flow of energy, definitely thermodynamics comes in also there. Energy is never created or destroyed, it's just transferred. We have to understand that all this is coming from somewhere. It's not just popping up out of nowhere. It has to come from somewhere. It's going to be cycled through this system over and over and over again. Everything is going to be reused, everything is going the reborn.

[00:20:48] Interviewer: All right, that's a very clever answer. [laughter] All right. Let's go ahead and I know you hate this but I'm going to ask you for it. [laughs] Number three, can you draw and explain the process of photosynthesis within the cell. We looked at it from a bigger point of view. Now I'm looking for a more biochemical point of view. If you look at the cell, if you could illustrate it out as well what happens during photosynthesis. Be as detailed as possible.

[00:21:29] Dan: All right, let's go for it. Photosynthesis, not much drawing to see. As far as the cell, obviously we're in a plant cell. We're going into the chloroplast. More specifically, we are going into the thylakoid membrane. Then we go into the stroma. As far as in the cell, you like pictures? Do you want anything?

[00:22:16] Interviewer: Pictures would be nice.

[00:22:19] Dan: All right, let's see what I can do. I'm going to write the equation again. 6H2O then 6CO2. All right. Then this, 6CO2. All right, we're going to start with the light-dependent reactions. We have our sunlight and what that's doing here is that's taking our H2O, that's going to split apart. We are working in the thylakoid membrane I believe for the light-dependent reaction. Split that in two. What we really want is those hydrogens. Oxygen is going to be kicked out right from the beginning in those light-dependent reactions. We are then going to move into the stroma for the light independent reactions. This is the toughie for me. So I know.

[00:24:25] Interviewer: You drew those four arrows, why?

[00:24:27] Dan: We know the light-dependent reaction is a cycle. It's called Calvin cycle as well. Off the top of my head, I'm drawing a blank right now. Are you going to say something there?

[00:24:51] Interviewer: Yes, I'm waiting for you. I just want to make sure that you've said all that you could say before I start talking.

[00:24:57] Dan: No, go ahead.

[00:24:58] Interviewer: All right, you have this cycle going in. Can you probably maybe at least elaborate what's the purpose of the cycle? What's going into it, what's coming out of it?
PRESERVICE TEACHERS’ CONCEPTUAL UNDERSTANDING

[00:25:08] Dan: We're taking those hydrogens into cycle. Our oxygen has already been split apart. Then we're going to take the oxygens and there's some NADPH in there somewhere which is just our electron carriers. We're going to transfer those hydrogens there and then at the end we're going to get glucose, more of the other details. Generally that's what's going on is we're just transferring those electrons through NADPH and then we're expending glucose out.

[00:25:53] Interviewer: Okay, all right, I see that you have brief illustration here. That's good. How does your illustration show the whole idea of the cycling of matter?

[00:26:10] Dan: A good one here would be when it gives off O2. It doesn't really need that oxygen to complete the process. So it's going to spit that O2 out immediately. Then that O2 is going to go back and it's going to be used in respiration in animals, and things of that nature. As far as your glucose, as I stated earlier, glucose is all about storage. That glucose is going to be stored later on in order to be broken down so that ATP can be created. That plant can grow and can go through all these processes as well.

[00:26:55] Interviewer: Okay, what about the flow of energy? How does your illustration talks about the flow of energy, and how does it go through photosynthesis? Why is energy coming in? Where is it coming out?

[00:27:17] Dan: Okay, the energy is coming in in the form of light, so really all a plant needs the light for is to be able to break that H2O down. It's being able to capture the energy from the light from the giant solar panel and it's going to be able to use that energy to break the H2O down to go into the light independent reactions so that it can create the glucose. As per the energy coming out, the O2 is coming out. That O2 is going to be used in other processes. That glucose is coming out which is bearing energy there in its molecules it's going to be able to used in other processes as well.

[00:27:54] Interviewer: Okay, cool, cool. You feel like you're exhausted?

[00:27:58] Dan: [laughs] No, I'm good.

[00:28:00] Interviewer: All right, the last thing I want to cover, I always seem to forget this question. What chemistry topics or key ideas do you see in this process here?

[00:28:11] Dan: In photosynthesis specifically?

[00:28:12] Interviewer: Yes.

[00:28:13] Dan: Reduction/oxidation is the big one.

[00:28:16] Interviewer: Okay, can you maybe give me an example, what gets oxidized or what gets reduced?

[00:28:25] Dan: NADPH is going to be the electron carriers.
Interviewer: It's going to get reduced.

Dan: Yes, I believe.

Interviewer: What is the before and after, I guess, when you say "being reduced"? It gets reduced into what? I guess, I think that's my question. What's the before and what's the big after?

Dan: It would be NADPH and then NADP plus.

Interviewer: It starts up at NADPH to NAD?

Dan: That's what we doing.

Interviewer: I want to make sure I'm clear.

Dan: Yes.

Interviewer: Okay.

Dan: Let me go with it. I guess I'm a little fuzzy on the details but that's fine.

Interviewer: I just want to know what you know. That's the reduction part. What about oxidation?

Dan: It's a good question. Want to say it has something to do with CO2, but I'm not 100% sure.

Interviewer: Okay, that's fine. Any other key chemistry topic that you can think of?

Dan: I would just maybe knowing the dynamics maybe of organic molecules and what makes something organic or makes something inorganic, how organic molecules interact, how organic molecules bond. We talked about a glucose molecule it’s a six carbon ring and things of that nature, how it bonds, how they interact with each other. Then we already stated thermodynamics and just how energy flows and is reused.

Interviewer: All right, last but not least. All right, John, explain the process of cellular respiration within the cell.

Dan: Okay.

Dan: All right, we are going to start with glycolysis, what’s going to happen in the cytoplasm. What we’re going to do here is we’re taking glucose which is a six carbon molecule and we’re going to split it into two pyruvic acids. Those pyruvic acids are going to move into the Krebs cycle. This is going to happen in the mitochondria. More specifically it’s going to be in the inner folds of the mitochondria. Krebs cycle we are using those pyruvic acids and we’re
going to create a net with two ATP in glycolysis, we actually make four but we use two in the process. We have a net of two in glycolysis. We're going down here for the Krebs cycle. Krebs cycle, we're going to make another two ATP. Basically, what’s happening here is we’re going to take these pyruvic acids and then we’re going to use NAD+. We are going to move those electrons around a little bit and then NAD+ and FADH are going to be produced, they’re going to move on to the electron transporting. Which is going to happen across the membrane of the mitochondria. We’re going to create a net of 32 to 34 ATP in best case scenario in the electron transport chain, and we are using the electrons from NAD+ and FADH to open channels in the membrane and then that’s going to create ATP from there.

[00:34:17] Interviewer: Once again seeing your process here how would you describe the cycling of matter through overall cellular respiration as you’re going through glycolysis to the Krebs cycle to the ETC?

[00:34:35] Dan: The big thing with cellular respiration is usually we’re using the product of the step before to go on to the next step. We’re taking these pyruvic acids they’re going directly into the Krebs cycle. Krebs cycle is going to make NAD+ and FADH, that’s going to go directly into the ETC and then that’s going to provide the energy to be able open those channels and create those ATPs.

[00:35:00] Interviewer: Speaking of energy, how would you describe the flow of energy through this cycle? Your inputs and your outputs, can you describe that to me as the flow of energy?

[00:35:17] Dan: Each step has it's inputs, each step has it's outputs. As far as flow, a buzzword there [laughs], it's very hard to conceptualize flow. State that again, make sure I'm understanding. I just want to make sure I'm getting this and fine.

[00:35:52] Interviewer: Yes, it's fine. I'm just trying to make sure I don't give away too much.

[00:35:57] Dan: I understand.

[00:35:59] Interviewer: I apologize if I'm seeming a little bit-

[00:36:02] Dan: No, I understand.

[00:36:03] Interviewer: -conservative at that point.

[00:36:05] Dan: [laughs].

[00:36:06] Interviewer: Just like you were talking about the cycle of matter, and you were saying how basically the product of one process cements the reacting of the next process. I want you to think about it almost like the same way when we're talking about how this energy start going through glycolysis and where does it end up at the end. Can you track down the energy for me, if that makes sense?
[00:36:35] Dan: Yes, okay, obviously everything's going to start with glucose, and that's our energy dense molecule, it's where most of our food is going to end up at. That glucose is going to be broken down into that pyruvic acid which is a three-carbon, so you're taking a six-carbon glucose breaking down into two three-carbon pyruvic acids. Those pyruvic acids are going to go into the Krebs cycle. The energy in the Krebs cycle is going to be in the form of NAD+ FADH which are going to be your electron carriers, which are going to carry your electrons through the electron transport chain. Then in the electron transport chain there's NAD+ FADH. You're going to open those membranes and eventually end up as ATP. When those membranes are open an ATP molecule will come in and then it's going to phosphorelated. Another phosphate is going to be added on to ATP.

[00:37:42] Interviewer: Once again, can you identify any chemistry concepts or topics?

[00:37:57] Dan: Would definitely have flow of electrons. How electrons are going to move within a system, definitely a big organic chemistry concept there. Once again just seeing how organic compounds interact, how they bond. How it's going to take energy to break down this glucose. Glucose is a very stable molecule, a six-carbon molecule, so we're having to expend energy to be able to get it out of that stable form into a more unstable form. Just interactions of that, I guess. I'm sure I'll think of four more when I walk out the door.

[00:38:54] Interviewer: [laughs] It's fine, trust me. It's okay. All right, do you have anything else you want to add?

[00:39:00] Dan: I'm good.

[00:39:01] Interviewer: Technically that's part one. I got a little-

[00:39:05] [END OF AUDIO]
Appendix G

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### Level 2i – Use of chemical equation inaccuracies

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<td>The equation of photosynthesis. For example: ( \text{C}<em>6\text{H}</em>{12}\text{O}_6 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} ). Any explanation that is based on the chemical equation such as carbon dioxide and water are produced. Any pictorial representation that is based on the chemical equation such as drawing an animal cell drawing arrows towards the cell to illustrate inputs and drawing arrows away for the cell to illustrate outputs. See Figure 2. In their explanation, there are errors such as using the wrong chemical equation.</td>
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<td><strong>Cellular Respiration</strong></td>
<td>The interviewer response after question 2 (John losing weight) and question 4 (cellular respiration process within a cell). Uses only chemical equation to explain phenomena. No error but incomplete in their explanation.</td>
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<td>Concept</td>
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| **Cycling of Matter** |  |  |

<p>| <strong>Cellular Respiration</strong> | The interviewer response after prompted for the flow of energy. Uses only chemical equation to explain phenomena. No error and complete in their explanation. | The equation of photosynthesis. For example: ( \text{C}<em>6\text{H}</em>{12}\text{O}_6 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} ). Any explanation that is based on the chemical equation such as ATP produced. Any pictorial representation that is based on the chemical equation such as drawing an animal cell drawing arrows towards the cell to illustrate inputs and drawing arrows away for the cell to illustrate outputs. See Figure 2. |
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**Cellular Respiration**  
**Cycling of Matter**  
The interviewer response after prompted for the cycling of matter. Use of chemical equation and names subprocesses or just use subprocesses to explain phenomena. Within their explanations, there are errors.  
The equation of photosynthesis. For example: \( C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O \). Any explanation that is based on the chemical equation such as carbon dioxide and water are produced. Any pictorial representation that is based on the chemical equation such as drawing an animal cell drawing arrows towards the cell to illustrate inputs and drawing arrows away for the cell to illustrate outputs. See Figure 2. Must include discuss about glycolysis, Krebs cycle, and electron transport chain.

**Cellular Respiration**  
**Flow of Energy**  
The interviewer response after prompted for the flow of energy. Use of chemical equation and names subprocesses or just use subprocesses to explain phenomena. Within their explanations, there are errors.  
The equation of photosynthesis. For example: \( C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O \). Any explanation that is based on the chemical equation such as ATP produced. Any pictorial representation that is based on the chemical equation such as drawing an animal cell drawing arrows towards the cell to illustrate inputs and drawing arrows away for the cell to illustrate outputs. See Figure 2. Must include discuss about glycolysis, Krebs cycle, and electron transport chain.
### Level 3ii – Sub-processes incomplete

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<td>Photosynthesis Cycling of Matter</td>
<td>The interviewer response after prompted for the cycling of matter. Use of chemical equation and names sub-processes or just use sub-processes to explain phenomena. While there are no errors in their explanation, it is incomplete.</td>
<td>The equation of photosynthesis. For example: $CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$. Any explanation that is based on the chemical equation such as glucose and oxygen is produced. Any pictorial representation that is based on the chemical equation such as drawing a plant cell drawing arrows towards the cell to illustrate inputs and drawing arrows away for the cell to illustrate outputs. See Figure 1. Must include discussion about light reactions and dark reactions (Calvin cycle).</td>
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### Level 3iii – Sub-processes complete

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## Level 4i – Full biochemistry with inaccuracies

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<td>Must discuss in detail the subprocess of photosynthesis. For example, during light dependent reaction, light from the sun split water molecules to hydrogen and oxygen atoms. May include chemical reaction for photosynthesis.</td>
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<td>explanations, there are errors.</td>
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## Level 4ii: Full biochemistry incomplete

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<td>The interviewer response after prompted for the cycling of matter. Describes the biochemistry within the subprocesses to explain the phenomena. The use of chemical equation may be included. No errors with their explanation but it is incomplete.</td>
<td>Must discuss in detail the subprocess of photosynthesis. For example, during light dependent reaction, light from the sun split water molecules to hydrogen and oxygen atoms. May include chemical reaction for photosynthesis.</td>
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<td><strong>Cycling of Matter</strong></td>
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<tr>
<td>Process</td>
<td>Interviewer Response</td>
<td>Must Discuss in Detail</td>
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<tr>
<td>Sub-process</td>
<td>Definition</td>
<td>Examples</td>
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<tr>
<td><strong>Photosynthesis Question</strong></td>
<td>The interviewer response after question 1 (seed to tree) and question 3 (photosynthesis process within a cell).</td>
<td>Must discuss in detail the subprocess of photosynthesis. For example, during light dependent reaction, light from the sun split water molecules to hydrogen and oxygen atoms. May include chemical reaction for photosynthesis.</td>
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<td><strong>Cellular Respiration Question</strong></td>
<td>The interviewer response after question 2 (John losing weight) and question 4 (cellular respiration process within a cell).</td>
<td>Must discuss in detail the subprocess of photosynthesis. For example, during light dependent reaction, light from the sun split water molecules to hydrogen and oxygen atoms. May include chemical reaction for photosynthesis.</td>
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<td>Concept</td>
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<tr>
<td>Energy Subcodes</td>
<td>Definition</td>
<td>Example</td>
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<tr>
<td>ATP</td>
<td>Energy is associated with ATP molecule</td>
<td>“We're taking a part of molecules and we're getting energy from that. It's storing energy in chemical bond which is what ATP is” “Energy output is ATP”</td>
</tr>
<tr>
<td>ATP = Energy</td>
<td>ATP and energy are synonymous</td>
<td>“The energy is specifically ATP. ATP is a molecule used by plant cells to undergo abnormal process used.” “so it's giving off energy, energy in the form of ATP.”</td>
</tr>
<tr>
<td>ATP Bonds breaking</td>
<td>Energy is released when a bond is broken in the ATP molecule</td>
<td>“ATP molecule breaking is what gives off the energy that we can use.” “We break down those ATPs because that’s what give that breakage of the adenine triphosphate, when the phosphate breaks off, that's where the energy comes from. I remember that-- all ties that to the sugar but I don't remember how.”</td>
</tr>
<tr>
<td>ATP Formation</td>
<td>Explanation about the formation of ATP</td>
<td>“As soon as that plant needs to expend energy. Photosynthesis is all about storage, cellular respiration is all about expenditure of energy. We're taking that stored glucose, and we're creating ATP from that” “The biggest thing is that you're producing more NADH and more ATP because the end game is really just producing lots and lots of energy.”</td>
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<td>ATP Work</td>
<td>ATP is needed to do work within the cell/organism</td>
<td>“Obviously, it's considered a product when we talk about cellular respiration. When we go into other processes that has to do with growing, that has to do with expanding the range of that plant, that ATP is going to then go in there. It's going to give it in the energy to do all the processes that it needs to” “Sunlight goes in. It's going to need some energy to- it’s going to need ATP to perform photosynthesis.”</td>
</tr>
<tr>
<td>Bonds</td>
<td>Energy is associated as within bonds of molecules</td>
<td>“Yes, so ATP is an energy storage molecule. It in itself is not an energy, it's just when the bonds break”</td>
</tr>
</tbody>
</table>
| Bonds of ATP                  | Energy is described being in the bonds of ATP molecule | “It doesn't provide any actual energy, but when we break these bonds, we do get some ATP out in certain areas by breaking those bonds, we're able to furnish it with the ATP.”  
  “ATP molecule breaking is what gives off the energy that we can use.” |
|-------------------------------|------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Bonds of glucose              | Energy is described being in the bonds of glucose molecule | “Energy is stored in the chemical bonds in here. Glucose is only used as a storage molecule.”  
  “We talked about a glucose molecule it’s a six carbon ring and things of that nature, how it bonds, how they interact with each other. Then we already stated thermodynamics and just how energy flows and is reused.” |
| Chemical Energy: ATP          | Energy is described as part of the chemical ATP      | “Energy is stored in the chemical bonds in here. Glucose is only used as a storage molecule”.  
  “Obviously, photosynthesis is how plants and autotrophs make their sugars, how they make their sugars to contain their energy. Then once they have made those, they use cellular respiration to break those down and use the energy.” |
| Chemical Energy: electron     | Energy resides in the subatomic particle electron    | “When cells need energy, this is the only usable form of energy. Up until that point, some of it's stored as glucose, that's why we're producing glucose when we need it for energy. Through this process it turns into ATP and when we want to use it”  
  “As soon as that plant needs to expend energy. Photosynthesis is all about storage, cellular respiration is all about expenditure of energy. We're taking that stored glucose, and we're creating ATP from that” |
|                              |                                                       | “We're adding some other molecules in but we're rearranging it until we get CO2 out and then we are using the energy, in this case, the form of electrons and hydrogen ions” |
| Chemical Energy: FADH | Energy resides in the energy carrier FADH | “Krebs cycle is going to make NAD+ and FADH, that’s going to go directly into the ETC and then that’s going to provide the energy to be able open those channels and create those ATPs.”
“‘The energy in the Krebs cycle is going to be in the form of NAD+ FADH which are going to be your electron carriers, which are going to carry your electrons through the electron transport chain.” |
| Chemical Energy: Fat | Energy resides in fat molecules | “The fat was used by his body for energy instead of-- looks like it was burned”
“‘Respiration also produce energy by breaking down glucose. When glucose runs out, our body begins to burn fat as well as muscle.” |
| Chemical Energy: Food | Energy resides in food | “John’s a person, people get their energy and matter through food which are organic molecules.”
“We’re taking that stored energy in the form of glucose”
“Energy. Light energy comes in and glucose is used for energy,” |
| Chemical Energy: Glucose | Energy resides in glucose molecules | “Krebs cycle is going to make NAD+ and FADH, that’s going to go directly into the ETC and then that’s going to provide the energy to be able open those channels and create those ATPs.”
“‘The energy in the Krebs cycle is going to be in the form of NAD+ FADH which are going to be your electron carriers, which are going to carry your electrons through the electron transport chain.” |
| Chemical Energy: NAD+ | Energy resides in the energy carrier NAD+ | “The biggest thing is that you're producing more NADH and more ATP because the end game is really just producing lots and lots of energy. NADH is getting reduced, so that's another byproduct of this one.” |
| Chemical Energy: NADH | Energy resides in the energy carrier NADH | “The biggest thing is that you're producing more NADH and more ATP because the end game is really just producing lots and lots of energy. NADH is getting reduced, so that's another byproduct of this one.” |
| Chemical Energy: Protons | Energy resides in the subatomic particle protons | “Then, using the proton front would be chemical energy as well.”
“We're adding some other molecules in but we're rearranging it until we get CO2 out and then we are using the energy, in this case, the form of electrons and hydrogen ions.” |
<p>| Chemical Energy: Water Flow | Energy resides in the compound water. Explanation of how energy is transferred from one substance to another | “I'm pretty sure. I'm pretty sure you split water and that's how you get the energy for the Calvin cycle.” “The matter is cycling but the energy flows through in one direction.” |
| Flow in cellular respiration | Discussion of Flow of energy specifically within the process of cellular respiration | “When he goes through this entire process at some point he is giving off energy in the form of heat, or in the form of whatever, and it's not being replenished fast enough.” “That energy is going to go into there and eventually that energy is going to be depleted, so that glucose is no longer being replenished, and then we're going to have to go to other sources of energy, in order to maybe be able to go through these processes.” |
| Flow in photosynthesis | Discussion of Flow of energy specifically within the process of photosynthesis | “Light energy, which will transform into chemical energy.” “I know CO2 is what gets cycled around the Calvin cycle, [laughs] and the end product ends up being glucose. You're basically putting in CO2, it's giving off and basically, carbons are getting shuffled around until you produce glucose, and you don't need the sun for that. More than likely, this just provides the energy for that.” |
| Flow in photosynthesis and cellular respiration | Discussion of Flow of energy specifically within the process of both photosynthesis and cellular respiration. | “We have the sun, the sun helped to pull light reactions as part of photosynthesis, the other chemical light reactions. Those are what breaks the bonds in H2O, that’s where splitting water is actually happening and then the carbon fixation happens in the Calvin cycle, so also the light reactions and the dark reactions. That energy eventually is going to be transformed into glucose which again is being transferred from light energy to chemical energy. Then when we go through cellular restoration we're giving out the chemical energy through ATP. The energy is flowing but it doesn't go back on a cycle. The matter is cycling but the energy flows through in one direction.” |</p>
<table>
<thead>
<tr>
<th>Concept</th>
<th>Definition</th>
<th>Example</th>
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</thead>
<tbody>
<tr>
<td>Law of Conservation</td>
<td>Any discussion about how energy is conserved.</td>
<td>“Energy is never created or destroyed, its just transferred”</td>
</tr>
<tr>
<td>Light</td>
<td>Energy is referred to as light from the sun.</td>
<td>“Okay. There’s photosynthesis, and so we have light energy coming in.” “Then, again, we have light coming in. Light energy which will transform into chemical energy” “It will use that as energy as well as sunlight, and use through photosynthesis”</td>
</tr>
<tr>
<td>Work</td>
<td>The ability to do work. Any discussion of energy that is not specifically coded with any of the sub codes of Energy above.</td>
<td>“with exercise, you burn more glycogen because you’re having a higher calorie demand, which means you need more energy just to do so” “If he was exercising this process would have been a lot more so he could have this energy to sustain the exercise”.</td>
</tr>
<tr>
<td>Work in cellular respiration</td>
<td>Energy work that is described during cellular respiration</td>
<td>“That's when sugars are broken down to release energy for the human to use, or plant, to use, or whatever organism” “Obviously to be able to cut his weight in half, he's going to have to expend more energy than he's taking in”</td>
</tr>
<tr>
<td>Work in photosynthesis</td>
<td>Energy work that is described during photosynthesis</td>
<td>“Whereas, photosynthesis needed light to improve because they needed that energy in this process energy is given off. We have to have cellular respiration which is right.” “Sunlight goes in. It's going to need some energy to- it’s going to need ATP to perform photosynthesis.”</td>
</tr>
</tbody>
</table>
All student research at KSU must be supervised by a faculty advisor. In order to ensure that the advisor has reviewed the IRB application materials and agrees to supervise a student’s proposed human subject research project this routing sheet, along with the application materials, must be submitted by the faculty advisor from their KSU email address to irb@kennesaw.edu.

By checking the boxes below, the faculty advisor for this project attests the following:

- [ ] I have personally reviewed each of my student’s IRB application documents (approval request, exemption request, informed consent documents, child assent documents, survey instruments, etc.) for completeness, and all documents pertaining to the conduct of this study are enclosed (consents, assents, questionnaires, surveys, assessments, etc.)

- [ ] I verify that the proposed methodology is appropriate to address the purpose of the research.

- [ ] I have completed a CITI training course in the ethics of human subject research within the past three years as have all researchers named within this application.

- [ ] I approve of this research and agree to supervise the student(s) as the study is conducted.

Faculty Advisor Name:

Date:
PRESERVICE TEACHERS’ CONCEPTUAL UNDERSTANDING

Kennesaw State University
Institutional Review Board

Exemption Request for Research with Human Participants

(Prior to submission of this form, review the IRB Exemption Screening Checklist at http://www.kennesaw.edu/irb决策-tree.html.)

1. Project Identification

<table>
<thead>
<tr>
<th>Category</th>
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<tbody>
<tr>
<td><strong>Project Title:</strong></td>
<td>Secondary biology teachers' conceptual understanding on biochemistry high school topics.</td>
</tr>
<tr>
<td><strong>Principal Investigator (PI):</strong></td>
<td>Kimberly Cortes</td>
</tr>
<tr>
<td><strong>PI Department:</strong></td>
<td>Chemistry and Biochemistry</td>
</tr>
<tr>
<td><strong>PI Phone:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>PI Email:</strong></td>
<td><a href="mailto:klinenbe@kennesaw.edu">klinenbe@kennesaw.edu</a></td>
</tr>
<tr>
<td><strong>KSU Co-Investigators:</strong></td>
<td>Edwin Estime</td>
</tr>
<tr>
<td><strong>Non-KSU Affiliated Co-Investigators:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Faculty Advisor:</strong></td>
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<tr>
<td><strong>Faculty Advisor Department:</strong></td>
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<td><strong>Faculty Advisor Phone:</strong></td>
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<td><strong>Faculty Advisor Email:</strong></td>
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<tr>
<td><strong>Proposed Study Dates:</strong></td>
<td>August 1, 2017 – December 31, 2018</td>
</tr>
<tr>
<td><strong>Name of External Funding Agency:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Funding Agency’s Deadline:</strong></td>
<td></td>
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</tbody>
</table>

2. Mark each category describing the proposed research:

<table>
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<tr>
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<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td><strong>Educational Purposes.</strong> Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods. Research is not FDA regulated and does not involve prisoners. Submit questionnaire(s), surveys, and consent documents.</td>
</tr>
<tr>
<td>Category 2</td>
<td><strong>Educational Tests, Surveys, Interviews, Public Observation.</strong> Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects’ financial standing, employability, or reputation. If research involves children as participants, procedures are limited to educational tests and observation of public behavior where investigators do not participate in the activities being observed. Research is not FDA regulated and does not involve prisoners. Submit questionnaire(s), surveys, and consent documents.</td>
</tr>
</tbody>
</table>
3. Briefly describe the intent of the proposed research.

The project, “secondary science pre-service teachers conceptual understanding on biochemistry high school topics”, will investigate science teachers conceptual understanding of biochemistry topics via drawings, interviews, and word concept map.

4. Describe how participants, data, and specimens will be selected.

(1) The subject sample are undergraduate and graduate students who are seeking a biology education degree.

(2) Current biology teachers

(3) Current college biology professors

5. Does the research involve deception?  □ Yes  □ No

6. Describe why research procedures will not cause a participant either physical or psychological discomfort or be perceived as harassment above and beyond what the person would experience in daily life.

All questions asked will be biology content related and these questions are relevant to the career choice of the subject. Participation is on a volunteer basis with no coercion and will be awarded a gift card and any previously developed materials from Mr. Estime for teaching biology that is requested. Participants will be given informed consent forms,
and the details of the study will be described on the forms. Any identity information will not be publicized.

7. Describe provisions to maintain the confidentiality and security of data both during and after study completion.

**All data collected will be kept confidential. Pseudonyms will be used to protect the identity of the subjects in any private or public discussion or presentation regarding this research, including transcripts. Only principal investigator as well as the research student will have access to the identities of the participants.**

8. Describe provisions to protect privacy of participants (e.g., interviews will be conducted in a private area of classroom; individuals will not be publicly identified, etc.).

**All interviews will take approximately 30 - 60 minutes and be conducted in a private room. Interview procedures follow a semi-structured method.**

9. Will the research involve obtaining data through intervention or interaction with participants? (e.g., physical procedures, manipulations of participants or their environment, communication or interpersonal contact between researcher and participant, including interviews, surveys, focus groups, online surveys, etc.)

   - Yes
   - No

   a. What age groups will be included? **Participants must be at least 18 years of age to participate.** *

   *Within the consent document, include a statement of age groups to be included in the study.

   b. Describe the consent/assent process to be used.

   **Participants will be given an informed consent form which will explain the purpose of the study as well as any time commitments required, which will also identify any incentives that will be offered to students in exchange for their participation.** Once students or teachers have consented to participate in the study the interview will be conducted.

10. Will an online survey be utilized in this study?  

   - Yes *
   - No

   *If yes, use the Online Survey Cover Letter template at [http://www.kennesaw.edu/irb/consent_documents.html](http://www.kennesaw.edu/irb/consent_documents.html).

11. List all survey instruments to be used (pre-/post-tests, online surveys, interview questionnaires, focus group questionnaires, etc.). Submit these documents along with this form.

**Informed Consent**

**Interview Guide**

Submit all survey instruments, consent documentation, etc., with this form to irb@kennesaw.edu. Be advised that if your study cannot be granted an exemption by the IRB, you may be directed to submit the IRB Approval Request form to assist the board with further review of your study. This will require additional processing and review time. Direct all questions to the IRB at (470) 578-2268 or irb@kennesaw.edu.
From: irb@kennesaw.edu <irb@kennesaw.edu>
Sent: Friday, October 6, 2017 4:30 PM
To: Kimberly Cortes
Cc: irb
Subject: Study 17-002: Science teachers conceptual understanding on biochemistry high school topics

10/6/2017

Kimberly Cortes (Linenberger), Ph.D.
KSU Department of Chemistry and Biochemistry

RE: Your Progress Report dated 6/30/2016, Study number 17-002: Science teachers conceptual understanding on biochemistry high school topics

Dear Dr. Cortes (Linenberger),

I have reviewed your application for revision of the study listed above. The requested revision involves changes to the protocol and consent form. Your request is eligible for expedited review under FDA and DHHS (OHRP) regulations.

This is to confirm that I have approved your request for revision as follows: investigation of science teachers and students working toward a science education degree, conceptual understanding of biochemistry topics via drawings, interviews, and word concept map 8/29/2017: The interview guide has changed. The participants will be probed to inquiry their understanding of chemistry concepts in the biological process of photosynthesis and cellular respiration. Interviews will be audio and video taped.

10/6/2017: Addition of current biology teachers once approved by the school district, interviews with biology faculty and the addition of a $10 gift card and at the choice of the participant any materials developed by Mr. Estime to teach biology at the high school level. Revised consent form submitted and approved..

You are granted permission to conduct your study as revised effective immediately. The date for continuing review remains unchanged at .

Please note that any further changes to the study must be promptly reported and approved. Contact the IRB at irb@kennesaw.edu or at (470) 578-2268 if you have any questions or require further information.

Sincerely,

Christine Ziegler, Ph.D.
KSU Institutional Review Board Chair and Director
Appendix I

Full concept maps of each participant

Dan’s concept map
PRESERVICE TEACHERS’ CONCEPTUAL UNDERSTANDING

Mya’s concept map
Liz’s concept map
Sky’s concept map
Eva’s concept map